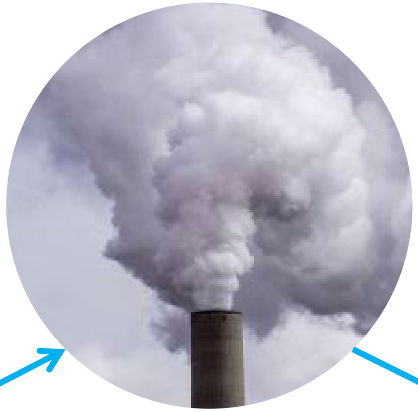
CLOSING LOOPS

Optimizing unitized facades for Circularity by Design for Disassembly

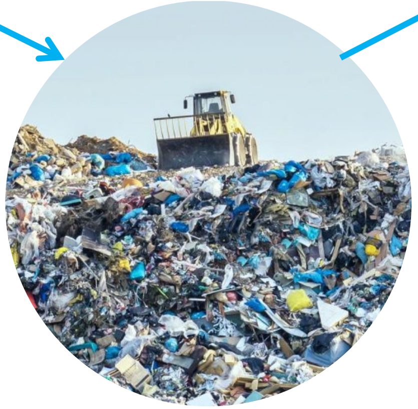
P5 Presentation – 24.06.2020 - Hans Gamerschlag

Problem

Climate change due to emissions



Emissions caused for product production



Products being discarded as landfill

Construction sector is a main waste producer

30% of all waste in the EU (European Commission, 2016)

Facades form a main part of construction

CLOSING LOOPS

Optimizing unitized facades for Circularity by Design for Disassembly

Intro | Research | Design | Result

1. INTRO
Problem

Objective

Questions

Methodology

2. CIRCULARITY
Circular Economy and Construction

Design for Disassembly

3. RATING SYSTEMS
Rating Circularity and Disassembly

Selection Rating Systems

4. COMPANY STUDY
Scheldebouw

Design and Production

Assembly and Disassembly Process

5. ANALYSIS EXISTING
Projects

Status Recycling

Rating Projects

6. PROPOSAL SYSTEMS
Design Objectives

Improvements

Guidelines

New Designs

7. ANALYSIS PROPOSALS
Rating New Designs

8. GREATER PICTURE
Circularity and Disassembly in Construction and Other Industries

9. CONCLUSION
Answers

Reflection

Discussion

Main objective:

Improving the façades of Scheldebouw for Circularity by applying principles of Design for Disassembly (DfD).

Main research question:

To what extent can Design for Disassembly contribute to optimize the facades of Scheldebouw for Circularity?

Design question:

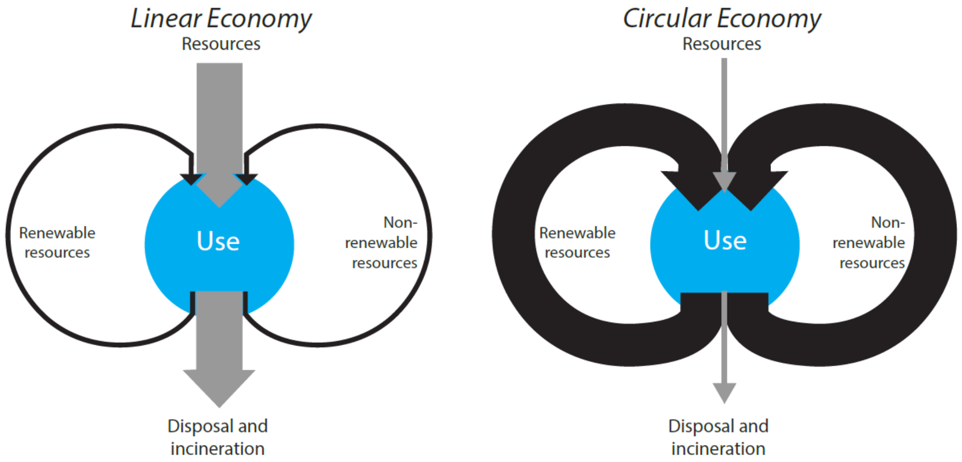
How does a façade look like when optimized for Disassembly and Circularity?

What is the Circular Economy?

The Circular Economy is an industry based economy which is restorative to the environment by replacing the present end-of-life concept with a closed loop concept. By using renewable energy and eliminating waste production and toxic substances and considering waste the start of the next phase of life the Circular Economy keeps products and materials productive in order to preserve or enhance product and material value while simultaneously retaining resources.

The linear economy:

'take-make-dispose', unbounded use of resources to produce products, and discarded them.



Source: PBL, 2014

The circular economy:

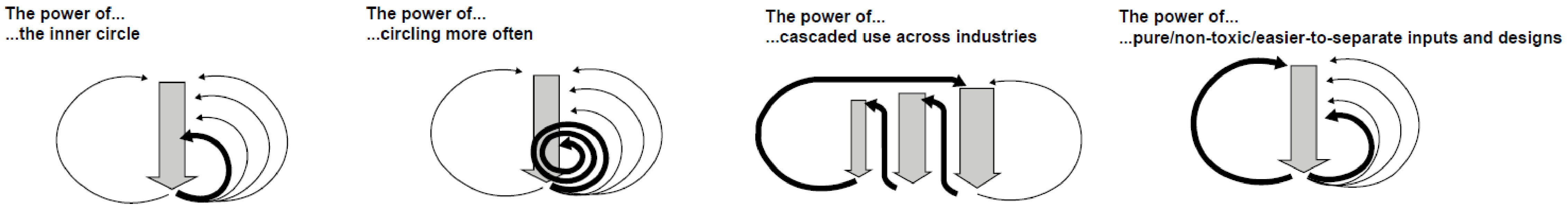
Focused on reuse, prevention of waste and emissions ('closing the loop').

What is the Circular Economy?

Three main principles exist on which the system is based (Ellen McArthur Foundation, 2013).

1. Preservation of natural assets
2. Improvement of revenue of resources.
3. Monitoring system performance and preventing performance loss.

Improvement of revenue of resources via circling materials:



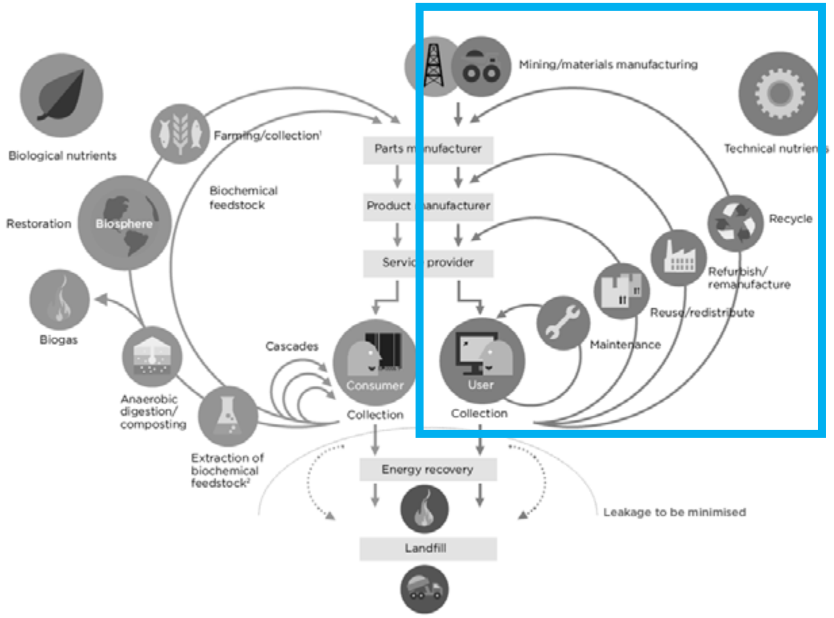
Source: Ellen McArthur Foundation, 2013

What is the Circular Economy?

Distinguishing in renewable and finite materials.

The biological cycle:

1. Cascading, reaping stored energy
2. Biochemical Extraction
3. Anaerobic Digestion
4. Composting



The technical cycle

1. Design for Maintenance
2. Design for Reuse
3. Design for Remanufacture
4. Design for Recycling

Source: Ellen MacArthur Foundation, 2014

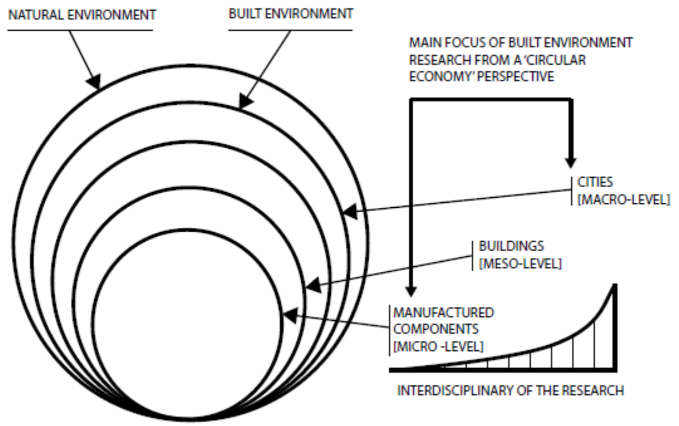
What is Circular Construction?

Circular Construction is…
… a construction created, planned, assembled, managed, upkept and dismantled in compliant ways to Circular Economy standards. (Pomponi & Moncaster, 2017)

But:
Limiting consumption, increasing performance, recycling and repeated usage are not enough to create a circular building.
Two important aspects are to be considered:-

Disassembly procedures.
Material choice to match the long life of buildings.

Unfortunately most research on circular construction takes place on meso level (big buildings) and macro level (cities).

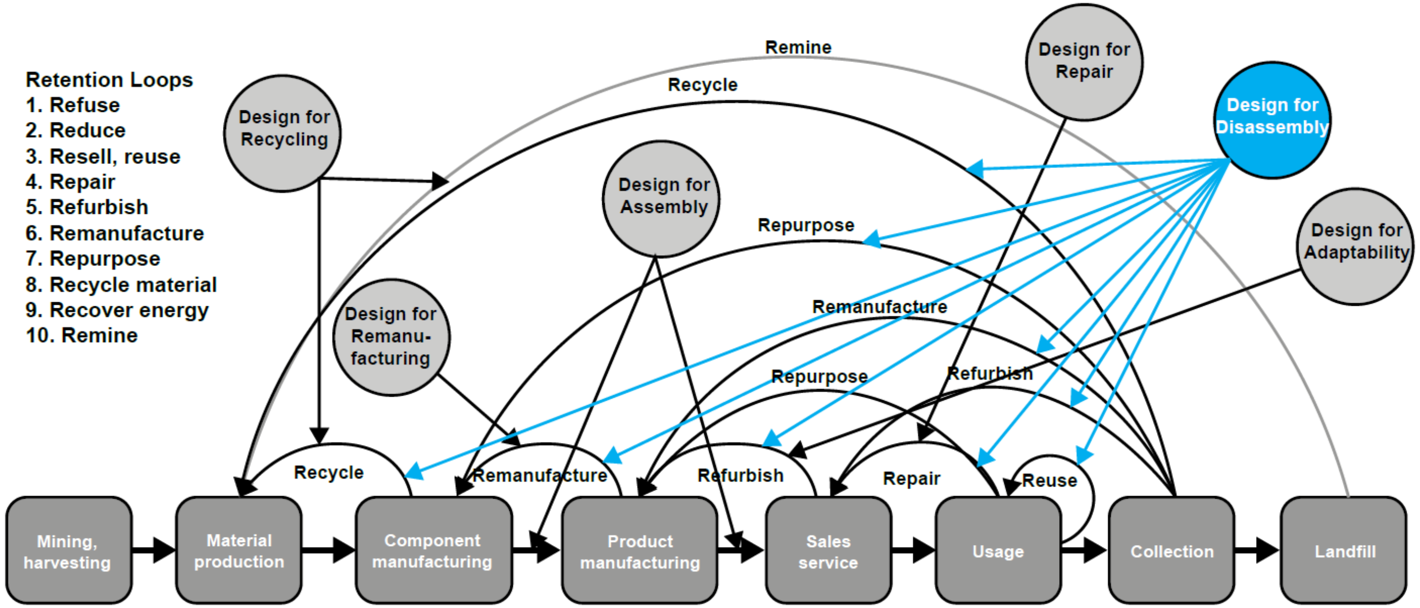


Source: Pomponi & Moncaster, 2017

What is Design for Disassembly?

Design for Disassembly is the process of systematic removal of desirable parts from an assembly while ensuring that there is no impairment of the parts due to the process.

Its significance lies in its support of enabling most of the return loops.
Hence it is a crucial principle to meet the aims of the CE.

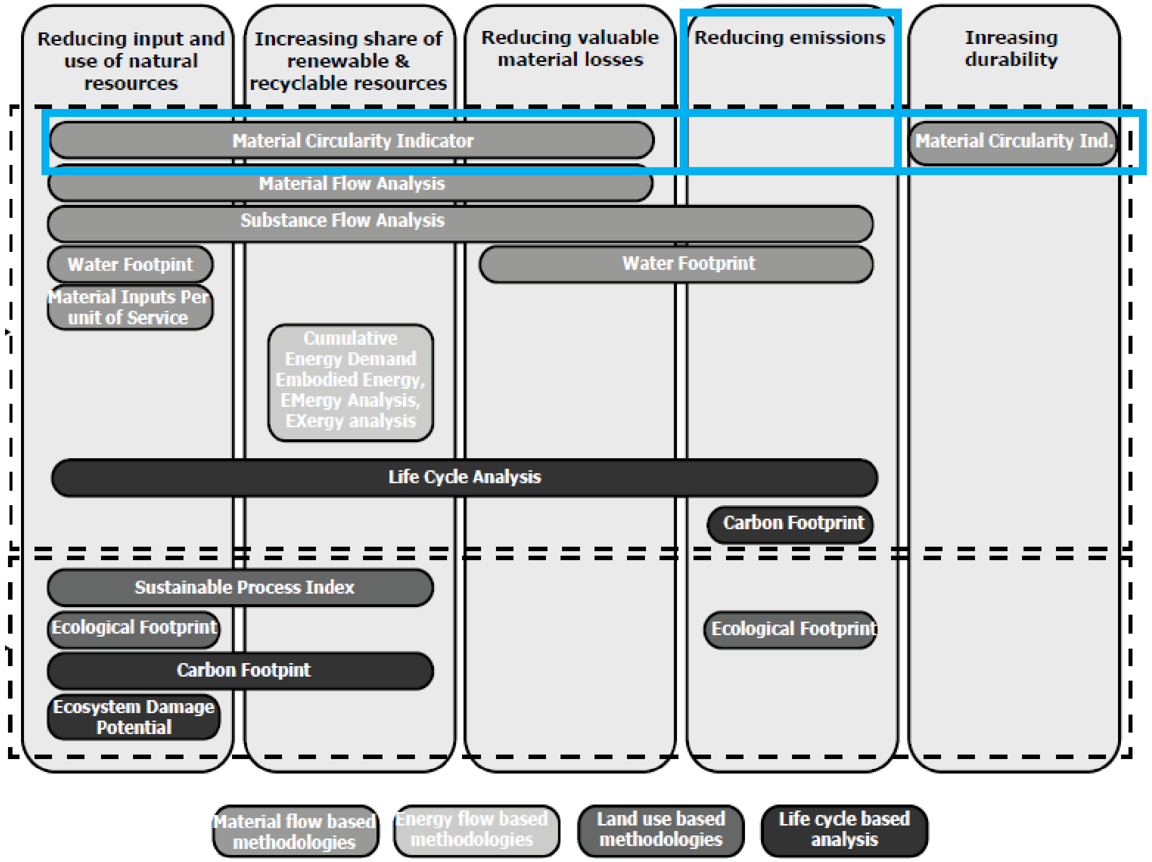


How to rate Circularity of a construction?

The crucial requirements for a rating method to measure are:

- Reduction of natural resources
- Reducing material losses
- Increasing renewable recyclable resources
- Reducing emission levels
- Increasing durability

(Elia, Gnoni, & Tornese, 2017)



Source: Elia, Gnoni, & Tornese, 2017, adapted

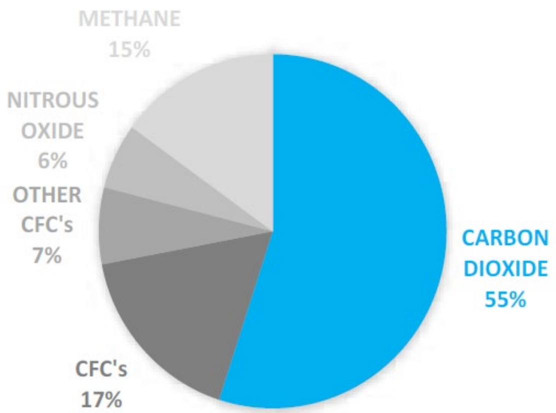
Which emissions to rate?

CO_2 is identified as one of the most harming gas contributing to climate change (Houghton, Jenkins, & Ephraums, 1991).

How to calculate the CO_2 emissions?

Multiple data input is required to calculate emissions at the various levels they occur e.g. production, transport, use, EoL (Charles, Rolls, & Tennant, 2000)

Software GRANTA EduPack is a collection of material training tools, databases and process information, tools to compare material choices.



Source: Houghton, Jenkins, & Ephraums, 1991

How to rate DfD

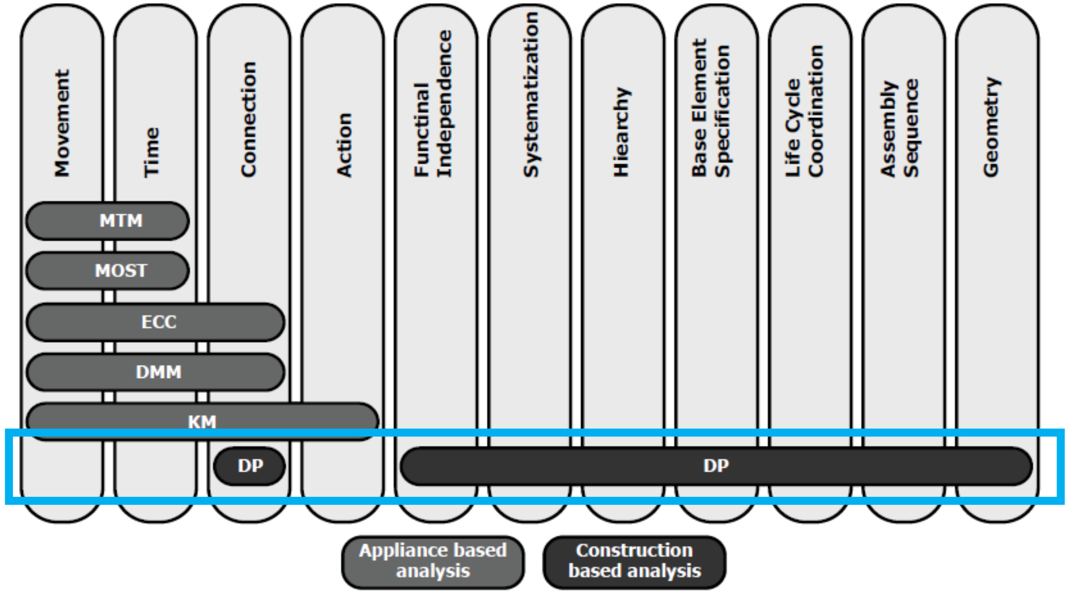
Comparison of different rating methods:

- Method Time Measurement (MTM).
- Philips ECC. Based on disassembly timings.
- Desai & Mital Method. Based on Method Time Measurement.
- Kroll method . Based on fastener types and difficulty scores.

  (All above based on household appliances)

- Disassembly Potential

  (The only rating method developed for construction)



Source: author

Scheldebouw in numbers:

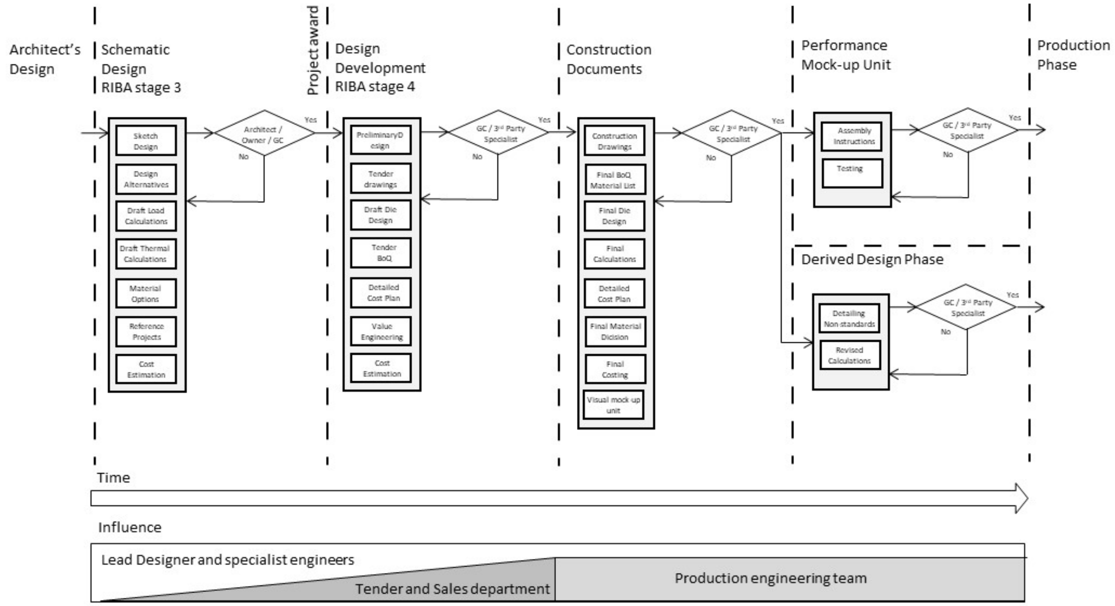
- 61 years existence
- 250 mayor projects completed
- 500 employees
- 154.000m2 total m2 façade installed
- 2 facilities in Netherlands: Middelburg and Heerlen

Façade production per year:

ca. 80.000m2 unitized façade
ca. 20.000m2 stick façade

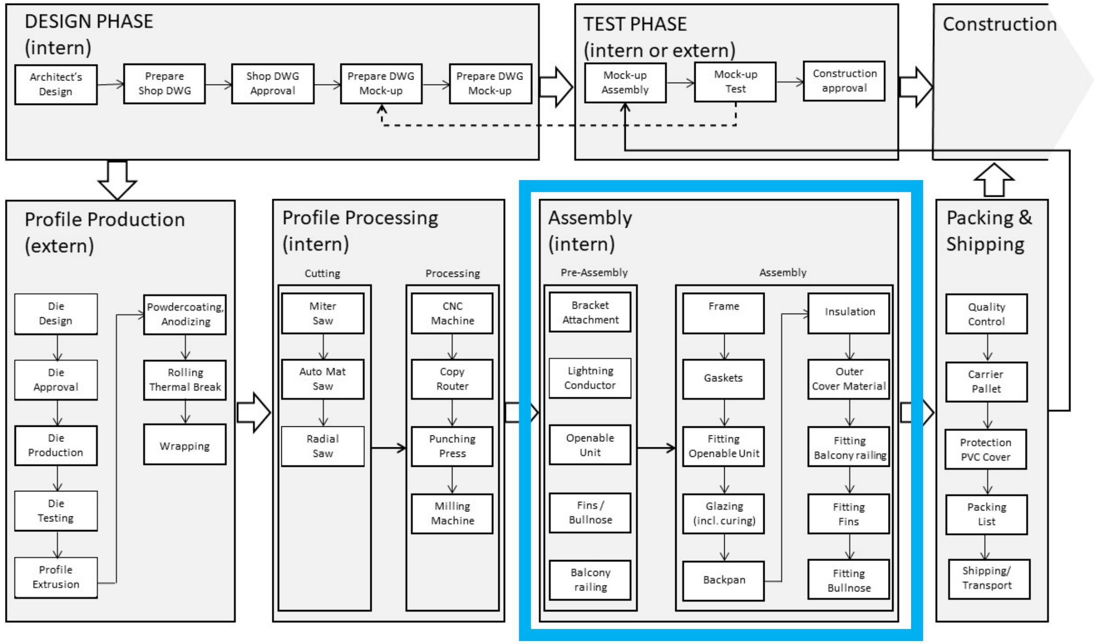
Scheldebouw Middelburg (source: Scheldebouw)

Planning phase



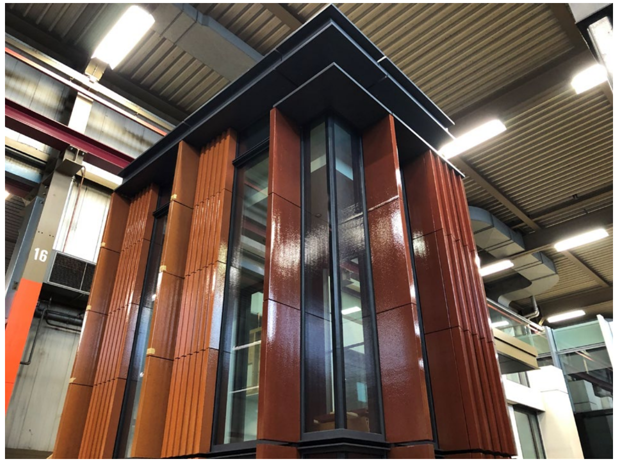
Planning procedure (source: author)

Fabrication phase



Fabrication procedure (source: author)

Assembly procedure



- Traditional assembly line work.
- The assembly sequence is clearly defined.
- The waste production is limited.
- Generous applications of adhesives.
- The number of various screw types is high.
- Focus on quality, performance and speed.

Disassembly exercise

- The disassembly took six hours.
- Hand tools were sufficient.
- Heavy items slowed down the process.
- The size of the element lead to long ways.
- The glued connections were most challenging.
- Rivets proved time consuming.

Bishopsgate, London

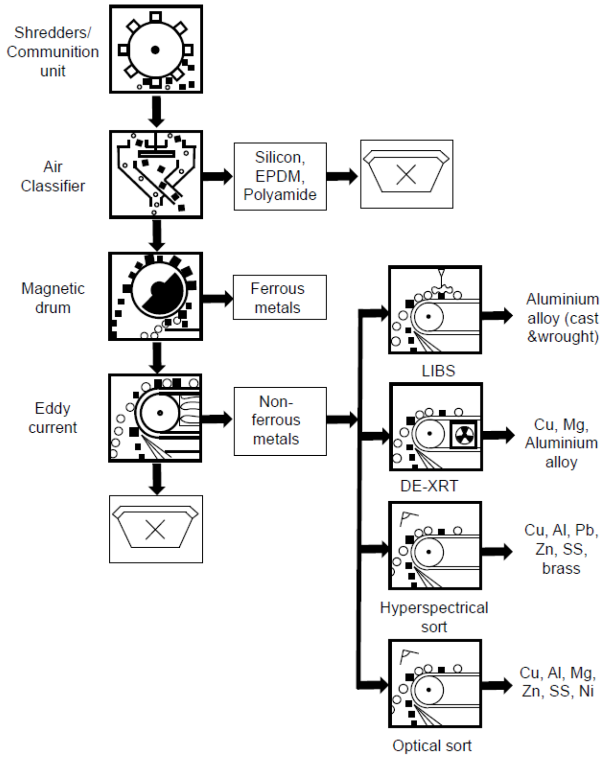
Lime Street, London

One Crown Place, London

ANALYSIS EXISTING SYSTEMS

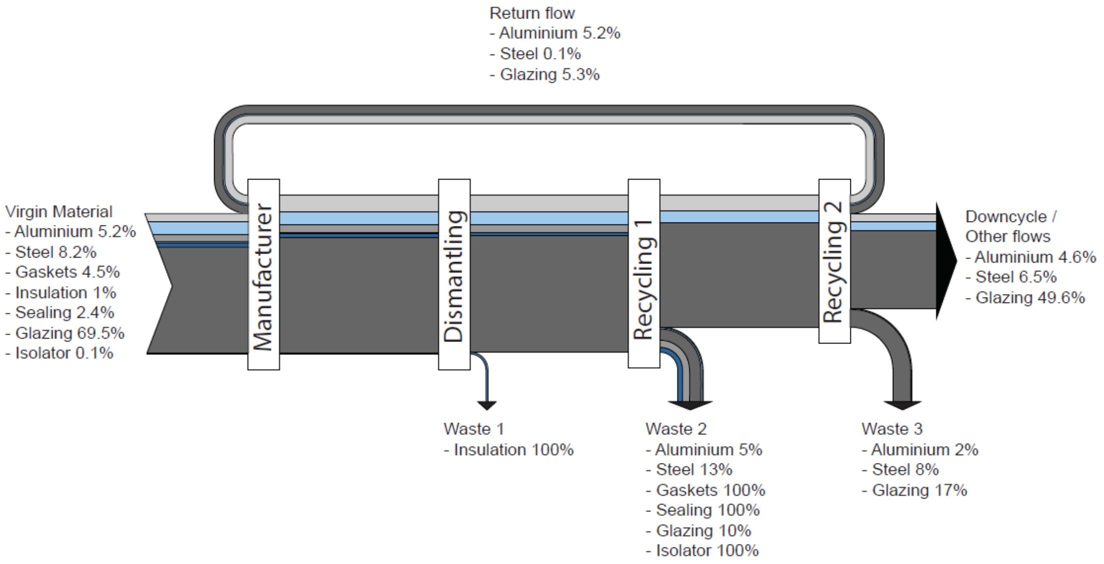
Current Recycling Practice and Material flow

Recycling procedure



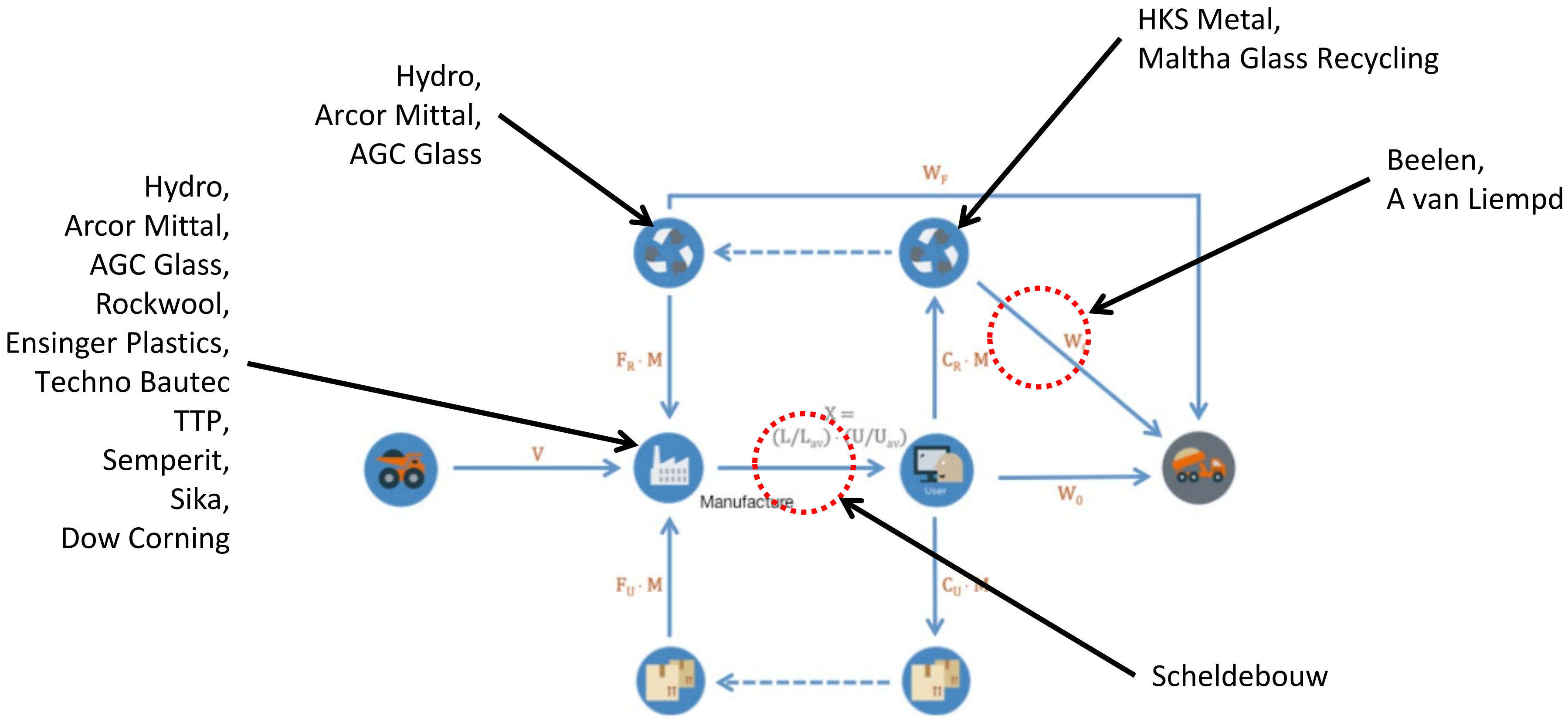
Source: Gundupalli, Hait, & Thakur, 2017, adapted

Material flow analysis (Lime Street)



Source: author, via specialist interviews

Material Flow Stations

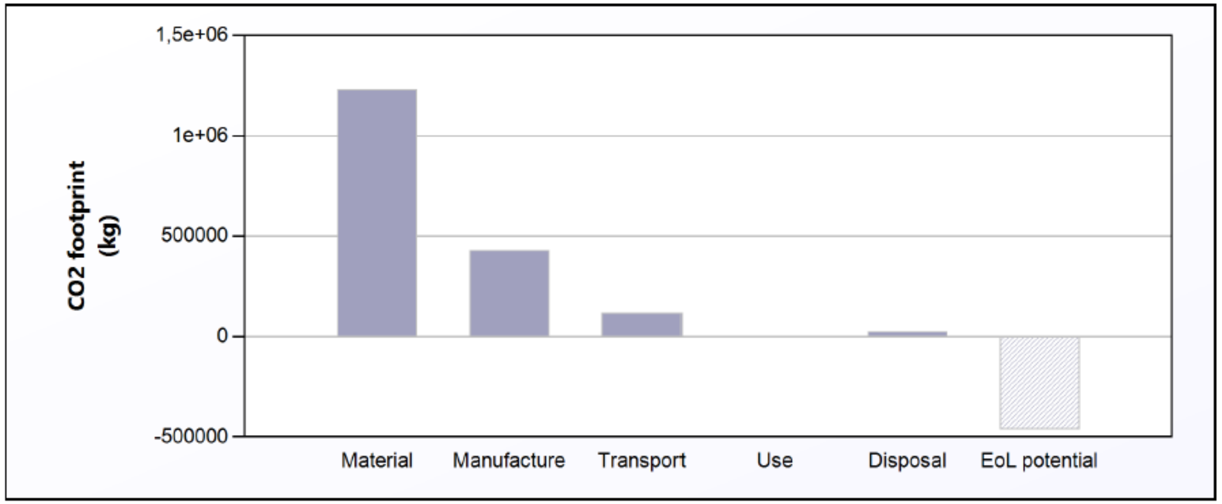


MCI parties (source: EMF 2015, adapted)

Results MCI

- Glazing by far the most heavy item (60 – 73% of total system weight)
- Unexpected high amount of virgin material (up to 95%) especially steel and glass
- No recycling of mineral wool, polyamide, sealants and gaskets
- Metals show the highest MCI value
- Results are similarly low except at Bishopsgate due to increased lifespan

Results CO2 footprint Analysis (Lime Street)



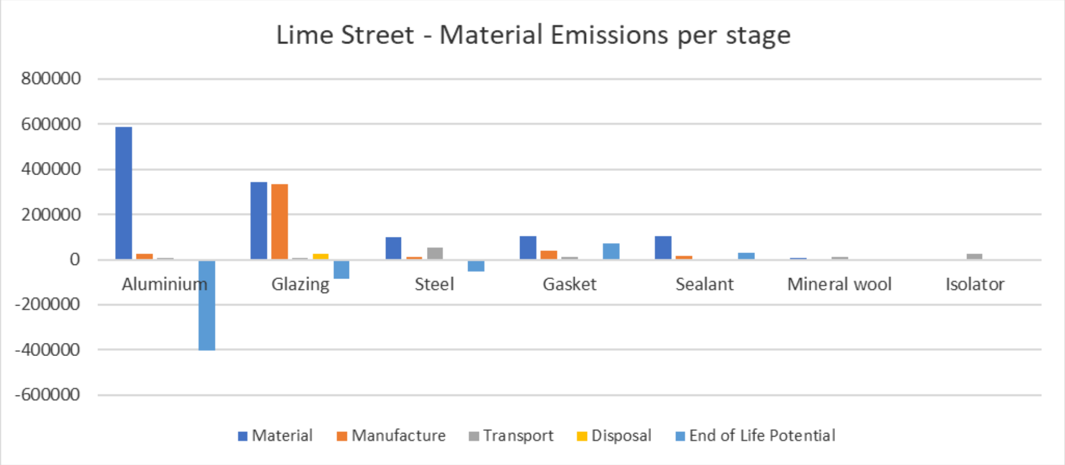
	CO2 (kg/year)
Equivalent annual environmental burden (averaged over 30 year product life):	6e+04

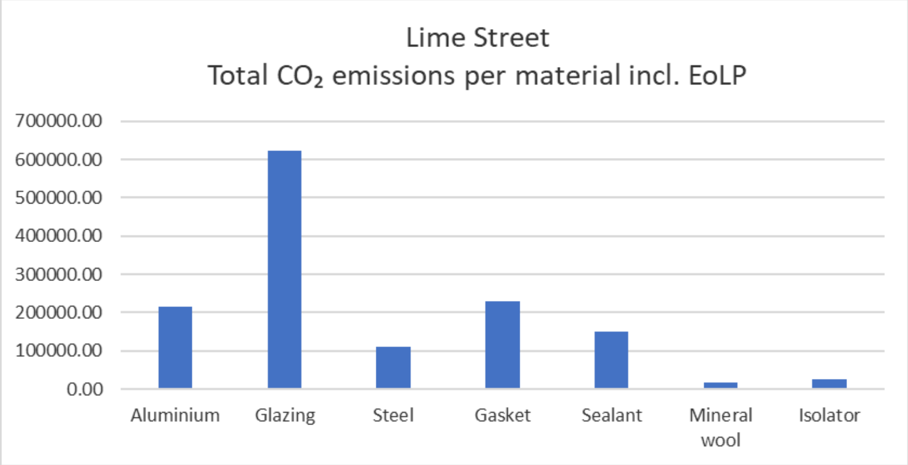
CO_2 Emission level with EoLP

	CO_2 Emission
Material	1,234,641
Manufacture	429,625
Transport	117,566
Disposal	31,452
EoLP	-444,320
Total	1,368,963
divided by use life of 30 years	**45,632**

Results CO2 footprint Analysis (Lime Street)

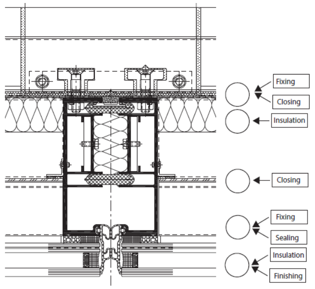
- Material production 3 times higher than manufacture and 10 times higher than transport
- Aluminium has with 65% the highest production emissions and the highest End-of-Life Potential
- Glass accounts for 46% of all emissions
- Gaskets and sealing have an impact despite their small share



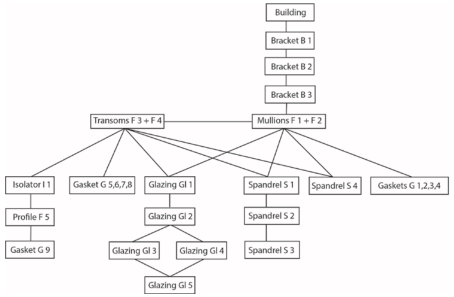


Results Disassembly Potential Analysis (Lime Street)

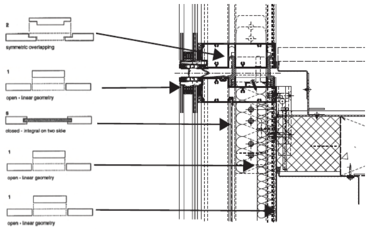
Functional Independence



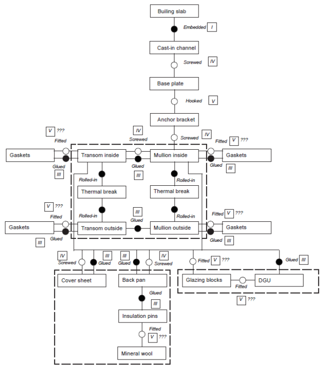
Relational Patterns



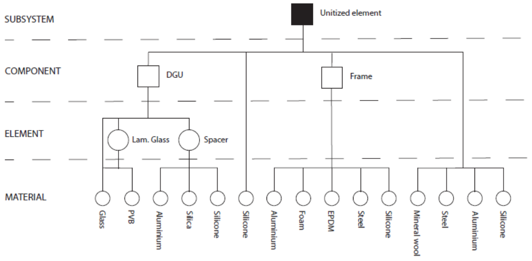
Geometry



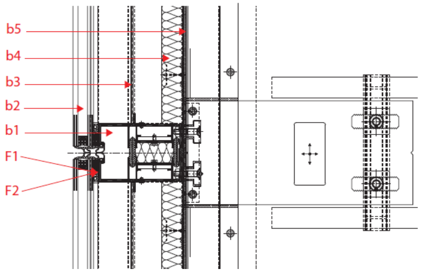
Connections



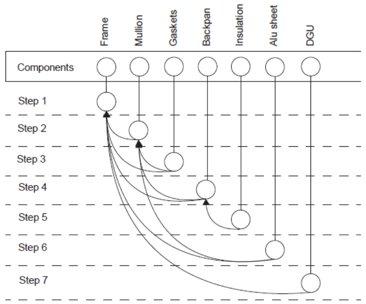
Systematization



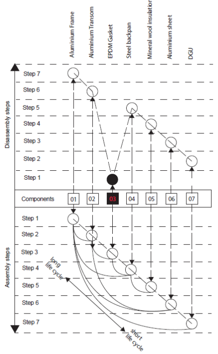
Base Element



Assembly Sequence

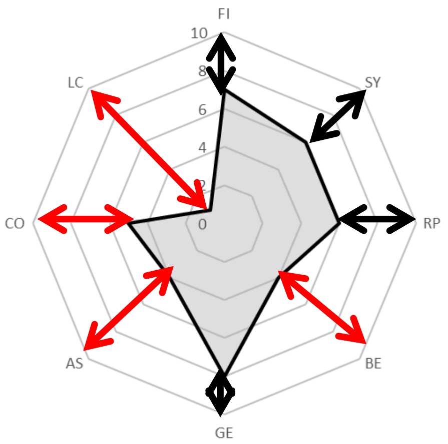


Life Cycle Coordination



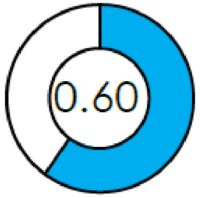
Results Disassembly Potential Analysis (Lime Street)

- Not a single rating aspect scored the highest score
- High potential for improvement especially at Base-element, Assembly, Connection and Life-cycle
- Many connections are permanent preventing disassembly
- Assembly sequence scoring low due to gasket placement at early stage
- Life-cycle coordination scoring low due to low life span of EPDM gaskets and glazing

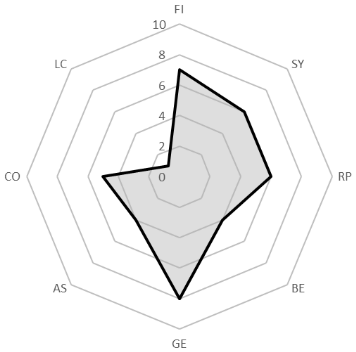


FI	7
SY	6
RP	6
BE	4
GE	8
AS	4
CO	5
LC	1

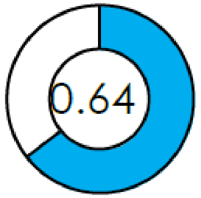
Lime Street



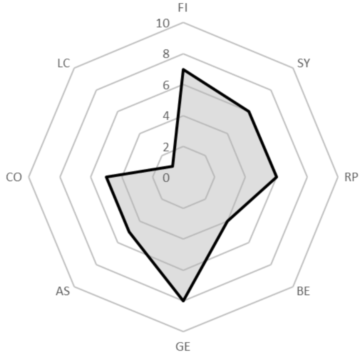
45,632 kg/a



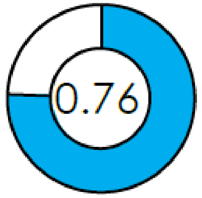
One Crown Place



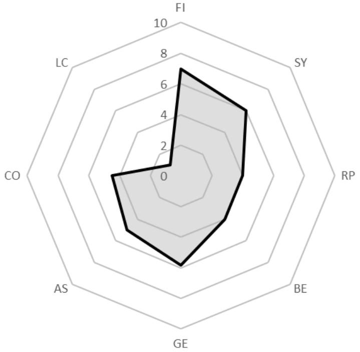
62,947 kg/a



Bishopsgate



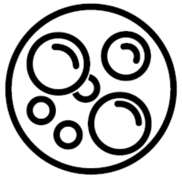
39,231 kg/a



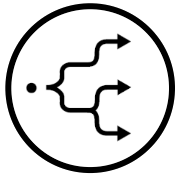
Note: CO_2 footprint with EoLP considered

Conclusions

- The tested systems show MCI values between 0.60 and 0.76
- The MCI indicates that there is ample room for improvement
- System with long life span scores best.

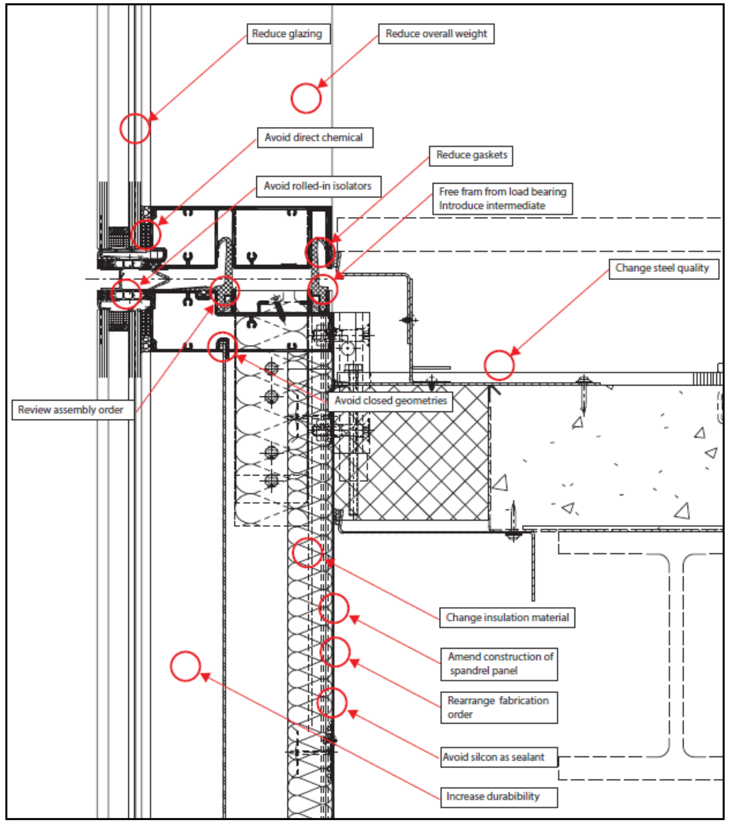


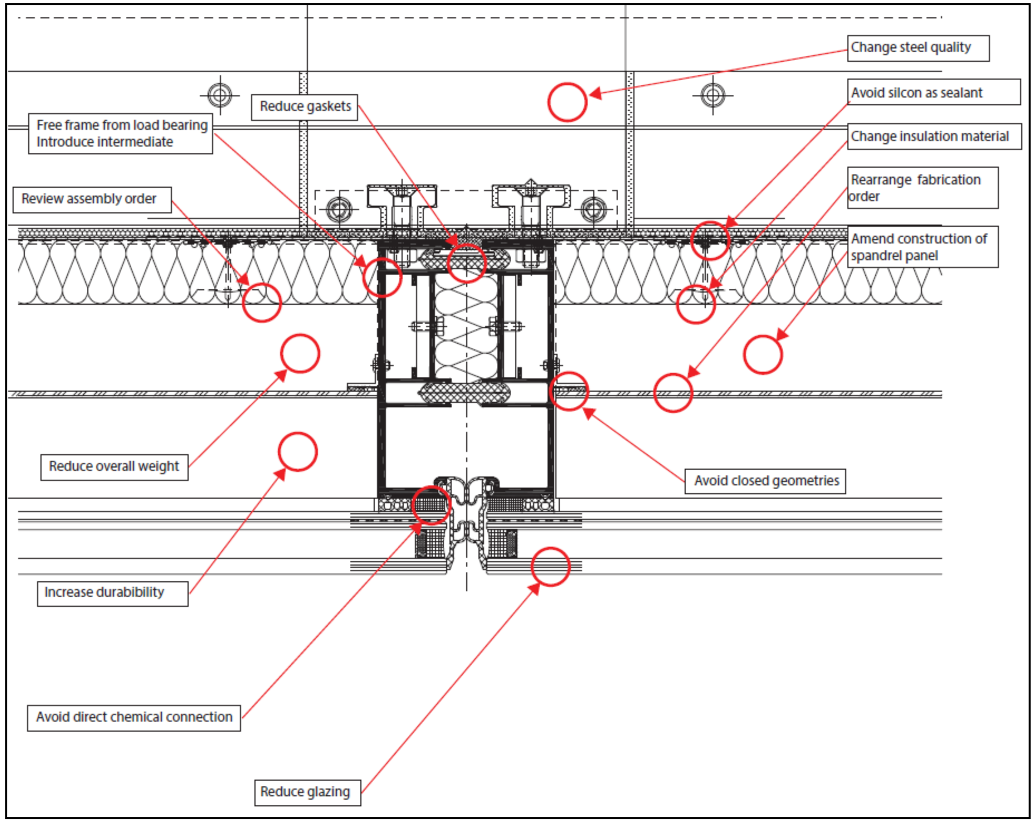
- The CO_2 emissions differ subject to the amount of materials applied.
- The material choice has a high impact, with Aluminium and glazing having the highest impact.
- End-of-life Potential can redeem emissions produced at production stage.
- System with long life span scores best.



- All systems show a similar DP level.
- The complicated systems score less.
- All systems score lowest on Life-Cycle Coordination.

Improvement points (Lime Street)





PROPOSED NEW SYSTEMS

Improvement existing systems

Improvement steps without major design changes:

1. Improvement MCI and CO_2 footprint through materials with high recycled content.

2. Improvement DP through changes to Systematization, Geometry and Connections.

3. Improvement of MCI through reduction of glazed area.

Improvement MCI footprint through materials with a high recycled content

Material	Current recycled feedstock	Available recycled feedstock
Aluminium	50%	75% (source: Hydro Circal)
Steel	0.8%	71.3% (source: Arcellor Mittal)
Polyamide	0%	100% (source: Insulbar RE)
Mineral wool	2%	40% (source: Isover)

Step 2: Calculation of Virgin Feedstock				
Material	Cycle	Recycled Feedstock Fr	Reused Feedstock	Virgin Material (kg)
Aluminium	Technical	**0.75**	0	1.719
Steel	Technical	**0.713**	0	1.559
Gaskets	Technical	0	0	2.988
Insulation	Technical	**0.4**	0	0.399
Sealing	Technical	0	0	1.582
Glazing	Technical	0.053	0	45.947
Isolator	Technical	**1**	0	0.000
				54.195

Step 4: Calculation of MCI-value					
Component	Linear Flow Index	Lifespan (a)	Utility Factor X (a / 25)	F(X)	MCI-value
Aluminium	0.16	30	1.20	0.75	0.88
Steel	0.16	30	1.20	0.75	0.88
Gaskets	1.00	30	1.20	0.75	0.25
Insulation	0.80	30	1.20	0.75	0.40
Sealing	1.00	30	1.20	0.75	0.25
Glazing	0.51	30	1.20	0.75	0.62
Isolator	0.50	30	1.20	0.75	0.63
				Total MCI	0.64

Example Lime Street
MCI 0.60 to 0.64

Improvement CO_2 footprint through materials with a high recycled content

CO_2 Emmission material production original recycled content

Material	Total mass(kg)	Recycled % as per CES	CO_2 kg/kg	CO2 footprint(kg)
Aluminium	67,840	40.5 - 44.7	8.62	584,974
Glazing	485,190	22.7 - 25.1	0.70	340,882
Steel	54,190	52.3 - 57.8	1.79	96,871
Gasket	29,880	0.10	3.42	102,063
Sealant	15,820	0.10	6.51	103,022
Mineral wool	6,660	23.8 - 26.3	0.87	5,814
Isolator	160	0.10	6.34	1,015
			Total	**1,234,641**

CO_2 Emission (kg) original vs. increased recycled content

	Original recycled content	Increased recycled content
Material	1,234,641	1,007,836
Manufacture	429,625	429,625
Transport	117,566	117,566
Disposal	31,452	31,452
EoLP	-444,320	-444,320
Total	1,368,963	1,142,158
over 30 years	**45,632**	**38,072**

CO_2 Emmission material production increased recycled content

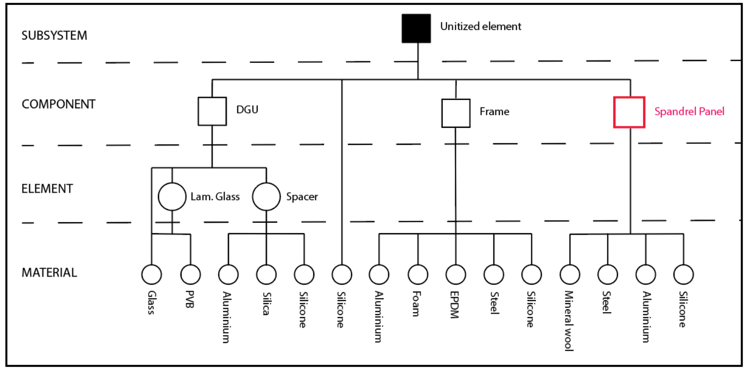
Material	Total mass(kg)	Recycled % NEW	CO_2 kg/kg	CO2 footprint(kg)
Aluminium	67,840	75.00	5.53	374,816
Glazing	485,190	22.7 - 25.1	0.70	340,882
Steel	54,190	71.30	1.50	81,068
Gasket	29,880	0.10	3.42	102,063
Sealant	15,820	0.10	6.51	103,022
Mineral wool	6,660	23.8 - 26.3	0.87	5,814
Isolator	160	100.00	1.07	171
			Total	**1,007,836**

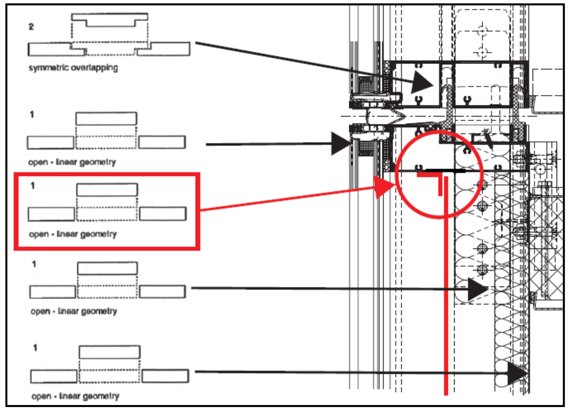
Example Lime Street

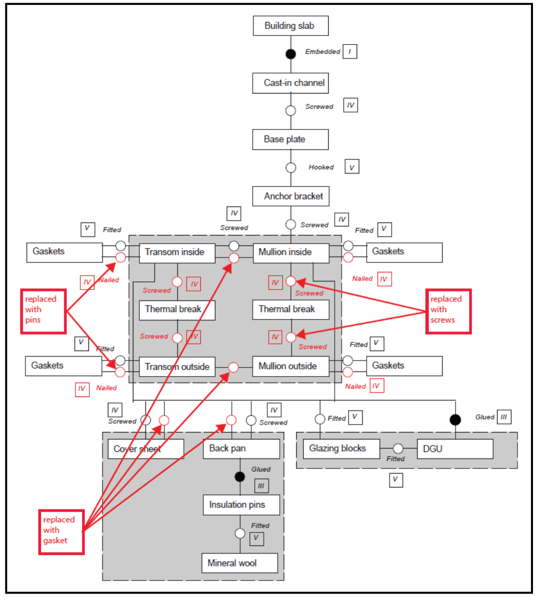
CO_2 from 45.632 to 38.072 kg/a

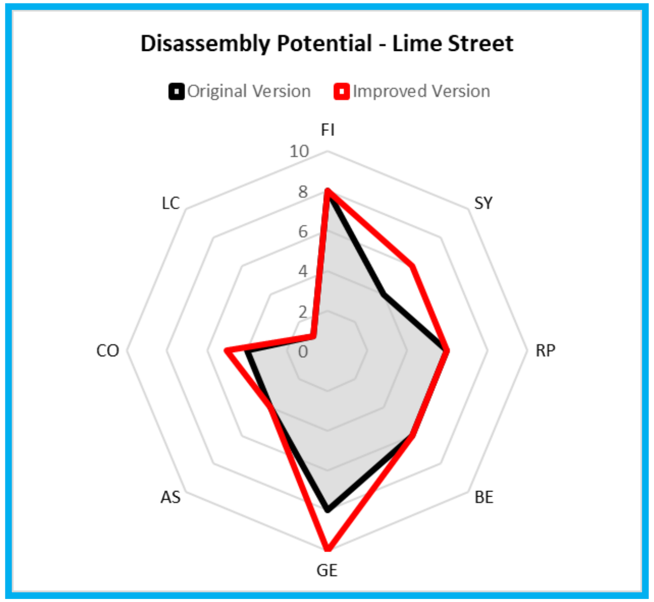
Note: CO_2 footprint with EoLP considered

Improvement DP through changes to Systematization, Geometry and Connections

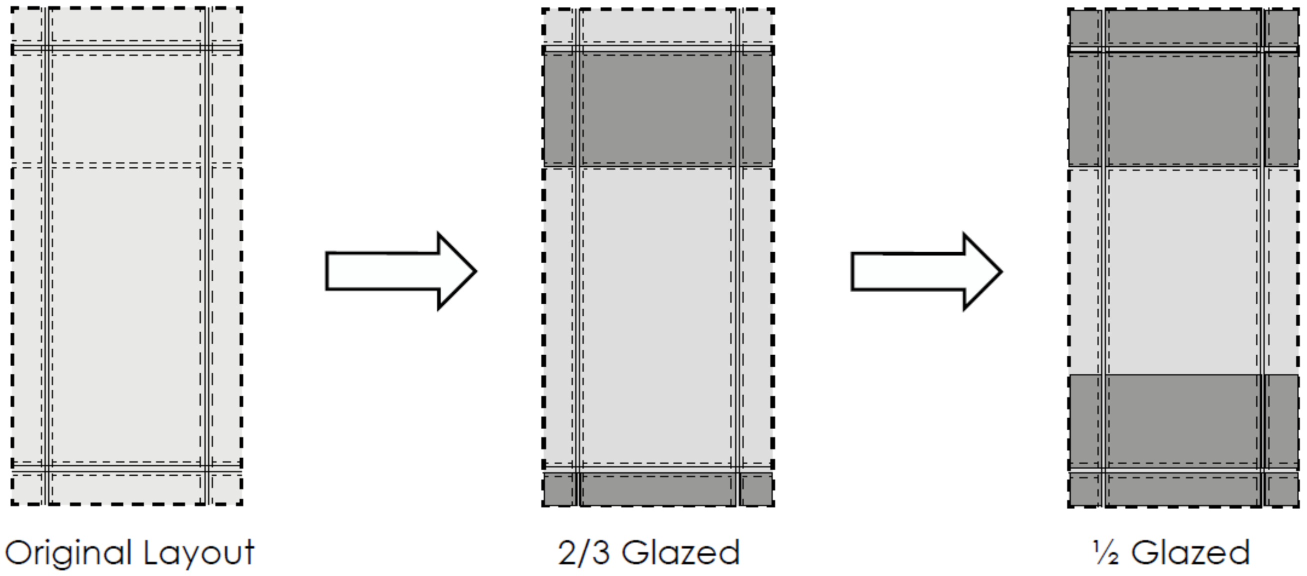








Improvement of MCI through a reduction of glazed area



Example Lime Street
MCI 0.60

Example Lime Street
MCI 0.61

Example Lime Street
MCI 0.62

6 | PROPOSED NEW SYSTEMS

Improvement existing systems

Improvement steps MCI

→ Produce façades for long life-spans. Improvement approx. 16 and 21%. ★★★

→ Chose materials with high recycled feedstock. Improvement approx. 6% ★★☆

Improvement steps CO_2 footprint

→ Plan systems for a long use-life cycle. Improvement approx. 40%. ★★★

→ Select materials of high recycled amount. Improvement approx. 16% ★★☆

→ Reduce glazing. Improvement approx. 12% ★★☆

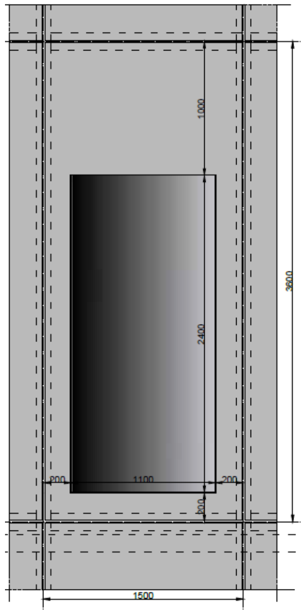
Improvement steps Disassembly Potential

→ Aligning materials life span with assembly sequence. Improvement approx. 30%. ★★★

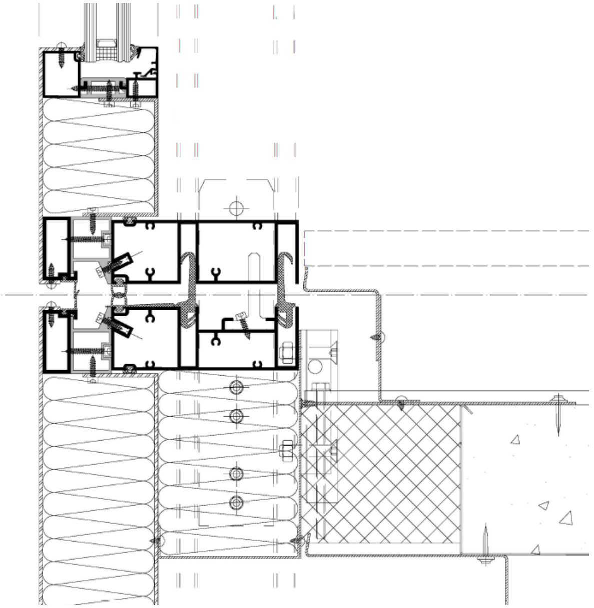
→ Converting spandrel panel into component. Improvement approx. 20%. ★★☆

→ Introducing more open linear geometries. Improvement approx. 20%. ★★☆

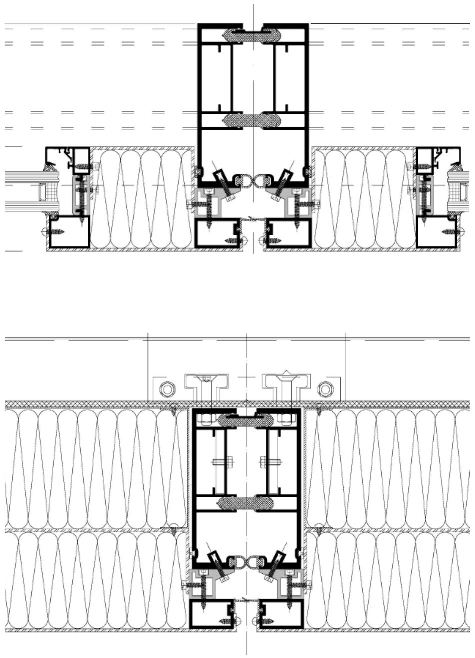
Planning for enhanced longevity through DfD



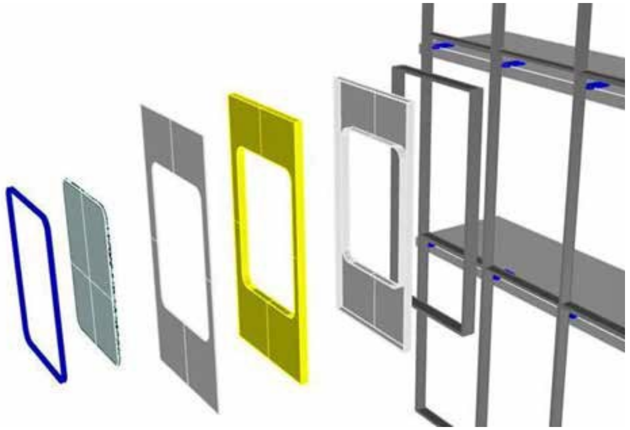
Elevation



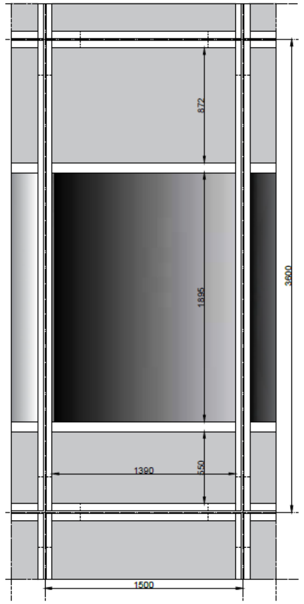
Stack joint



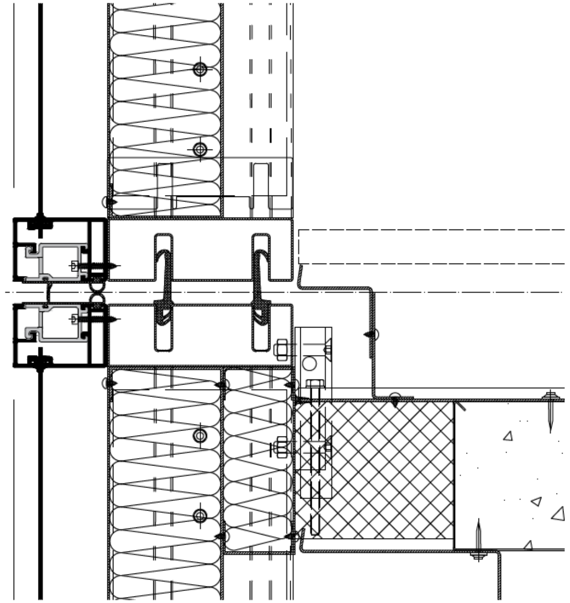
Horizontal sections



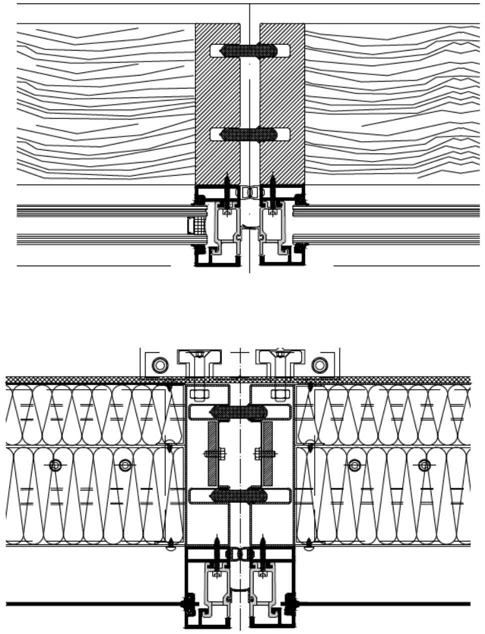
Planning for reuse of frame components



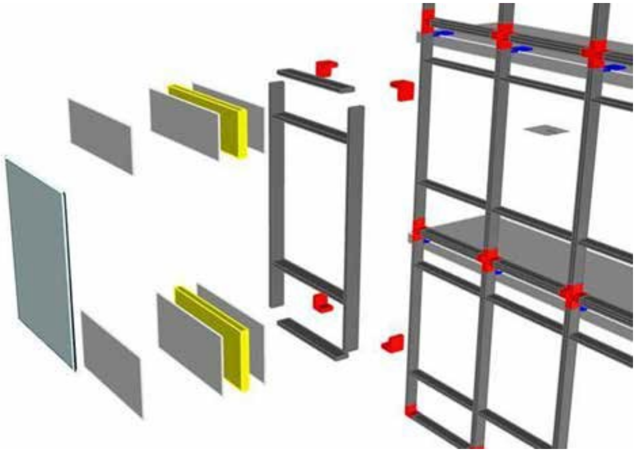
Elevation



Stack joint

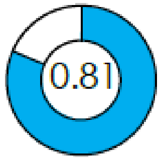
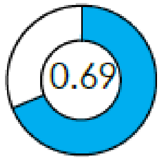
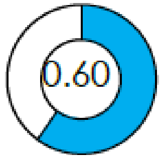
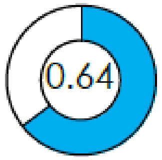
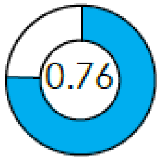
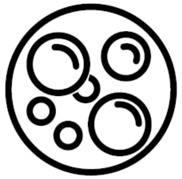
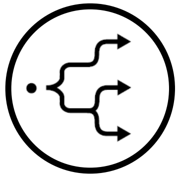
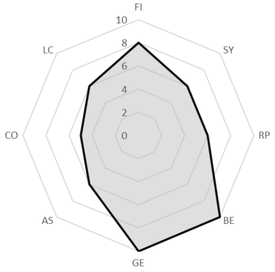
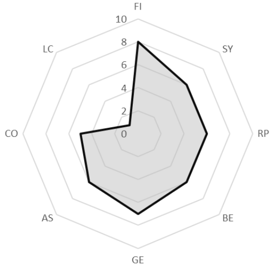
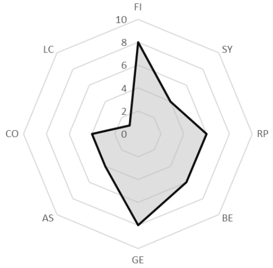
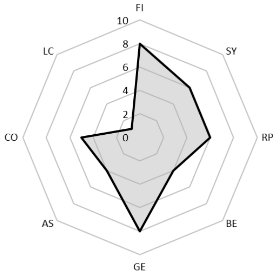
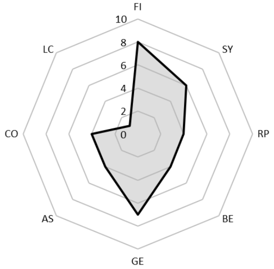


Horizontal sections



ANALYSIS PROPOSED SYSTEMS

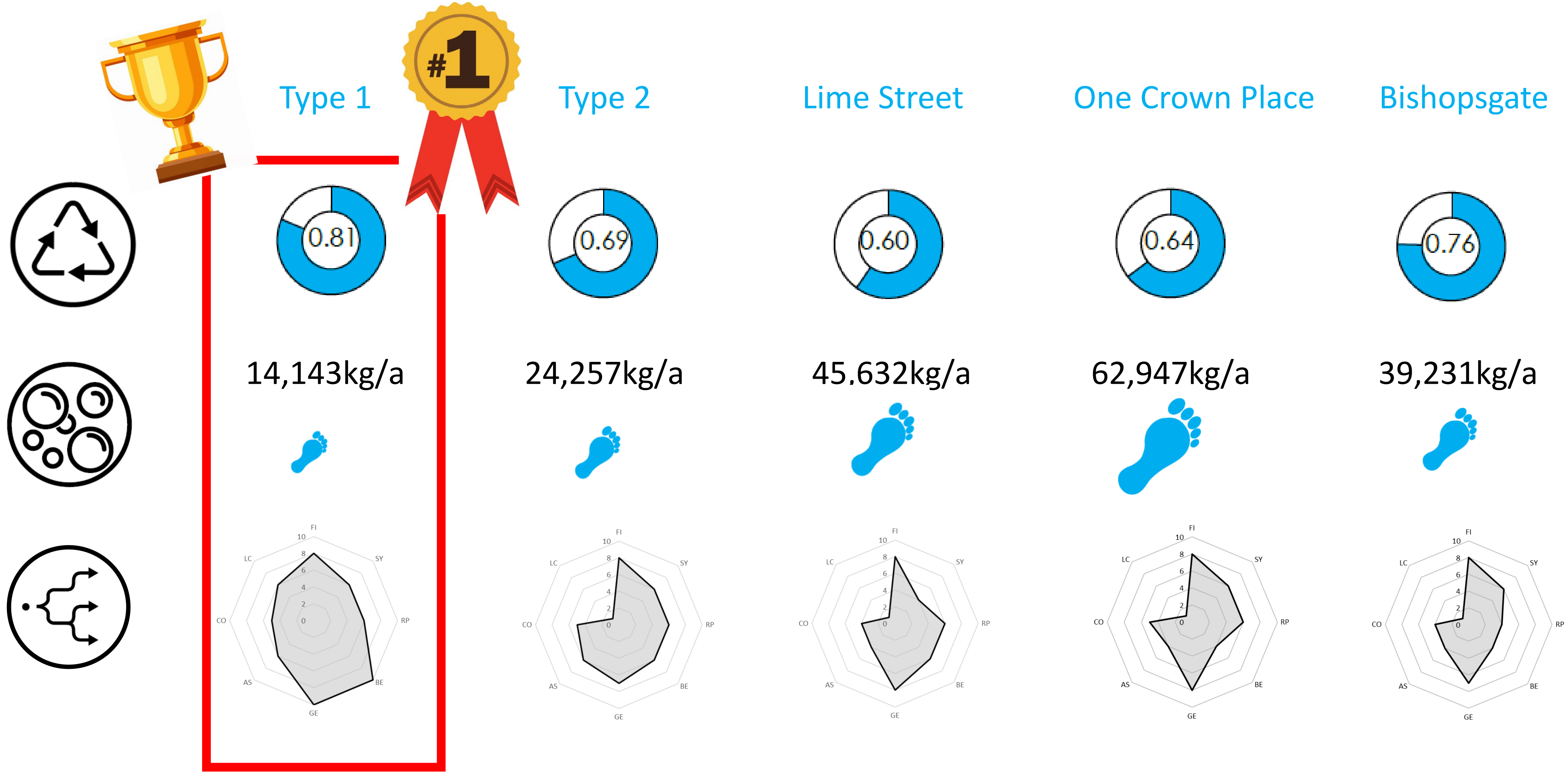
Rating New Designs

	Type 1	Type 2	Lime Street	One Crown Place	Bishopsgate
	 0.81	 0.69	 0.60	 0.64	 0.76
	14,143kg/a 	24,257kg/a 	45.632kg/a 	62,947kg/a 	39,231kg/a 
					

Note: CO_2 footprint with EoLP considered

ANALYSIS PROPOSED SYSTEMS

Rating New Designs



Note: CO_2 footprint with EoLP considered

Circularity and Disassembly in Construction

Croxford et al. reviewed the circularity of two buildings with different building service systems.
One standard building equipped with modern HVAC and building service technology.
The other building outfitted with materials and technology supporting circular economy aspects.

Main conclusion for achieving circularity with building service systems:

1. Durability and resilience of used products, plus enabling straightforward disassembly.

2. Information exchange through digital technology, allowing involvement of all stakeholders.

3. Shifting from product sales as a service business model shifts towards service contracts, retaining ownership and 'ecological responsibility' with the supplier.

(Croxford, Mendoza, Portal, & Rovas, 2018)

Circularity and Disassembly in other industries

Repair and remanufacture cycles of automotive parts have been established since cars exist.
A French company successfully remanufactures automotive parts since 1949.

Remanufactured parts allow repair of older cars of reduced value with parts that are less expensive and come with guarantee.

The continued use of the vehicle maintains its usage and its value.
The plant provides several hundred jobs in the region.
The remanufacturing saves plenty of raw materials and energy.

(Ellen MacArthur Foundation, 2020)

Outlook

In the past thermal and structural performances and with air- and water tightness were main keys for façade design.

Performance requirements were regularly increased but are now hard to achieve and to justify. The focus of the legislator shifted from the performance to environmental burden.

The ‘Milieu Prestatie Gebouwen’ (MPG) measures the environmental impact of the materials used in a building. As of 1 January 2018, the maximum limit for the MPG is 1.0.

Since other performance of the facades are hard to increase, the ecological footprint will become more important.

In the future facades will be rated more strictly on their environmental burden.

Summary

The comparison of the two projects HVAC showed the importance of disassembly and to transform businesses from a product to a performance/service model.

The French remanufacturing plant proved that Circular business models are most successful, beneficial for the local economy and the environment.

With the introduction of MPG the legislation started to regulate the environmental performance of building products, the advantages of the Circular Economy are more and more shifting into focus.

In brief, businesses in the future will be successful if they manage offer their services based on the principles of the Circular Economy, with Design for Disassembly being one key aspect to achieve this. Businesses will have to adapt their products and services accordingly.

9 CONCLUSION

Answer to Research Question

To what extent can Design for Disassembly contribute to optimize the facades of Scheldebouw for Circularity?

Design for Disassembly increases the longevity of a façade by enabling replacement of material with short live-cycles.

DfD helps to keep the façade productive and maintains the value of the façade. Therefore DfD contributes to meet Circularity.

Longevity produced the best results, in combination with materials of high recycled content.
A totally circular façade is not achieved. DfD is a facilitator not a guaranty for circularity.

But a circular product is not sufficient to achieve a circular business.

The transfer from selling products to leasing performance is the key.

CONCLUSION

Answer to Design Question

How does a standard façade of Scheldebouw look like when optimized for Disassembly and Circularity?

Main principles of Scheldebouw’s facades were adopted.

No radical change from the existing systems except a reduction in glazing area.

Aesthetically no differences except smaller glazing area.

Main amendments in connection details, base element design and element geometries.

Glued connections, especially structural glazing were avoided.

Material choices and recycling efficiencies set limits to reach Circularity.

CONCLUSION

Further Research

Recommendations for further research:

Local production and application abroad – How does that fit circularity?

Low recycled amount in glazing - How can it be improved?

Short life span of gaskets and double glazed units – How can their life spans be prolonged?

Recycling vs. Reuse – With current high recycling rates, does reuse make sense?

9 | # CONCLUSION

Reflection

Shortcomings of the rating systems

Material Circularity Indicator

- Calculating method stalls at certain recycling ratios
- Reduced does not allow more than two recycling stops, result can be criticized
- Some material flows are missing, no measuring of toxicity

CES EduPack

- Hybrid materials are not covered in database
- Database is found on worldwide data, more precision would be beneficial
- Student version has various shortcomings on data entry

Disassembly Potential

- No consideration of actions or time for disassembly. No calculations of costs possible.
- Various aspects of the element not considered e.g. dimensions and weight
- A maximum of DP might not be necessary and result in over-design and costs

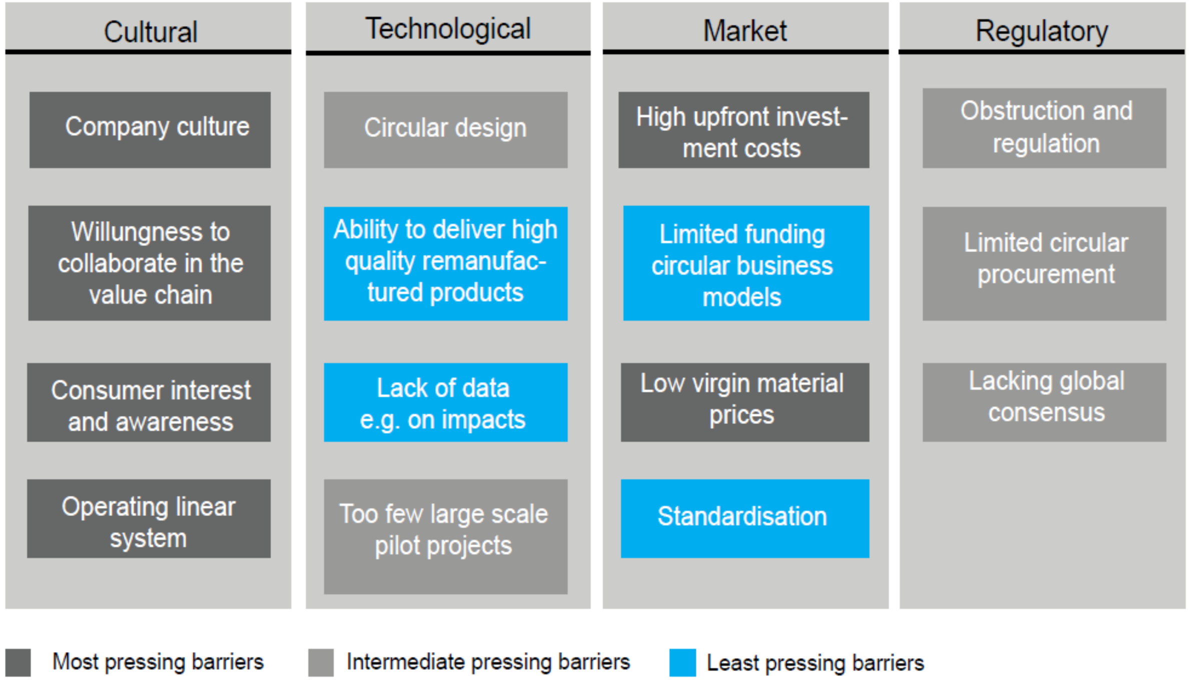
Barriers

The change from a linear to a circular business model faces hurdles of 4 categories:

- cultural
- technological
- market
- regulatory

Kirchherr et al. defined cultural and market hurdles as most pressing.

The technological challenge is considered minor.

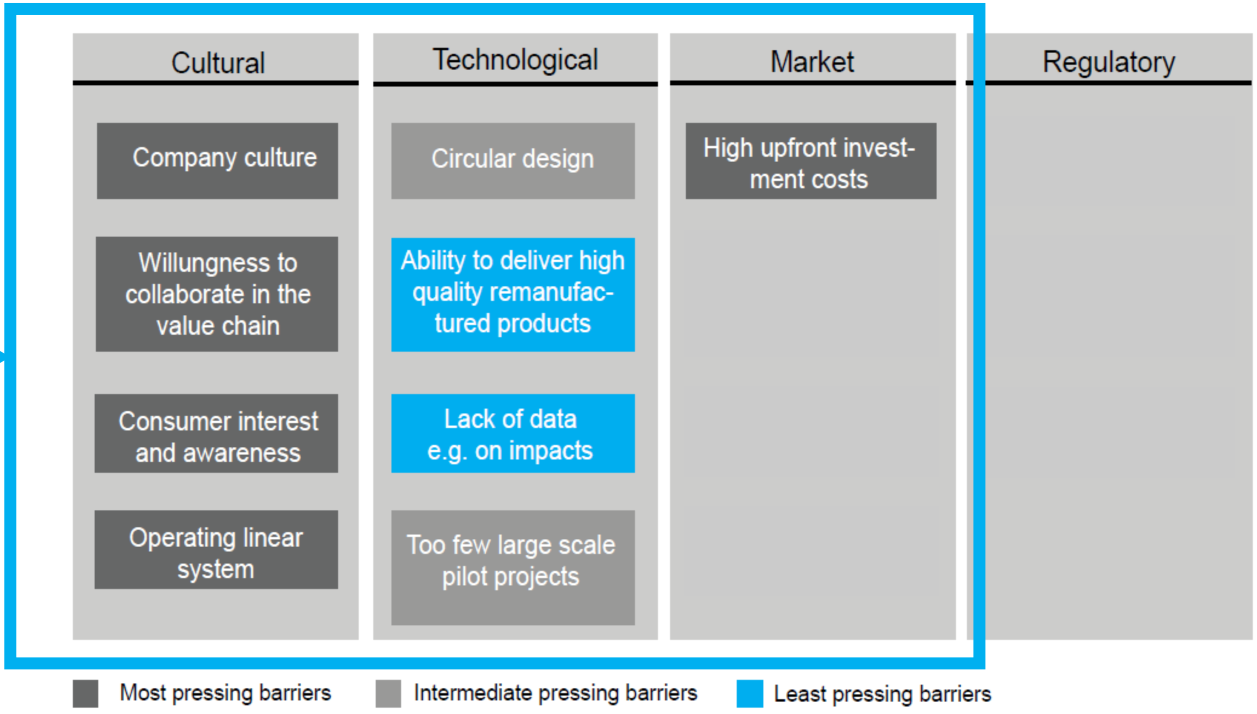


Source: Kirchherr, et al., 2017

Barriers

Most of the pressing hurdles Scheldebouw can overcome.

Or at least it is in their hands.



Source: Kirchherr, et al., 2017

Action plan

Business level

4.
- Starting experimental small-scale projects
- Training staff about the circular economy
- **Shifting from selling products to leasing performances**

Service level

3.
- Active advisory about circularity to customers
- Establishing circularity passports for new designs
- Offering services and solutions for façade disassembly
- Servicing retention-loops offering repair, remanufacture, etc.

Product level, design changes

2.
- Incorporating DfD principles
- Improving longevity and durability
- Enhancing adaptive capacity

Product level, no design changes

1.
- Applying material with recycled feedstock content
- Checking alternative suppliers
- Checking alternative materials

CLOSING LOOPS

Thank you!