Closing loops

Optimizing unitized façade elements for disassembly

Hans Gamerschlag

Critique points previous presentation

- **Missing correctness**, accuracy, efficacy and evidence.
- Improve **problem statement**, objective and research questions.
- Provide reflection on **research method**, data and context.
- Focus on **Scheldebouw** and its specific requirements, provide more detail.

1 Main problem

1. The current unitized facades of Scheldebouw are not designed with the **end of their service life** in mind.
2. As a **result** at the end of their service life the **facades are demolished** and the materials are downcycled or ending up as landfill.
3. The main amount of the **material and energy** involved to produce the facades in the first place is **lost**.

1 Main objective

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

1 Main research question

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

1 Background-questions

1. What means Circularity in the Built Environment?
2. Why is Design for Disassembly important?
3. Who is Scheldebouw?
4. What are the facades of Scheldebouw?

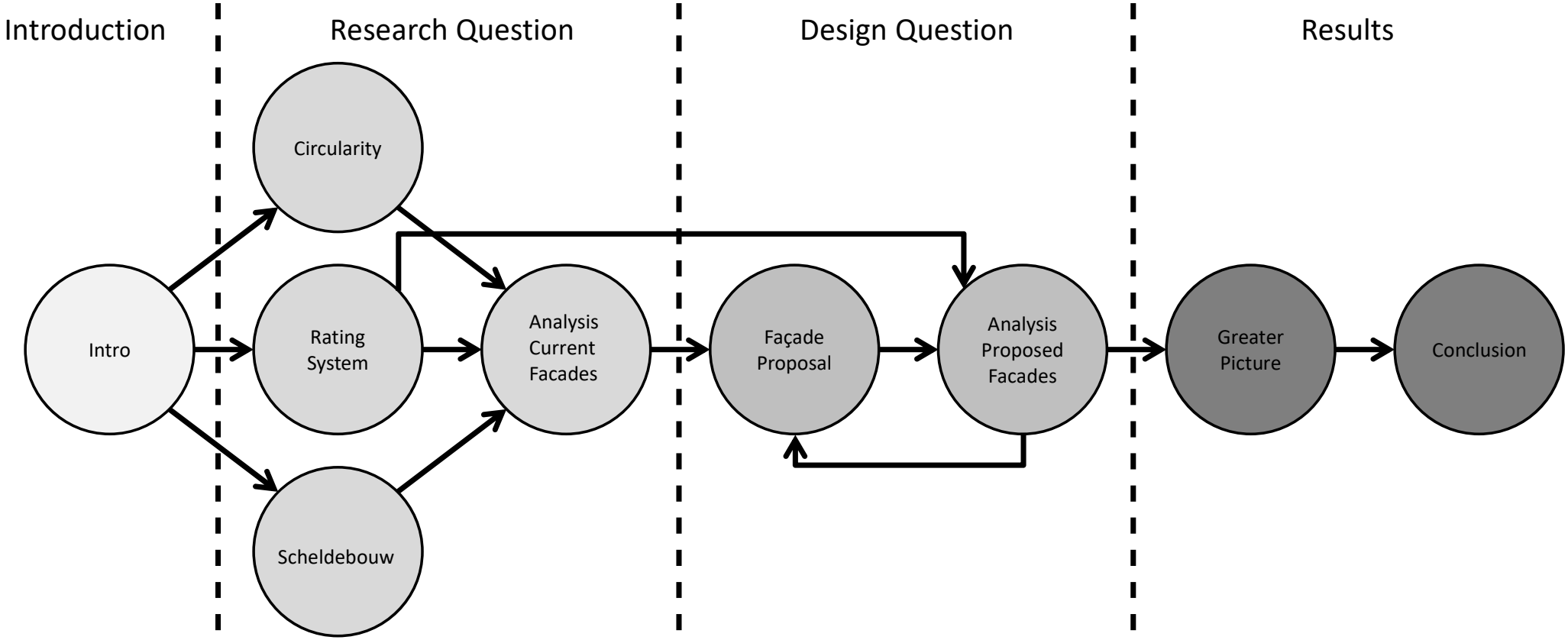
1 Sub-questions

1. How can a construction be rated for Circularity?
2. How can Design for Disassembly be rated?
3. What are the standard principles of Scheldebouw's systems?
4. What is the current salvage practice of facades?
5. To what quantity are facades re-used or recycled?
6. How are façades of Scheldebouw designed and assembled?
7. What are the current obstacles for disassembly?

1 Final product

A façade proposal based on design principles of Scheldebouw optimized for Disassembly in order to improve its level of Circularity.

1 Approach and Methodology
Logical organisation



1 Approach and Methodology
Logical organisation

Introduction

1. Introduction

Research Question

2. Circularity
3. Rating Systems
4. Scheldebouw
5. Analysis Current Facades

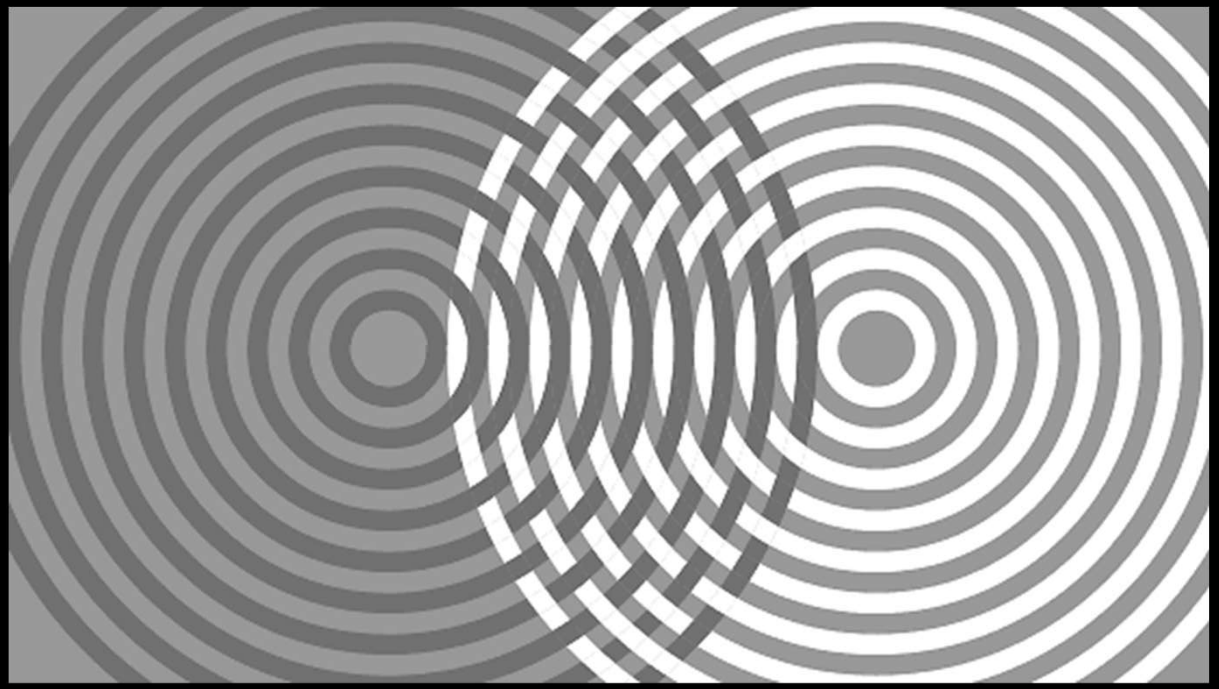
Design Question

6. Façade Proposal
7. Analysis Proposed Facade

Results

8. Greater Picture
9. Conclusion

2 Approach and Methodology
What is the ‘Circular Economy’?



2 Approach and Methodology
What is the 'Circular Economy'?

Various Definitions

Ellen MacArthur Foundation (2014) - "A circular **economy** is an **industrial** system that is **restorative or regenerative** by intention and design. It replaces the **end-of-life concept** with restoration, shifts towards the use of **renewable energy**, eliminates the use of **toxic** chemicals, which impair reuse and return to the biosphere, and aims for the **elimination of waste** through the superior design of materials, products, systems and business models "

European Commission (2014a) "A circular economy preserves the **value** added to the products for as long as possible and virtually **eliminates waste.** The **resources** are **retained** within the economy when a products has reached the end of its life, so that they **remain** in **productive** use and create further **value**" -

Aldersgate Group (2012) - "The circular economy is a generic term for an **industrial economy** that, by design or intention, is **restorative** and **eliminates waste**. Material flows are of two types; **biological nutrients**, designed to re-enter the biosphere safely, and **technical nutrients** (nonbiological materials), which are designed to **circulate** at high quality, with their economic **value preserved** or enhanced"

OPAi & MVO (2014) - "The circular economy can be defined as an **industrial economy** with an **resiliency** as intention has and consumption where it is possible changes into usage. The circular economy is based on **closing the loops** and to (where possible infinite) extend a cycle. It invites therewith to more use of **renewable energy**, **minimalize** the **pressure** on the ecological system, **eliminate** the use of **toxic** substances, and assumes that **waste** is the start of the next phase of life and that **reuse** is included in the design phase".

2 Approach and Methodology
What is the ‘Circular Economy’?

Key aspects

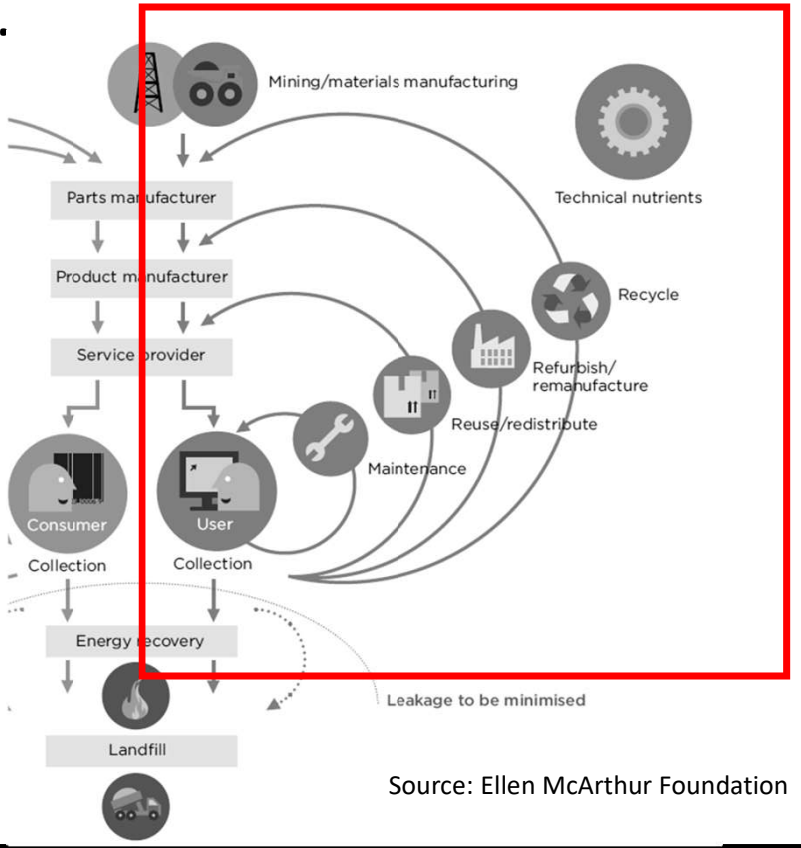
- Industrial economy
- restorative to the environment
- replacing present end-of-life concept with closed loop concept
- using renewable energy
- eliminating waste production and toxic substances
- waste considered the start of the next phase of life
- keeping products and materials productive
- preserving or enhancing product or material value
- retaining resources

2 Approach and Methodology
What is the ‘Circular Economy’?

Division in biological and technical cycle.

Loops of the technical cycle:

1. **Maintenance**: allowing repair and upkeep.
2. **Reuse**: prolonging life time by enabling reuse.
3. **Remanufacture**: remaking components as new, with warranty.
4. **Recycle**: upcycling into new components,
   downcycling for lower quality use or disposal.



Source: Ellen McArthur Foundation

2 Approach and Methodology
What is the ‘Circular Economy’?

Loops/circles have different values:

- **Power of inner circle.**
  Cycles closer to the source preserve more value.
- **Power of circling longer.**
  More and often cycles of material lead to better and longer usage.
- **Power of cascaded reuse.**
  Cascaded reuse of material maximises value extraction.
- **Power of pure inputs.**
  Higher purity and quality results in longer lifetime and efficiency.

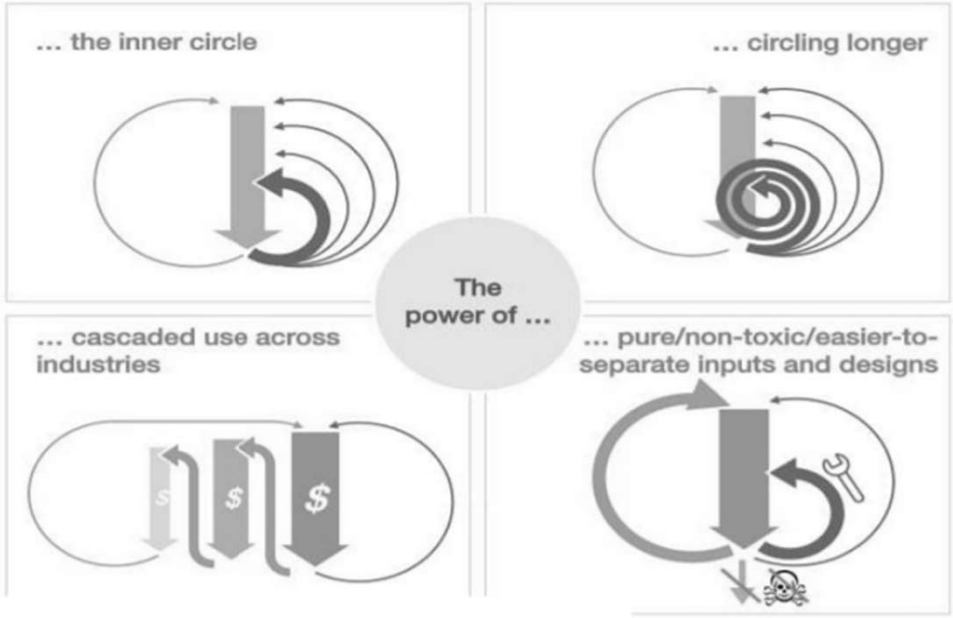


Figure 3. Sources of Value Creation for the Circular Economy (EMF, 2015a: 13)

2 Approach and Methodology
What is the ‘Circular Economy’?

Key prerequisites according the Ellen MacArthur Foundation:

1. **Conservation** of natural resources by:
   - controlling resource stocks
   - replacing finite with renewable resources
2. Aiming for **highest output of resources** by:
   - **applying materials**, components, products at **highest value**
   - **keeping materials**, components, products **always productive**
3. **Monitoring** system performance and preventing performance loss.

2 Approach and Methodology
What defines a ‘Circular’ Construction?

‘A circular building as construction created, planned, assembled, managed, upkept and dismantled in compliant ways to Circular Economy standards.’ (Pomponi and Moncaster, 2017)

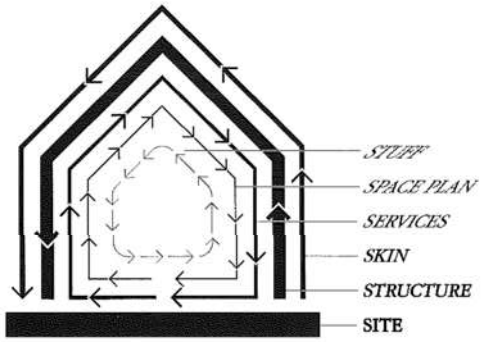
But: Limiting consumption, increasing performance, recycling and repeated usage are not enough to create a circular building.

Two important aspects are to be considered:-

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

2 Approach and Methodology
What defines a 'Circular' Construction?

- Buildings can be divided into shearing layers of change in relation to the hierarchy of components.
- Six different layers: interior, space plan, services, structure, skin and site.
- Each layer is considered to have a different life cycle.

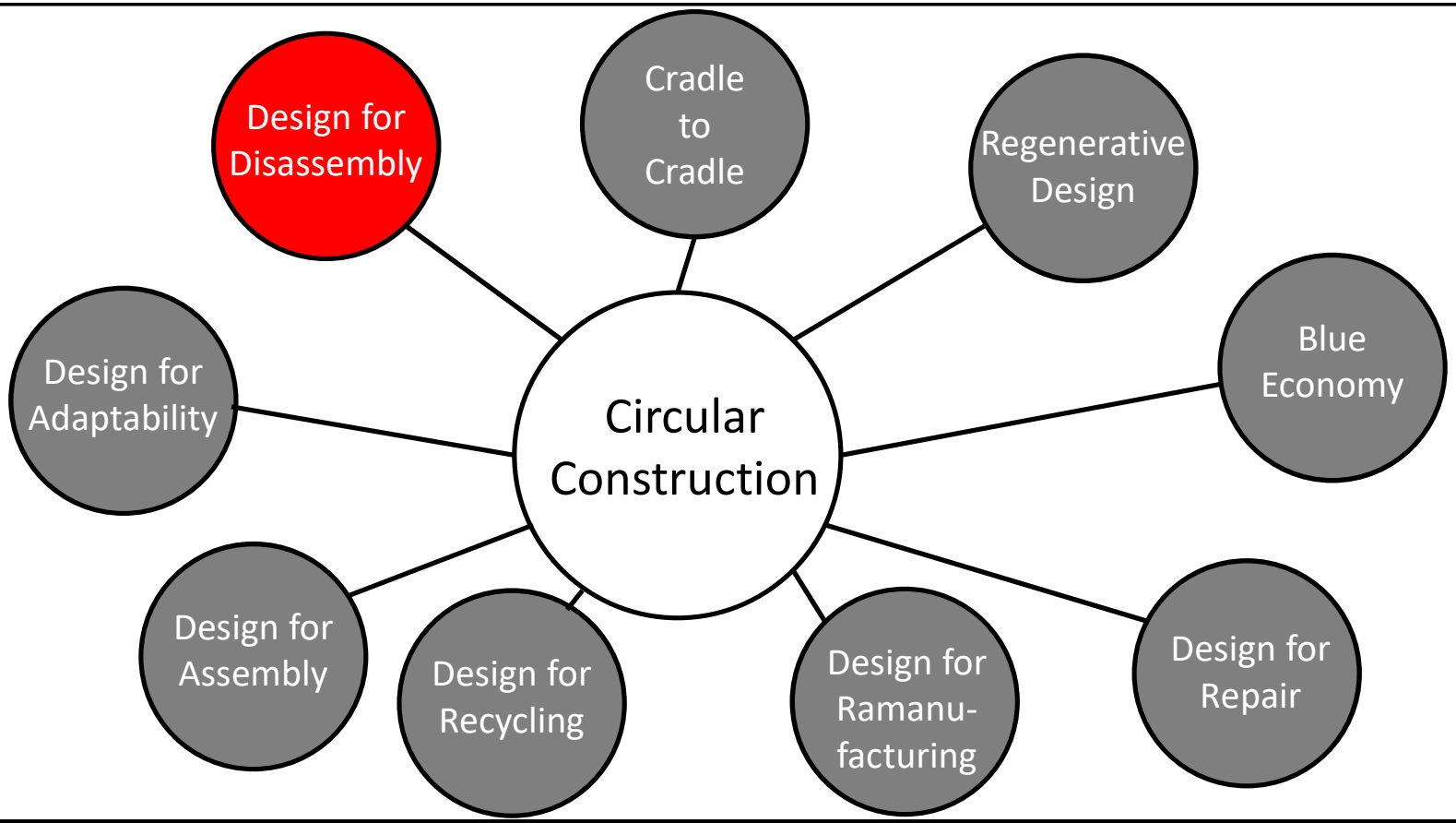


SHEARING LAYERS OF CHANGE. Because of the different rates of change of its components, a building is always tearing itself apart.

Layer	Life span (years)
Site	Eternal
Structure	30 - 300
Skin	20
Services	7 - 15
Space plan	3 - 30
Stuff	Daily

Source: Brand (1994)

2 Approach and Methodology
Framework of ‘Circular’ Construction



2 Approach and Methodology
Framework principles

Cradle To Cradle

- **Waste equals food.** All waste is nutrient in Biosphere or Technosphere.
- Using **renewable energy** of sun-, wind-, biomass- or hydropower.
- **Celebrate diversity.** Diversity from nature as example for industries and design. (McDonough & Braungart, 2010)

Regenerative Design

- Mankind and the built environment exist within an **ecosystem**.
- A **building** should produce a **positive effect** on its **nature**.
- **Understanding of project and nature** is key to a regenerative design. (Mang & Reed, 2012)

Blue Economy

- Industrial economy model aiming to **change society from shortage to plenty**.
- Using **local resources** by **tackling issues** that cause environmental and related problems in **innovative ways**.
- **Natural systems** cascade nutrients, matter and energy – **waste is non existent**. (Pauli, 2010)

Design for Recycling

- **Collection, separation, and processing** of products and materials **for recovery** to use in the form of raw materials in the manufacture of new products.
- Recycling of parts and materials **reduces the need for virgin material**, thus reducing extraction.(Henstock, 1988 and VDI, 1991)
- Reduces the used product to its **raw material value**. (Hundal, 2000)

2 Approach and Methodology
Framework principles

Design for Ramanu-facturing

- Remanufacturing is a process of bringing used products to **a "like-new" functional** state with **warranty**.
- Remanufacturing **reduces landfill and the levels of virgin material**, energy and specialised labour used in production.
- It is preferable to recycling because it **adds value to waste** products by returning them to working order. (Ijomah et al., 2007)

Design for Repair

- Enabling the **removal and substitution of parts** or components, beyond ordinary maintenance. (Giudice et al., 2006)
- Key feature for **lifetime extension** and to reach **highest material efficiency yields**. (Stahel, 2013).
- Applying to the **use-phase** of the product (Tecchio et al., 2016)

Design for Adaptability

- Based on the **hypothesis that product life ends** because a product is **unable to adapt** to change.
- Design principle to change products to **active, adaptive systems**.
- **Adaption by user and producer.** The user can extend the service life of the product while the manufacturer can adapt the design. (Hashemian, 2005)

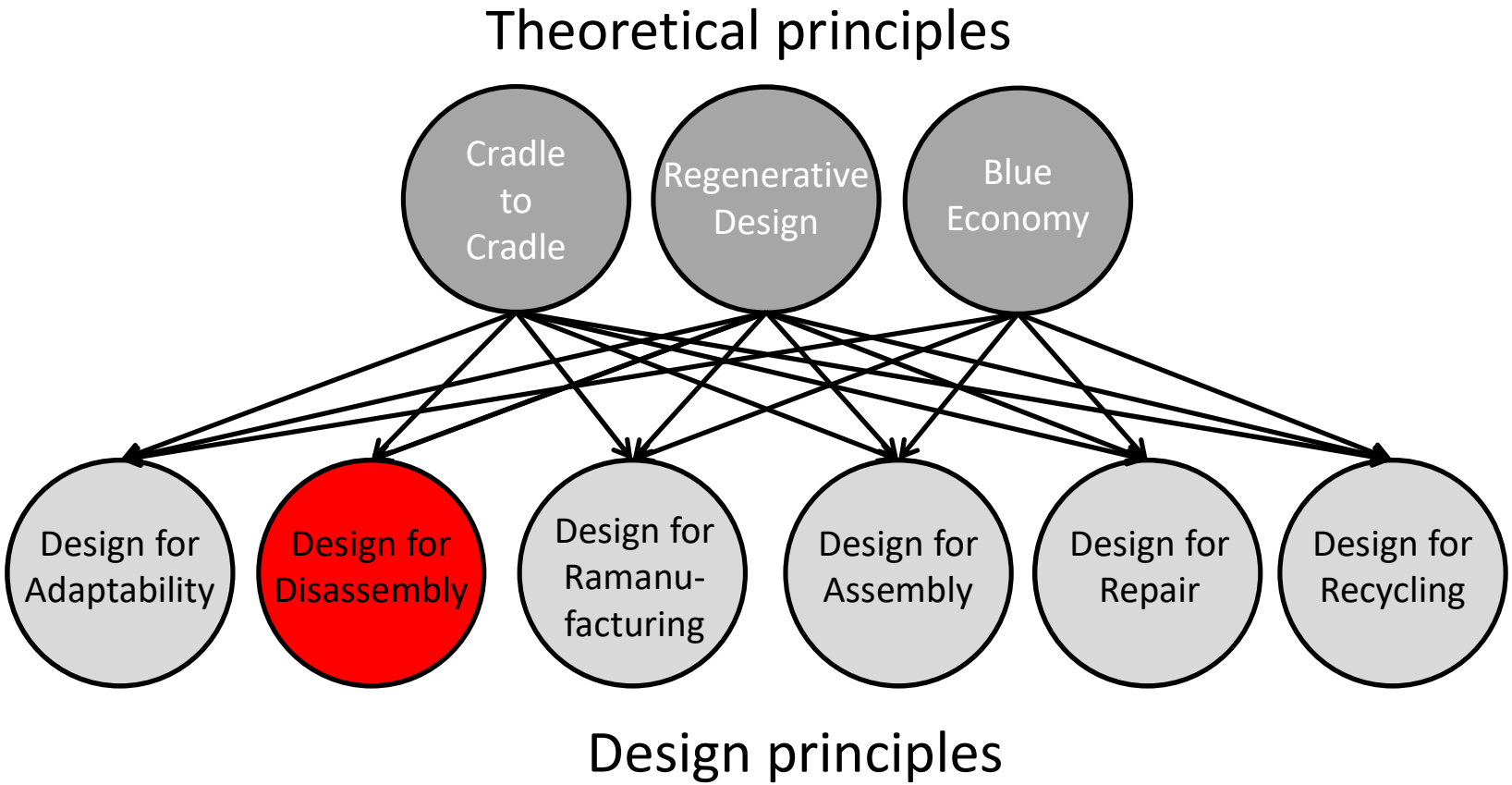
Design for Assembly

- Approach in which products are planned with **ease of assembly in mind**.
- Aiming to **increase assembly speed** and **reducing assembly costs** by reviewing number and shape of parts, connection methods.
- **Providing components features** which make it easier to grasp, move, orient and insert them. (Boothroyd & Alting, 1992)

Design for Disassembly

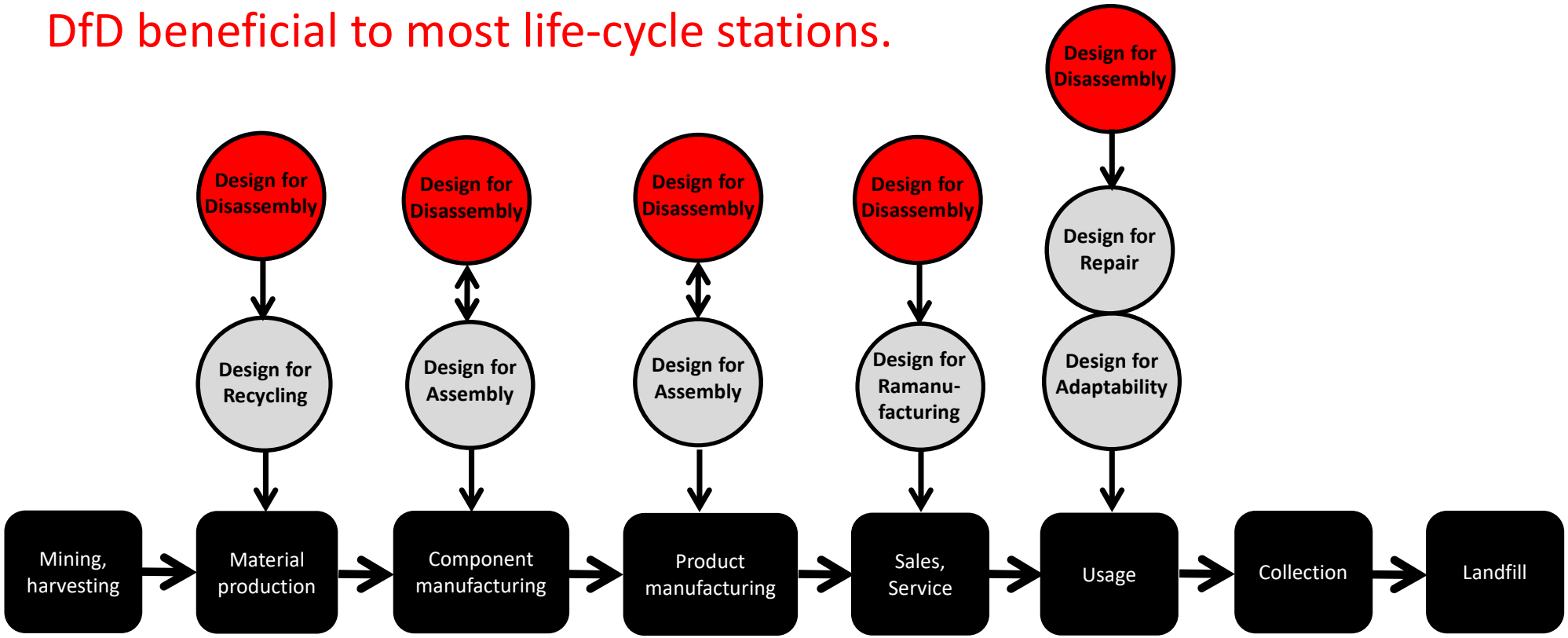
- Aiming to **ease dismantling** of products or structures.
- Allowing to **split products into its elemental components**, sub-parts, elements.
- **Facilitating maintenance, repair, re-use or recycling**. (McDonough & Braungart, 2010)

2 Approach and Methodology
Framework principles

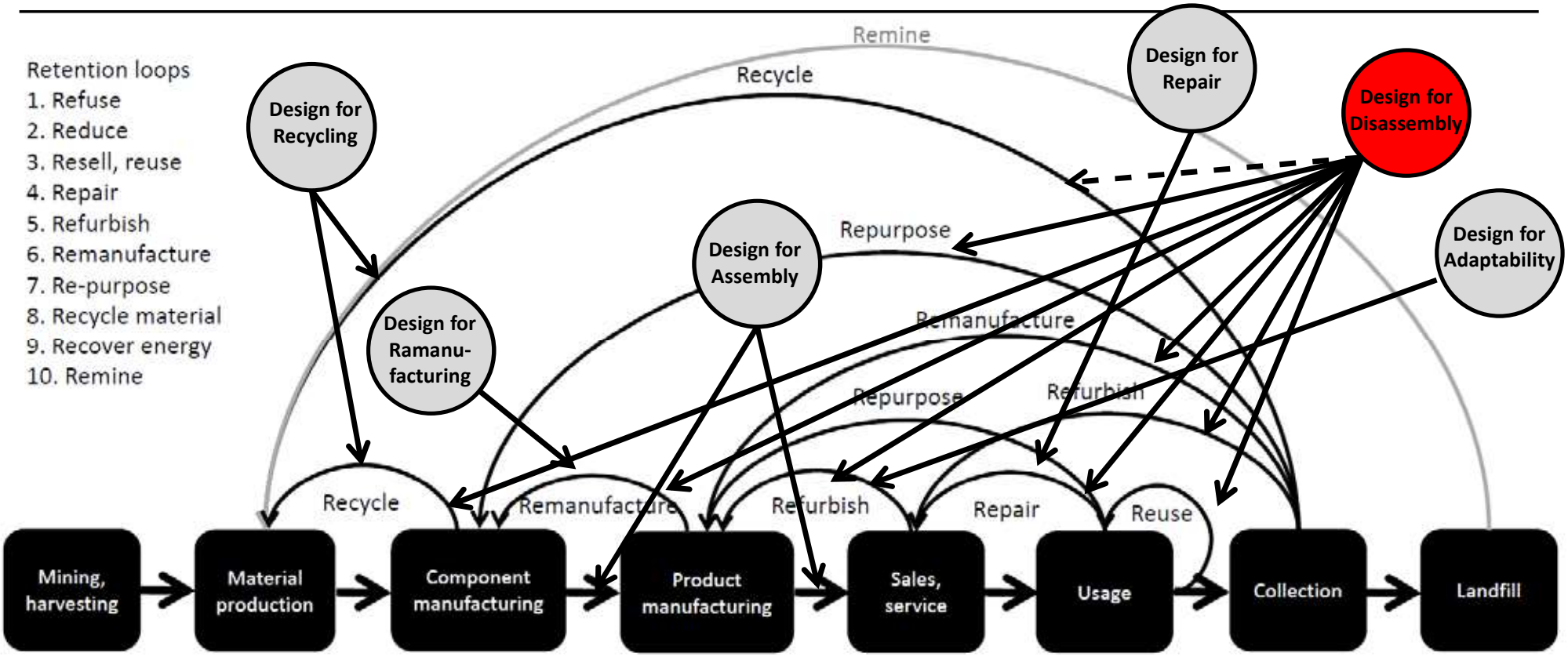


2 Approach and Methodology
Framework – Influence on product life

DfD beneficial to most life-cycle stations.



2 Approach and Methodology
Framework – Influence on loops



2 Approach and Methodology
Framework – Influence on loops

DfD applicable to slow and close loops.

Table 1. Design Strategies to Slow and Close Loops

Design Strategies to slow loops	**Design strategies to close loops**
Designing long-life products	Design for a technological cycle
Design for attachment and trust	Design for a biological cycle
Design for reliability and durability	Design for dis- and reassembly
Design for product-life extension	
Design for ease of maintenance and repair	
Design for upgradability and adaptability	
Design for standardization and compability	
Design for dis- and reassembly	

Reference: Bocken et al., 2016: 310

2 Approach and Methodology
Framework – Influence of DfD

Conclusion:

DfD supports the Circularity framework.

DfD supports many retention loops.

DfD applies to slow and close loops.

→ DfD is very beneficial to meet the aims of Circular Economy.

2 Approach and Methodology
Keys to Design for Disassembly

A study by Crowther (1999) on successfully disassembled buildings shows:

1. **Light materials**
2. Separation of structure and enclosure
3. Minimum technology solutions
4. Completeness of the building system
5. Open rather than closed systems
6. Standard module of construction
7. **Limited number of standard parts**
8. Use of industrialised mass production processes
9. Sequencing of disassembly
10. **Disassembly at all levels**, from part recycling to whole building reuse

2 Approach and Methodology
Keys to Design for Disassembly

Key principles according to Guy & Ciarimboli (2003).

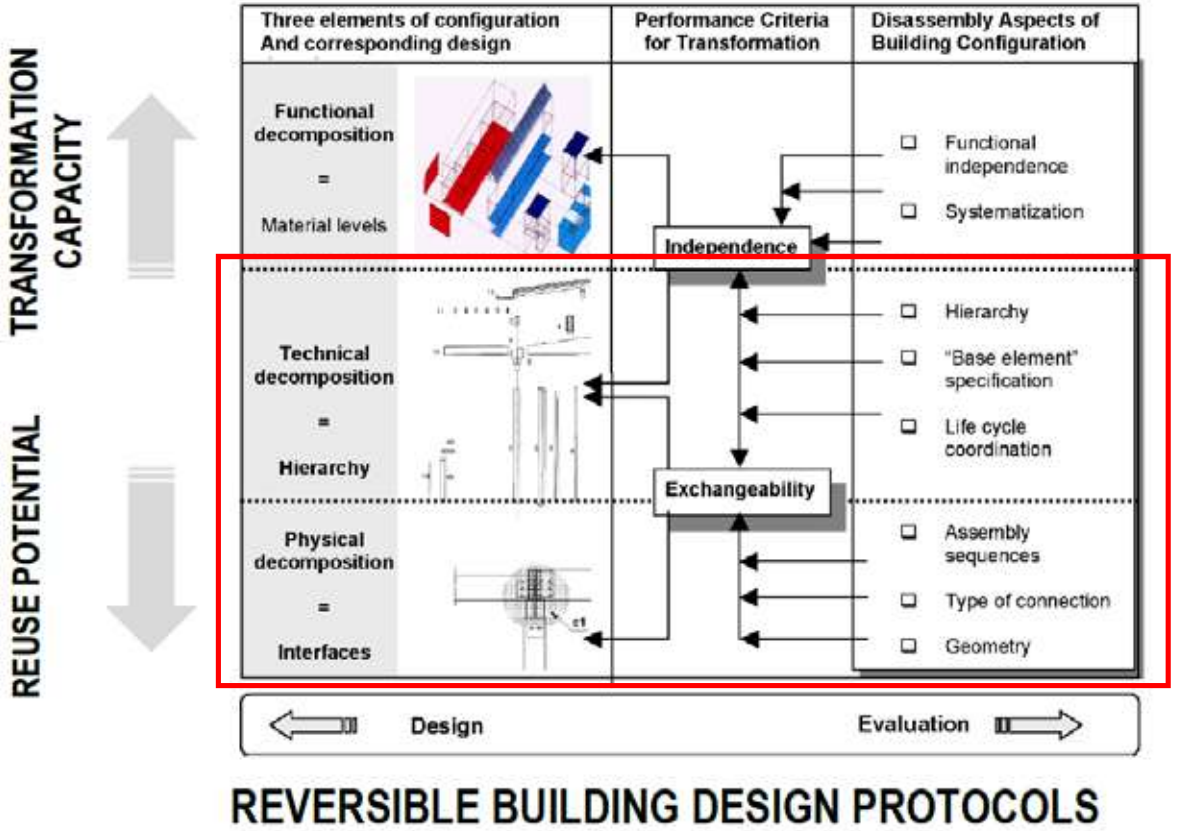
1. Document materials and methods for deconstruction.
2. Select **materials** with **low future impacts** and **high quality**.
3. Design connections that are accessible.
4. Minimize or **eliminate chemical connections**.
5. Use bolted, screwed and nailed connections.
6. Separate mechanical, electrical and plumbing (MEP) systems.
7. Design to the worker and labour of separation.
8. Simplify structure and form.
9. Allow interchangeability via modularity, independence, and standardization.
10. Enable **safe deconstruction**.

2 Approach and Methodology
Design principles Circularity and DfD

Material properties according Geldermans (2016)

1. High quality 2. Sustainably sourced 3. Non-toxic	**Elemental properties**
4. Potential for biological or technical cycle 5. Standardised dimension 6. Physical connections and open system 7. Material to match lifespan of layer	**Relational properties**

2 Approach and Methodology
Design principles Circularity and DfD



Source: Durmisevic (2010)

2 Approach and Methodology
Design principles Circularity and DfD

Connection properties according to Durmisevic (2010)

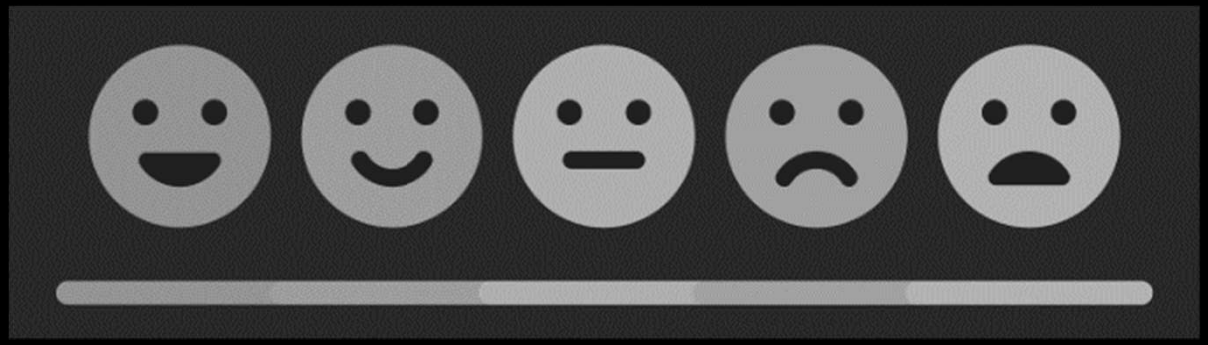
2. Technical decomposition

- **Open order of structure**, independent parts allow separate exchange
- **Base element role**, holding all other elements of one cluster, to be disassembled last
- **Life Cycle Coordination**, disassembly order to match life expectance of materials

3. Physical decomposition

- **Assembly order** to be parallel to speed up procedure
- **Connection types** either direct or indirect via a supplementary part
- **Geometry open / linear** to prevent constricted hinderance

3 Approach and Methodology
Establishing a rating method



3 Approach and Methodology
Establishing a rating method

- In order to **rate present** systems and an **amended version** a rating system is to be applied.

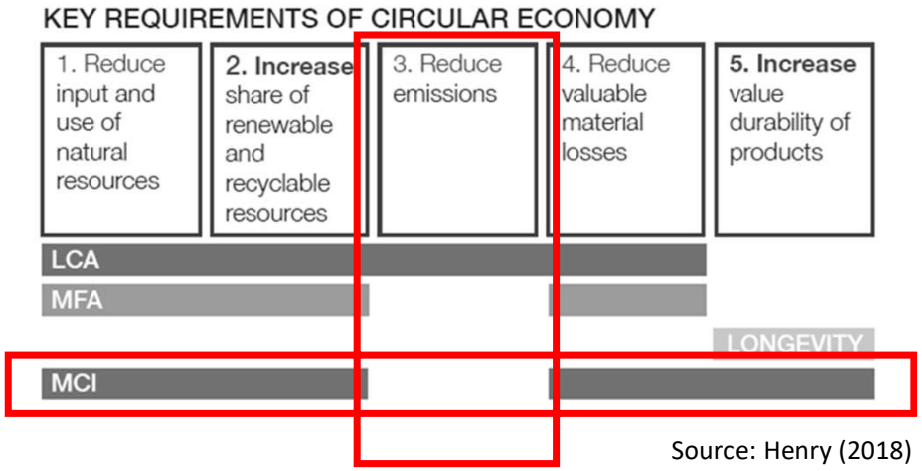
- The rating system shall indicate a systems' **compliance with principles** of Circular Construction and Design for Disassembly (DfD).

- **No generally accepted rating** system for circularity exists yet.

- The aim is to **review various existing rating** systems for their suitability and chose the most promising.

3 Approach and Methodology
Establishing a rating method

Henry (2018) checked rating methods for circularity based on criteria for circularity set out by Elia, Maria & Tornese (2017).



Source: Henry (2018)

She found shortcomings in MCI regarding emission.

3 Approach and Methodology
Establishing a rating method for CIRCULARITY

Material Circularity Indicator (MCI)

- **Determines position** of a material between total linear or circular performance. Between 0 and 1.
- **Enables comparison** between material choices for circularity.
- **Non-renewable materials** of the technical cycle only.
- Does not recognize recycled or re-used materials during usage.
- Does not take emission reduction into account.

3 Approach and Methodology
Establishing a rating method for CIRCULARITY

CO_2 Emissions Calculation

- Carbon dioxide is one of the **greenhouse gases**.
- A better circular performance does not automatically mean a lower CO_2 emission.
- **Solid and straightforward** method.
- **Complementary** impact **indicator**.

(Ellen MacArthur Foundation, & GRANTA DESIGN, 2015).

3 Approach and Methodology
Establishing a rating method for DfD

- **U-effort**. Based on properties of connectors.
- **Philips ECC**. Based on databases of disassembly time.
- **Desai & Mital**. Based on Method Time Measurement (MTM).
- **Kroll**. Based on fastener types and difficulty scores.
- **eDiM**. Based on assembly times.
- All methods **based on** Electrical and **Electronic Equipment** (EEE) and aiming at disassembly time.

➡ **Suitability of methods for façade disassembly is limited.**

Vanegas et al. (2016)

3 Approach and Methodology
Establishing a rating method for DfD

Disassembly Potential by Elma Durmisevic

- **Criteria** regarding the **disassembly performance** of a component.
- Indicators for **material level, hierarchy composition and physical interfaces**.
- **Outcome demonstrates flexibility** of component/building element ranging from static, over semi-open to dynamic (most flexible).
- Results can be visualized with a radar chart.

3 Approach and Methodology
Establishing a rating method

Three rating methods chosen:

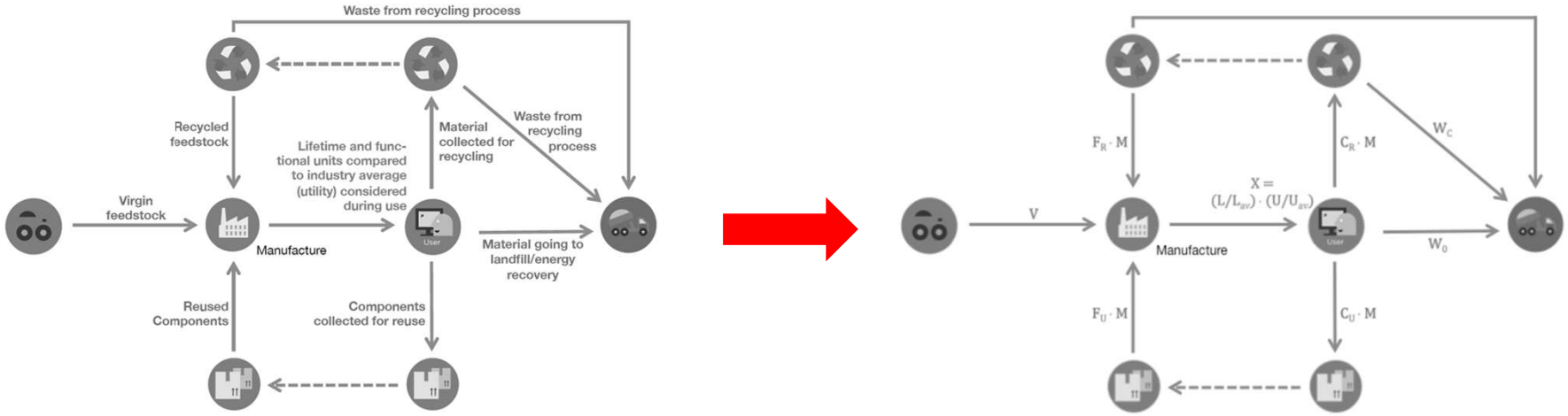
MCI Material Circularity Indicator to cover most aspects of Circularity

CO_2 CO_2 Emissions Calculation to close shortcomings of MCI

DP Disassembly Potential

3 Approach and Methodology
Establishing a rating method

MCI From scheme to mathematical model



Source: Allan McArthur Foundation and Granta (2015)

3 Approach and Methodology
Establishing a rating method

MCI Input required for Virgin Feedstock and Unrecoverable waste

1. In order to calculate the **Virgin Feedstock** :-

-**Fraction of mass** of feedstock from **recycled resources**.

-**Fraction of mass** of feedstock from **reused resources**.

2. In order to calculate the **Unrecoverable Waste** :-

- **Fraction of mass** of subassembly/material being collected **to go into a recycling** process at the end.
- **Fraction of mass** of subassembly/material being collected **for component reuse**.
- **Efficiency of the recycling process** used for the portion collected for recycling.
- **Fraction of mass** of subassembly/material being collected to **go into a recycling process**.

3 Approach and Methodology
Establishing a rating method

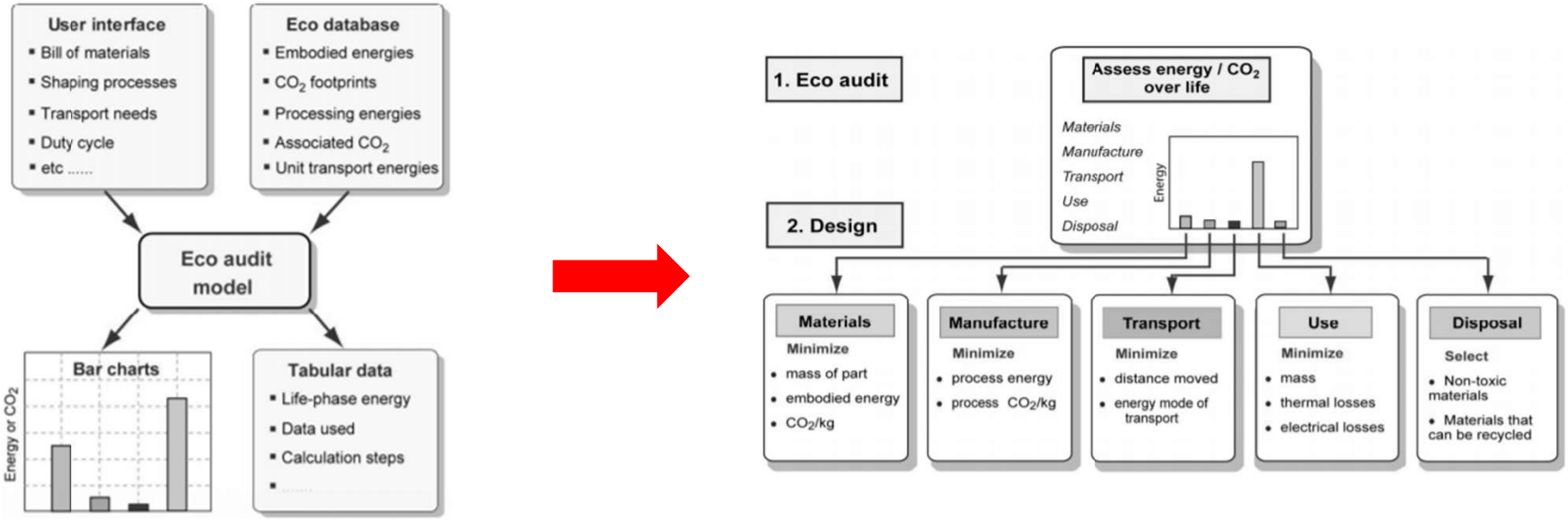
MCI Service life and waste scenarios of standard materials

Material	Aluminium	Glass	Mineral Wool	Terracotta	Natural stone	Mild steel	Stainless steel	EPDM	Silicone	GRC
Service life years	75	30	75	75	75	75	75	40	?	?
Waste scenario										
Landfill %	10	27	85	1	84					
Incineration %	28	1	5	8	14					
Recycling %	63	72	10	91	2					

Service years source: SBR 2011
Waste scenario source: Nibes 2012

3 Approach and Methodology
Establishing a rating method

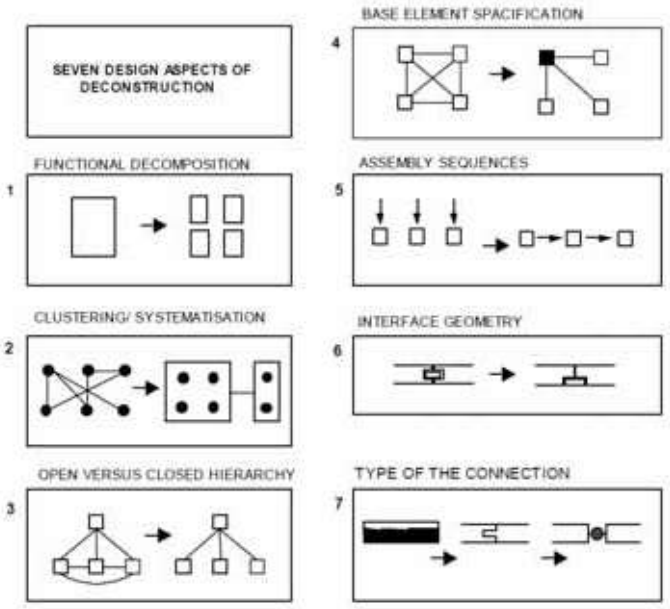
CO_2 Steps and results of CO_2 emission calculation using CES

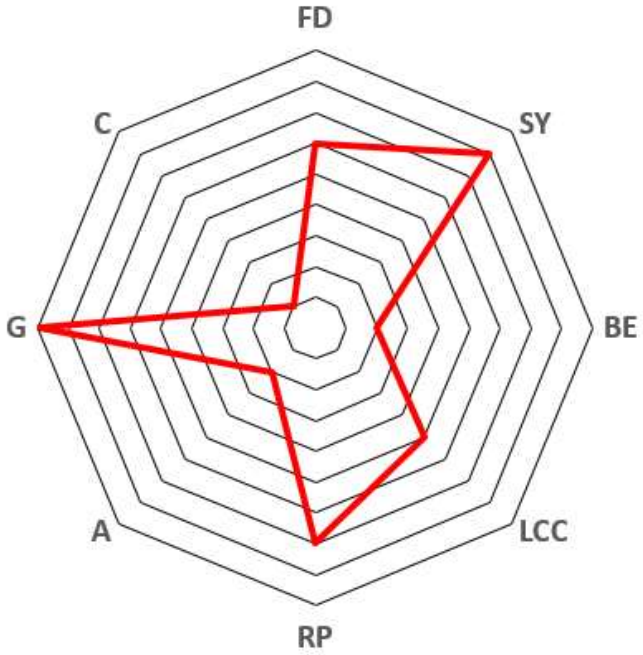


Source: Granta Design (2018)

3 Approach and Methodology
Establishing a rating method

DP Steps to determine Disassembly Potential

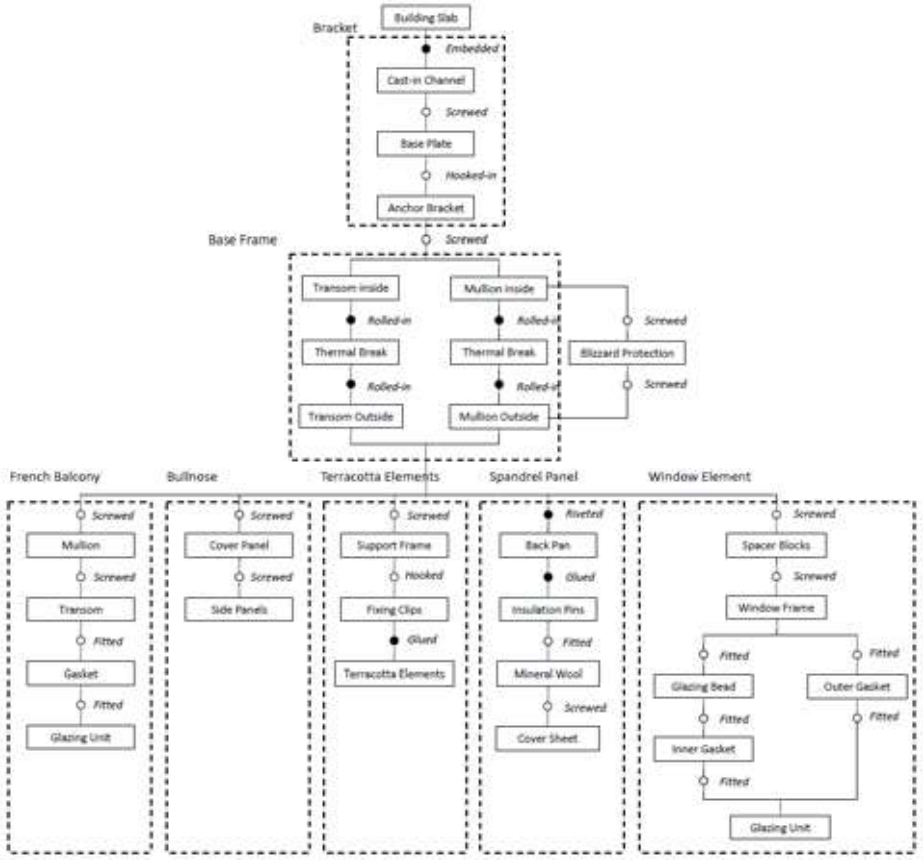




Source: E. Durmisevic (2010)

3 Approach and Methodology
Establishing a rating method

DP Hierachy diagram



4 Approach and Methodology
Company review

4 Approach and Methodology
Company review

SCHELDEBOUW

- 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

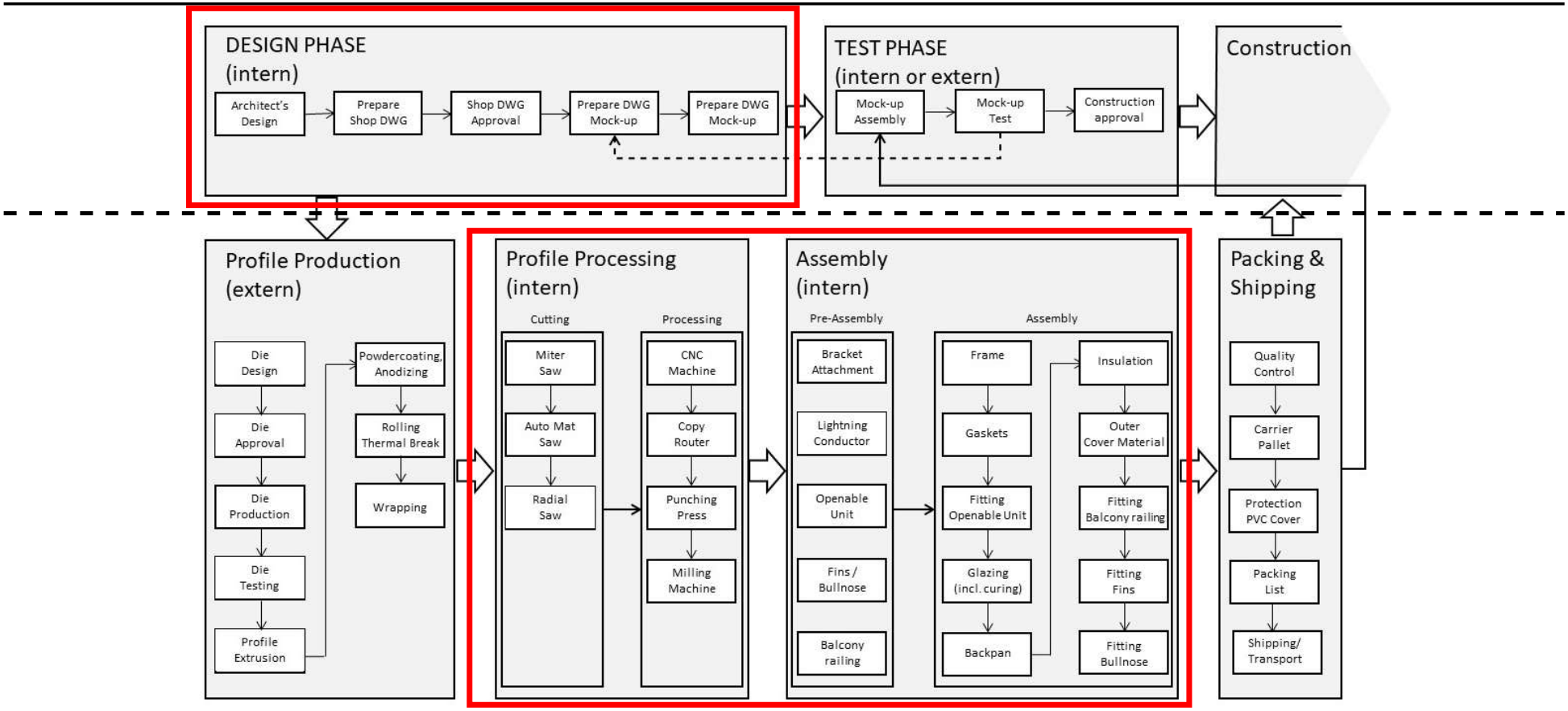
4 Approach and Methodology
Company review – SWOT analysis

SCHELDEBOUW

Strengths	Weaknesses
Market leader Innovative Products Tailor-made solutions Quality product Great references Worldwide network Complete A – Z service	High prices Limited offer spectrum Dependence on big projects High up-front costs Labour intensive product
Opportunities	**Threats**
Continuous urban growth Stricter environmental regulations Geometries getting more complex	Cheaper Competition Political uncertainty of market area Rising material and labour costs

4 Approach and Methodology
Company review –Assembly

SCHELDEBOUW



4 Approach and Methodology
Company review - assembly practice

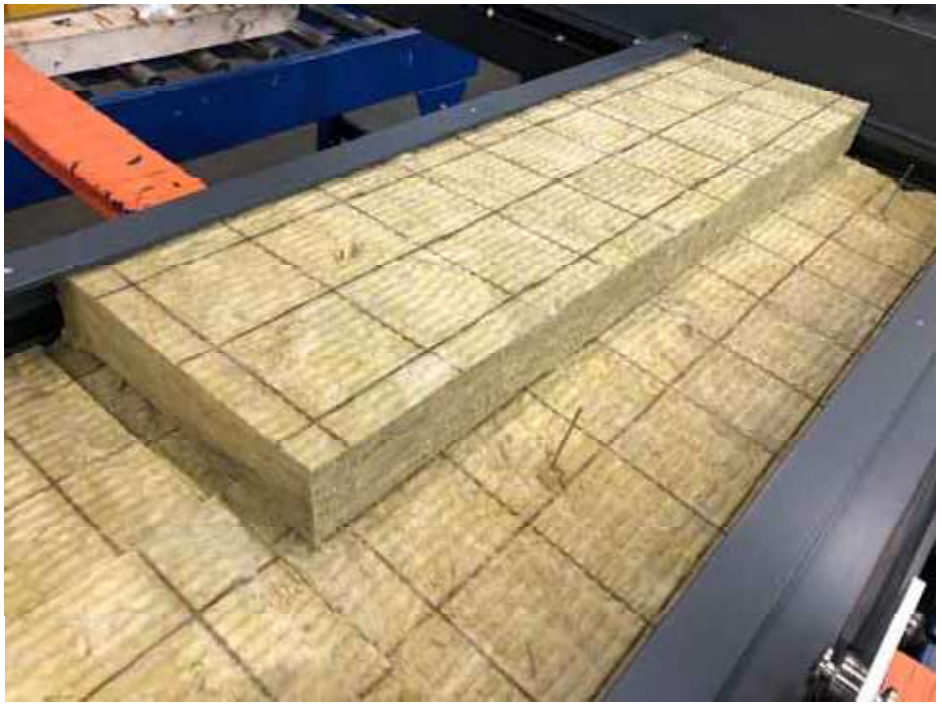
Pre-assembly

Pre-assembly

4 Approach and Methodology
Company review - assembly practice

Table 2

Table 3



4 Approach and Methodology
Company review - assembly practice

Table 6

Table 7

4 Approach and Methodology
Company review - assembly practice

Conclusions

- Traditional **assembly line** work.
- The assembly sequence is clearly defined.
- The **waste** production during assembly **is limited**.
- Generous applications of **adhesives**.
- The number of various **screw types** is high.
- The number of screw head types is limited to two.
- Heavy items are lifted in **via crane**.
- Focus on **quality, performance and speed**.

4 Approach and Methodology
Company review – System review

SCHELDEBOUW

Principles of Scheldebouw's unitized systems

Bishopsgate, London

Lime Street, London

One Crown Place, London

4 Approach and Methodology
Company review – typical system

SCHELDEBOUW

Bishopsgate, London	Material	Volume (m3)	Density (kg/m3)	Mass (kg)	Mass per Area (kg/m2)
Unit dimension (m)	Aluminium		2702		
3,8 x 1,5	Glazing		2500		
Area per unit (m2)	Stainless Steel		8000		
5,7	Mineral Wool		70		
	EPDM		1500		
	PVC		1400		

Lime Street, London	Material	Volume (m3)	Density (kg/m3)	Mass (kg)	Mass per Area (kg/m2)
Unit dimension (m)	Aluminium		2702		
3,925 x 1,5	Glazing		2500		
Area per unit (m2)	Stainless Steel		8000		
5,888	Mineral Wool		70		
	EPDM		1500		
	PVC		1400		

One Crown Place, London	Material	Volume (m3)	Density (kg/m3)	Mass (kg)	Mass per Area (kg/m2)
Unit dimension (m)	Aluminium		2702		
3,6 x 1,7	Glazing		2500		
Area per unit (m2)	Stainless Steel		8000		
6,12	Mineral Wool		70		
	EPDM		1500		
	PVC		1400		
	Terracotta		2060		

?

Average Project	Material	Volume (m3)	Density (kg/m3)	Mass (kg)	Mass per Area (kg/m2)
Unit dimension (m)	Aluminium		2702		
	Glazing		2500		
Area per unit (m2)	Stainless Steel		8000		
	Mineral Wool		70		
	EPDM		1500		
	PVC		1400		
	Terracotta		2060		

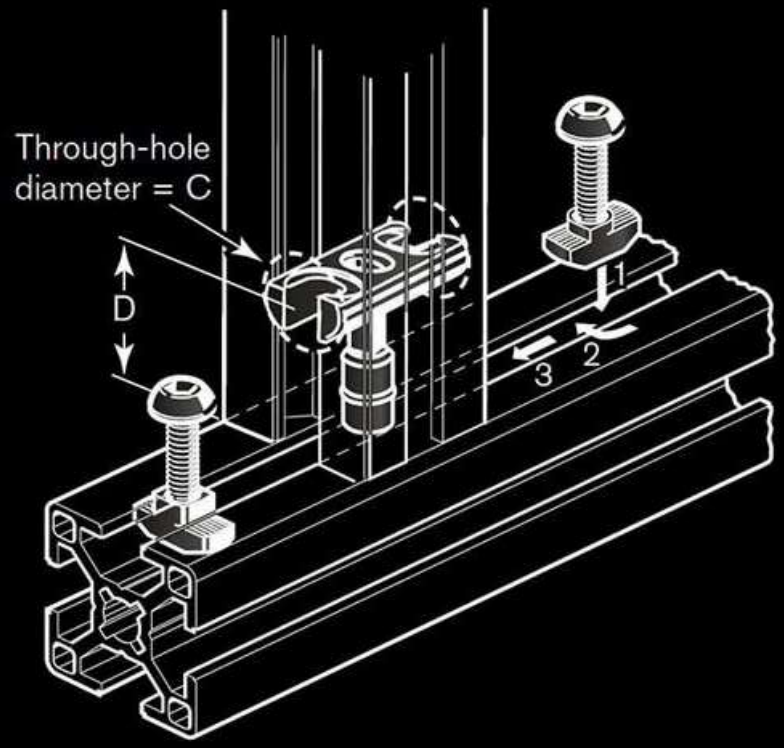
4 Approach and Methodology
Company review

SCHELDEBOUW

- What is the current salvage practice of Scheldebouw's facades?

- % materal being reused
- % material being recycled
- % material being landfilled

5 Approach and Methodology
Analysis Current Facades



5 Approach and Methodology
Analysis Current Facades

- How do the unitized facades of Scheldebouw rate for Circularity?
- How do the unitized facades of Scheldebouw rate for DfD?

- How are the unitized facades currently disassembled and what are the main challenges to overcome?

- What conclusion can be drawn for a new improved system?

5 Approach and Methodology
Analysis Current Facades - disassembly

Used element

Used element

5 Approach and Methodology
Analysis Current Facades - disassembly

Step 1 – Removal of GRC elements

Step 2 – Removal of substructure

5 Approach and Methodology
Analysis Current Facades - disassembly

Step 5 – Removal Aluminium plate

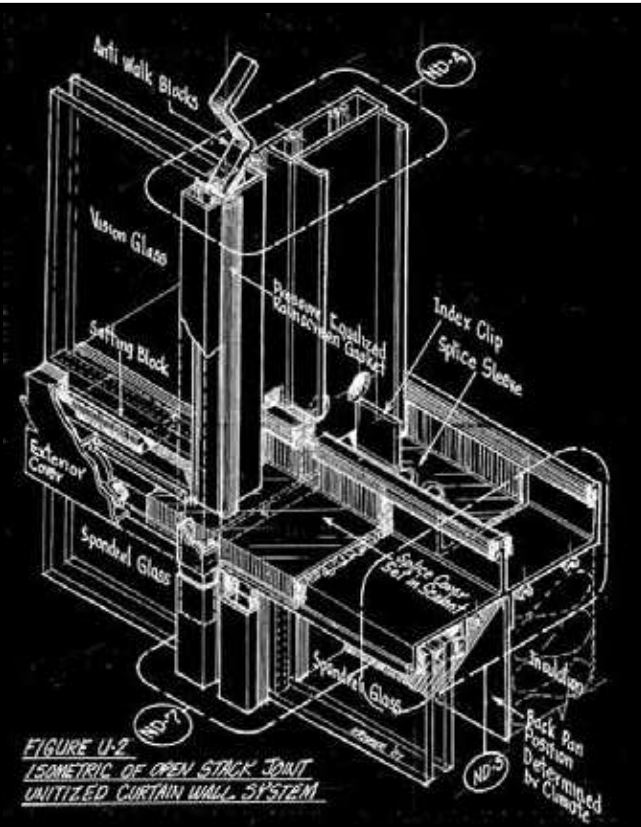
Step 6 – Removal Insulation

5 Approach and Methodology
Analysis Current Facades - disassembly

Conclusions

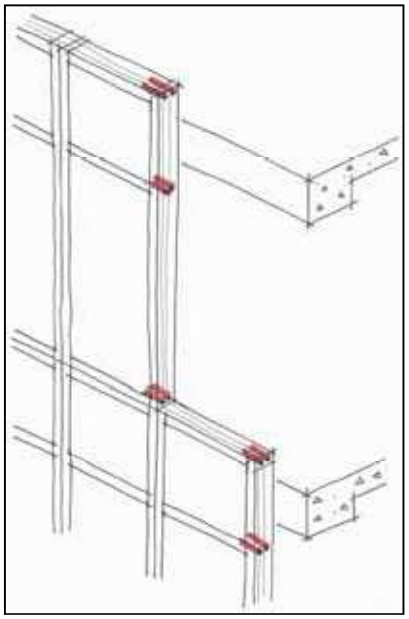
- The disassembly took **six hours**.
- The disassembly sequence had to be figured out.
- **Hand tools** were sufficient.
- Heavy items slowed down the process.
- The size of the element lead to long ways.
- The **glued connections** were **most challenging**.
- **Rivets** proved time consuming.
- Storage can influence disassembly speed.

6 Design Phase

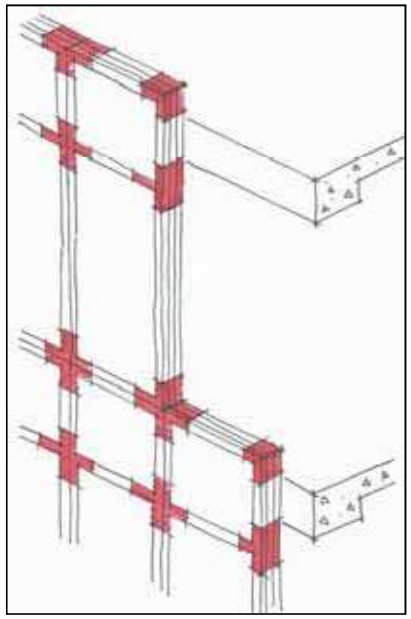


6 Design Phase
Proposed Design

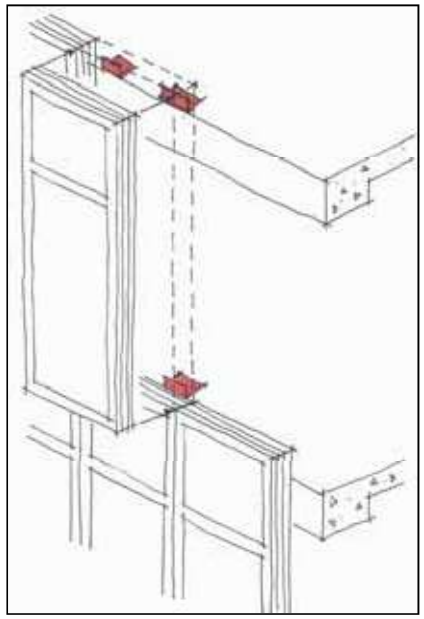
Designing a new systems streamlined for disassembly and circularity considering the results and experiences from the previous analysis.



1. Design for **total disassembly**



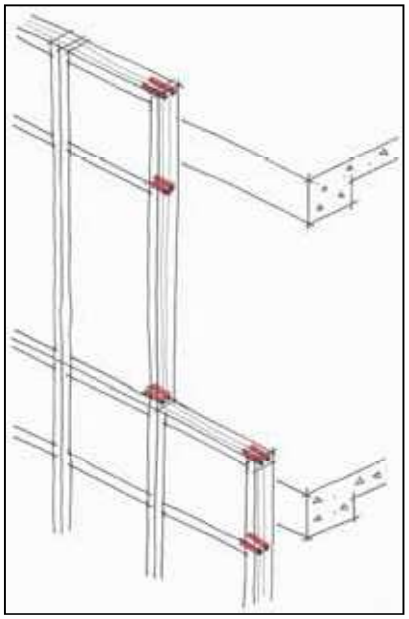
2. Design for **component reuse**



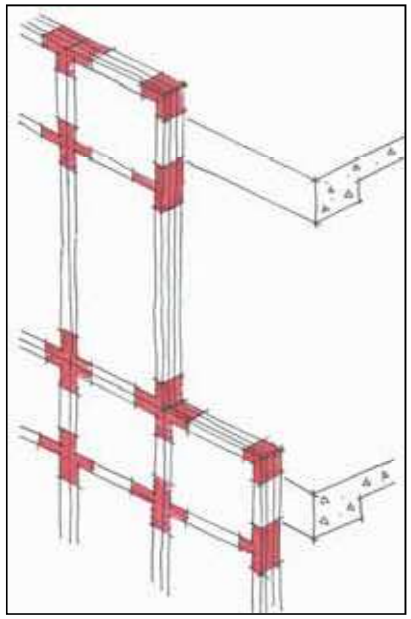
3. Design for **total reuse**

6 Design Phase
Proposed Design

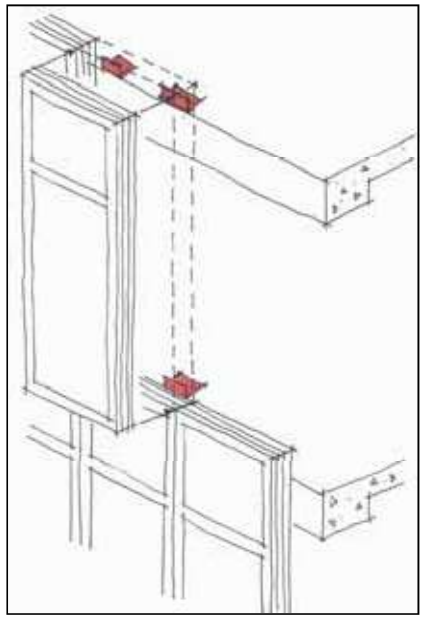
Designing a new systems streamlined for disassembly and circularity considering the results and experiences from the previous analysis.



1. Design for **highest MCI**



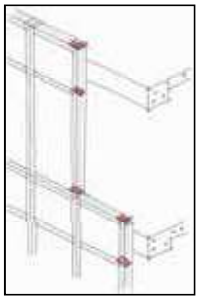
2. Design for **lowest CO_2**



3. Design for **highest DP**

7 Design Phase
Rating Facade

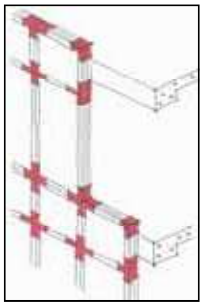
- Assessing the system with the previous established rating system.
- Comparing with the benchmark system.



MCI .....

CO_2 .....

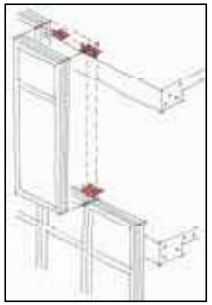
DP .....



MCI .....

CO_2 .....

DP .....



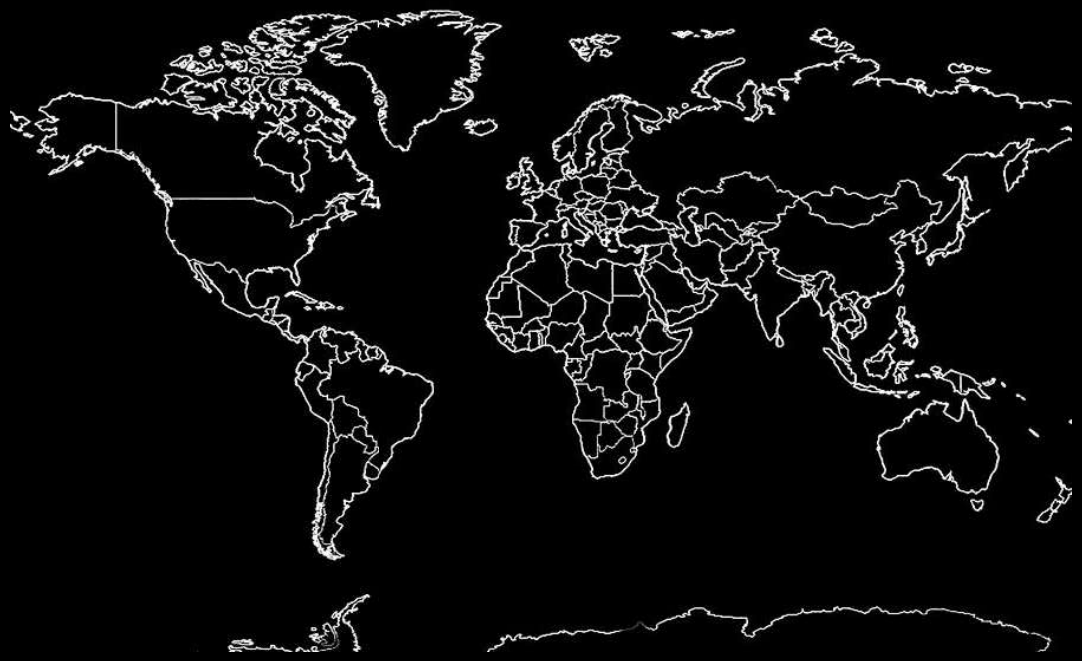
MCI .....

CO_2 .....

DP .....

8

Results
The Greater Picture and Results



8 Results
The greater picture

- Current status of **DfD in construction industry**
  - general status
  - other building elements i.e. HVAC
- Current status of **DfD in other industries**
  - car industry
  - household appliances
- Outlook
- Summary

9 Results
Answering Research and Design Question

- Answering the Research Question
- Answering the Design Question
- Further Research
- Reflection

Thank you!