Circular Façade Systems and Construction: Design for Remanufacturing Window Systems

P5 | MSc 4
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Problem Statement

TAKE

Resource Extraction
Problem Statement

TAKE
Resource Extraction

MAKE
Manufacturing · Distribution · Use
Problem Statement

Take: Resource Extraction
Make: Manufacturing · Distribution · Use
Dispose: Waste
Problem Statement

40% of the materials that enter the global economy

40-50% of the global output of GHG emissions & acid rain agents

TAKE
Resource Extraction

MAKE
Manufacturing · Distribution · Use

DISPOSE
Waste

Research Framework
Literature Review
Company Analysis
Case Study Analysis
Design
Conclusions
Problem Statement
Problem Statement

Circular Economy

- Manufacture
- Use
- Reuse
- Recycle
- Remanufacture
- Resource Extraction

Concept diagram of a CE. Image by author.
Nederland circulair in 2050
Rijksbreed programma Circulaire Economie
Circulaire Economie in de bouw

>95% Recycling
>85% GWW

△ <3% terug naar B&U
interne recycling in GWW
A demand for a design strategy for façade systems taking into account **circularity** can contribute to **product life extension scenarios**, and is an alternative to demolition.
Kawneer Nederland B.V.

AR 90 & AR 100 Programmes - Recycling Aluminium
Main Research Question

How can Kawneer’s façade window systems be improved in terms of circularity, as a long-term sustainable strategy?
Focus and Restrictions

RT 82 HI + Window System
High Insulating Passive House window

RT 82 HI + System exploded. Image by kawneer.com
Methodology

Practice #1 Research
- Company interviews
  - Technique
  - Face to face
    - Structured
    - Multiple
    - Recorded
    - Transcribed & synthesised

Practice #2 New Design
- Feedback
  - Redesign Concept
  - Closing the loop
    - Further research

Literature Review
- Analysis
  - Inductive Method (redesign discussion)
  - Physical Analysis of Existing Window System

Research Methodology
- Circular Economy
- Circular Built Environment
- Remanufacturing
- Window Systems
- Case Study: RT 82 HI +
Literature Review
1. Design out of waste
2. Build resilience through diversity
3. Shift to renewable energy sources
4. Think in systems
5. Think in cascades
Circular Built Environment

- Technology
- Regions
- Cities
- Buildings
- Products
- Materials

- Economy
- Management
- Design
- Flows & Resources
- Society & Stakeholders
Circular Built Environment

“Time is the essence of the real design problem”
Circular Built Environment

Buildings are not static entities
Circular Built Environment

Shearing Layers of Change (Brand, 1994)
Circular Built Environment

Slowing Resource Loops
Based on (Bocken et al., 2015)
Circular Built Environment

Design strategies for slowing resource loops
Based on (Bocken et al., 2015)

How to design long-lasting products?

- Designing long-life products
- Reliability
- Durability
- Design for product life extension
- Maintenance
- Repair
- Upgrade
- Remanufacture
Circular Built Environment
Design strategies for slowing resource loops
Based on (Bocken et al., 2015)

How to design long-lasting products?

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What is Remanufacturing?

Based on (Boorsma, 2016)
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- Returning a used product to at least OEM original performance specification from the customers’ perspective
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- Returning a used product to at least OEM original performance specification from the customers’ perspective.

- Through a series of manufacturing steps acting on an end-of-life part or product.
What is Remanufacturing?

Based on (Boorsma, 2016)

- Returning a used product to at least OEM original performance specification from the customers’ perspective.

- Through a series of manufacturing steps acting on an end-of-life part or product.

- This gives the resultant product a warranty that is at least equal or better to that of a newly manufactured equivalent.
What is Remanufacturing?

Based on (Boorsma, 2016)

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- Through a series of manufacturing steps acting on an end-of-life part or product.

- This gives the resultant product a warranty that is at least equal or better to that of a newly manufactured equivalent.

- After this, the product receives a serial number.
What is Remanufacturing?

What is the difference?

Interview to Dr. Nabil Nsar by Dr. David Peck

Rebuilding, and refurbishment, are basically bringing the product back to a working condition and ensuring that it will function. **But it is not like a new condition, like what we do with remanufacturing.**

Remanufacturing requires to bring the product back to like new condition. **Basically, you have a rebirth of the product.**
How are products Remanufactured?

**Process**

Based on (ERN, 2016), (Steinhilper, 1999)

1. Entrance Diagnosis
2. Disassembly
3. Thorough cleaning of parts
4. Sorting of parts
5. Reconditioning/replenishment of parts
6. Reassembly
7. Final testing

**QUALITY ASSURANCE**

Remanufacturing process. Image by author. Icons source: flaticon.com
Design for Remanufacturing (DfRem)

Based on (Nasr and Thurston, 2006), (Charter and Gray, 2008), (Hatcher et al, 2011)

Steps Involved

Detail Engineering

Product Strategy
Design for Remanufacturing (DfRem)

Based on (Nasr and Thurston, 2006), (Charter and Gray, 2008), (Hatcher et al, 2011)

ENTIRE REMANUFACTURING PROCESS

Steps Involved

Detail Engineering

Product Strategy

Research Framework  Literature Review  Company Analysis  Case Study Analysis  Design  Conclusions
How to Design for Remanufacturing?

DfRem

Based on (Sundin, 2004), (Hatcher, 2011), (Ijomah et al., 2014), (Vogtländer et al., 2017)

RemPro Matrix

<table>
<thead>
<tr>
<th>Remanufacturing Step</th>
<th>Inspection</th>
<th>Cleaning</th>
<th>Disassembly</th>
<th>Storage</th>
<th>Reprocess</th>
<th>Reassembly</th>
<th>Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Property</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Identification</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Verification</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Access</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Handling</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Separation</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Securing</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Alignment</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Stacking</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wear Resistance</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.4 RemPro-matrix based on Sundin (2004). Image by author.

Product Properties

- **Durable materials**
- Identify components that require similar assembly/disassembly tools and techniques
- Disassemble should not damage the components
- Standardization, Modularity, and interchangeability
- The product is designed to recover its functionality.
- Selection of materials that can survive cleaning processes (i.e. the material melting point of the selected material is higher than clean process temperature)

...etc
Why should we Remanufacture products?

Benefits

Based on CRR (Centre for remanufacturing & Reuse, 2018)

Remanufacturer

- Local & skilled jobs
- Higher profit margins
- New manufacturing techniques
- Better customer relationships

Environment

- Reduction in:
  - Raw material consumption
  - Energy consumption
  - CO₂ emissions
  - Materials sent to landfill

Customer

- Lower prices
- Availability
- Purchasing flexibility
- Longer lasting products
Analysing Kawneer Nederland B.V.
Kawneer Nederland B.V.

Modular Façade Systems

Windows and doors

Sliding windows and doors

Curtain Walls

Custom Made

Accessories
Figure 5.1 Scheme of the relationship of stakeholders. Image by Klein (2013).
# Business Model Canvas

## Key partners
1. Suppliers (hardware, insulation, etc.)
2. Alcoa (parent company)
3. Façade builders
4. TU Delft BK, etc.

## Key activities
1. Product Design
2. Product integrator
3. Purchasing hardware and other key accessories
4. Assembling elements into products
5. Products are tested
6. Products are packed and sent to the client

## Value propositions
(a) Product: reliable aluminium systems with high thermal insulation and performance.
(b, c) Service: Technical support, advice during project development, and technical guidance.

## Customer relationships
- Long term relationships built through dedicated personal assistance.

## Customer segments
(a) Façade Manufacturers
(b) Architectural Firms
(c) Consultants

## Key resources
1. Technical and product design knowledge
2. Distribution network
3. Storage facility
4. Testing facility
5. Softwares, website

## Cost structure
- Fixed costs (overhead)
- Variable costs (procurement)

## Revenue streams
- Trade fairs
- Office Sales
- e-commerce
- Advertisement

## Channels
- How do customers usually purchase your products or services?
- How do Christopher usually purchase the value that you provide to them?
- What are the different revenue models?
## Business Model Canvas

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### Key partners
What are your most important partners?
- Which key resources do you acquire from partners?
- Which key activities do your partners perform?

### Customer segments
- What are the customer segments that either pay, receive or decide on your value proposition?
- What are the customer segments that either persuade or influence your customers?
- How do customers initially find or need your products or services?

### Key resources
What are the resources you need to create & deliver your value proposition?
- Technical and product design knowledge
- Distribution network
- Storage facility
- Testing facility
- Softwares, website

### Channels
- Trade fairs
- Office Sales
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### Cost structure
- Fixed costs (overhead)
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### Revenue streams
- How do customers initially find or need your products or services?
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Product’s Lifecycle
Product’s Lifecycle

SOURCING

ALCOA
Extraction of virgin feedstock
Aluminium 6060
Origin:
- America
- Colombia
- Brazil
- Suriname
+ Recycled Aluminium

- Rubber
- Glass
Product’s Lifecycle

**SOURCING**

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- Extraction of virgin feedstock
  - Aluminium 6060
    - Origin:
      - America
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- Glass

**PRODUCTION**

**Material Manufacturer**
- Processed Materials
  - Extruded profiles from aluminium billets

**Kawneer**
- Manufacturing of Components
  - Aluminium profiles with thermal breaks
  - Hardware pieces
  - Accessories

**Facade Builders**
- Manufacturing of Products
  - Assembly of components into complete façade systems
Product's Lifecycle

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- **User/Owner**
  - Final Products
  - Maintenance
Product’s Lifecycle

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    - Assembly of components into complete façade systems

**USE**
- User/Owner
  - Final Products
    - Maintenance
- Weapon Company
  - Waste Manager
  - Recycled Material
    - Collection & separation

**END-OF-LIFE**
- Demolition
- Recycled Material
Product's Lifecycle

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  - Aluminium profiles with thermal breaks
  - Hardware pieces
  - Accessories
- Facade Builders
  - Manufacturing of Products
    - Assembly of components into complete façade systems

**Use**
- User/Owner
  - Final Products
    - Maintenance

**End-of-Life**
- Demolition Company
  - Waste Manager
  - Recycled Material
    - Collection & separation

- HKS Recycling Company
  - 6060 Aluminium
  - Collection of the components with potential for recycling
Case Study Analysis

RT 82 HI +
Product's Benchmark

RT 82 HI + Aluminium Triple Glazed Window Frame
Kawneer

CS 104 HI Aluminium Triple Glazed Window Frame
Reynaers

AWS 90 SI + Aluminium Triple Glazed Window Frame
Schüco
## Window Systems: State of the Art

### Selected Systems & Materials

<table>
<thead>
<tr>
<th><strong>Aluminium</strong></th>
<th><strong>U-PVC</strong></th>
<th><strong>GRP</strong></th>
<th><strong>Hybrids</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>RT 82 Hi + Aluminium Triple Glazed Window Frame - Kawneer</td>
<td>PVC Triple Glazed Prestige Window Frame - Inoutic</td>
<td>GRP Triple Glazed Window Frame - Ecliptica</td>
<td>Platin Passiv Timber/Alum. triple Glazed Window Frame - Josko</td>
</tr>
<tr>
<td>CS 104 Hi Aluminium Triple Glazed Window Frame - Reynaers</td>
<td></td>
<td></td>
<td>Safir Plus PVC/Alum./GRP Triple Glazed Window Frame - Josko</td>
</tr>
<tr>
<td>AWS 90 SI + Aluminium Triple Glazed Window Frame - Schüco</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Steel

- Opificio TABS Steel triple glazed window frame
- Palladio
## Window Systems: State of the Art

<table>
<thead>
<tr>
<th>Thermal Insulation</th>
<th>Drainage</th>
<th>Stiffness</th>
<th>Sound Insulation</th>
<th>Adjustable Glazing Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT 82 HI + Aluminium - Kawneer</td>
<td>CS 104 HI Aluminium - Reynaers</td>
<td>AWS 90 SI + Aluminium - Shuco</td>
<td>Opificio TABS Steel Triple Glazed Window Frame</td>
<td>PVC Triple Glazed Prestige Window Frame - Inoutic</td>
</tr>
<tr>
<td>Triple glazed frame GRP - Ecliptica</td>
<td>Triple glazed frame Timber/Aluminium - Josko</td>
<td>Safrir Plus PVC/AL/GRP window frame - Josko</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Research Framework**  **Literature Review**  **Company Analysis**  **Case Study Analysis**  **Design**  **Conclusions**
## Harris Profiles by Window System

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight</th>
<th>Aluminium</th>
<th>Steel</th>
<th>Timber</th>
<th>uPVC</th>
<th>GRP</th>
<th>Al/Wood</th>
<th>Al/PVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightness</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Durability</td>
<td>3</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>3</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Cyclability</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>High strength</td>
<td>2</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>2</td>
<td>7</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Low maintenance</td>
<td>4</td>
<td>7</td>
<td>6</td>
<td>3</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Low thermal conductivity</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Low initial cost</td>
<td>3</td>
<td>6</td>
<td>3</td>
<td>7</td>
<td>7</td>
<td>1</td>
<td>5</td>
<td>4</td>
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<tr>
<td>Complex shapes</td>
<td>1</td>
<td>7</td>
<td>5</td>
<td>3</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Low primary embodied energy</td>
<td>4</td>
<td>1</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Reusable</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>4</td>
<td>1</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Ease of repairness</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>No need for a thermal break</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5.68</strong></td>
<td><strong>5.60</strong></td>
<td><strong>5.47</strong></td>
<td><strong>4.27</strong></td>
<td><strong>4.37</strong></td>
<td><strong>5.96</strong></td>
<td><strong>5.17</strong></td>
<td></td>
</tr>
</tbody>
</table>

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*Research Framework* | *Literature Review* | *Company Analysis* | *Case Study Analysis* | *Design* | *Conclusions*
Façade's Function Analysis

Outside

Context-Specific Conditions
- Solar radiation
- Temperature
- Humidity
- Precipitation
- Wind
- Surrounding noises
- Amount of gas and dust
- Mechanical loads
- Electromagnetic radiation
- Urban surroundings
- Local resources
- Socio-cultural context

Supplementary functions with a direct effect
- Thermal insulation
- Sunshading
- Measures influencing the microclimate (i.e. vegetation)

Supplementary building services
- External collectors
- PV/PVT
- Heatpipes
- etc

Inside

- Comfortable temperature/humidity range
- Amount & quality of light
- Air exchange rate
- Comfortable air velocity
- Comfortable sound level

- Visual relationship with external
- Differentiation of private & public areas
- Mechanical damage protection
- Fire protection
- Limitation of toxic loads

Supplementary functions with a direct effect
- Glare protection
- Privacy provision
- Redirection of daylight
- Storing/releasing energy for heating & cooling

Supplementary building services
- Convectors/radiators
- Artificial lighting
- Air conditioning (centralised/decentralised)

Protective Functions
- Insulation/Attenuation
- Seals & barriers
- Fitters
- Storage
- Redirection
- Physical barriers

Regulatory Functions
- Controlling/regulating
- Responding / Changing

Façades w. Integral Services
- Integral air/water collection
- Solar walls
- Media transport distribution
- Heat recovery systems
Reference Project

Brick cavity wall with RT 82 HI +

Brick construction

Cavity

Insulation layer

Prefab. Concrete

RT 82 HI +

Figure 7.1 Detail of the reference project, brick cavity wall with the RT 82 HI+. Image by author.
Reference Project

Brick cavity wall with RT 82 HI +

Brick construction

Cavity

Insulation layer

Prefab. Concrete

RT 82 HI +

Create a durable construction

- Deviate wind loads
- Deviate impact loads
- Carry self weight
- Handle loads from structural and thermal expansion
- Secure an air and vapour tight construction
- Secure rain and water tightness
- Create stiffness perpendicular to surface
- Fix to primary structure of building
- Integrate joints to allow movement
- Allow damage free movement
- Allow vapor tight connection of parts

Incorporate water sealing system

Absorb radiation

Ventilate excessive heat.

Heat air

Cool Air

Maintain air tightness

Provide thermal insulation

Provide enough fresh air

Filter air

Create transparent facade areas

Provide sun shading

Allow natural daylight

Redirect daylight

Reduce glare

Provide mechanically controlled ventilation

Figure 7.1 Detail of the reference project, brick cavity wall with the RT 82 HI +. Image by author.

Support use of the building

- Provide light
- Allow visual contact
- Create visual comfort
- Provide a safe environment
- Keep climate within a given range
- Prevent falling out
- Monitor performance

- Control performance

Research Framework

Literature Review

Company Analysis

Case Study Analysis

Design

Conclusions
Detailed Function Analysis

Functions & Components

- Create stiffness perpendicular to surface
- Fix to primary structure of the building
- Integrate joints to allow movement
- Allow damage free movement
- Allow vapour tight connection of parts
- Incorporate water sealing system
- Block radiation
- Ventilate excessive heat
- Maintain air tightness
- Provide thermal insulation
- Provide enough fresh air
- Create transparent façade areas
- Provide sun shading
- Allow natural daylight
- External Brickwork
- Cavity
- Insulation layer
- Internal blockwork (prefab, concrete)
- RT 82 HI + Al. window frame
  (openable/tilt & turn)
- Triple IGU
- Sunshade
- Waterproof layer
- Steel lintel
- Metal clad flashing
- Window connectors
Assessments
RT 82 HI + Circular Analysis

(1) DfD
Design for Disassembly

(2) DfA
Design for Adaptability

(3) DfRem
Design for Remanufacturing
Assessment on Design for Disassembly

DfD

Figure 7.12 Results of the DfD assessment of the RT 82 HI +. Image by author.
Assessment on Design for Adaptability (DfA)

**Methodology**

1. **Versatile**: Possible to reconfigure

2. **Refittable**: Biodiversity, climate regulating, aesthetics, active technology

3. **Convertible**: Window Area (+/-)

4. **Scalable**: Increase/Decrease building size

5. **Movable**: Move all systems

6. **Reusable**: Reuse of elements or subsystems/components

---

**Research Framework**  
**Literature Review**  
**Company Analysis**  
**Case Study Analysis**  
**Design**  
**Conclusions**
Assessment on Design for Adaptability (DfA)

Results

Versatile

7

6

5

4

3

2

1

0

Reusable

Moveable

Convertible

Refittable

Figure 7.17 Results on the DfA assessment for the RT 82 HI+. Image by author.

69.52%
Assessment on Design for Remanufacturing (DfRem)

Methodology

- Durable product
- Recovery of product functionality
- Standardization & Modularity
- High remaining value
- Affordable cores
- Stable Technology
- Core availability (5-7 years)
- Designed for Disassembly
Assessment on Design for Adaptability (DfA)

Results

- Access to spare parts
- Durability
- Product functionality can be recovered
- Consumer acceptance
- Stable product technology
- Standarization, Interchangeability
- High remaining value
- Affordable Cores

82.5%
Conclusions on the Assessments

(1) Complex Geometry of Product Edge
(2) Type of connection is not optimal for circularity
(3) There is no clear guidance on how to disassemble
(4) Too many elements = Too many connections!
(1) Complex Geometry of Product Edge

(2) Type of connection is not optimal for circularity

(3) There is no clear guidance on how to disassemble

(4) Too many elements = Too many connections!

(5) Ease of Assembly = Ease of Disassembly = Reuse
Design
Design Requirements

**Functional**
- Separate and filter between exterior and interior space
- 1. Create a durable construction
  - Bear structural loads
  - Keep materials and components in working condition
  - Enable water and vapor management in construction
- 2. Provide a comfortable interior climate
  - Create a comfortable temperature
  - Create a comfortable humidity level
  - Create visual comfort
- 3. Support use of the building
  - Keep climate within a given range
  - Provide a safe environment
  - Maintain comfortable climate

**Circular**
- 1. Is able to circulate hierarchically between the technical cycles of reuse, remanufacture, and recycling.
- 2. Is designed for disassembly, for adaptability
- 3. It reduces natural resources input and uses sustainable materials.
- 4. It measures the reduction of emission levels.
- 5. It measures the reduction of valuable material losses.

**Aesthetical**
- 1. Provides ease of change in finishings
- 2. Provides ease of change in frame form
- 3. Allows for slender construction
- 4. The aesthetic quality is not inferior to a non-circular product
# Starting Point

Based on Harris Profiles Results

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight</th>
<th>Aluminium</th>
<th>Steel</th>
<th>Timber</th>
<th>uPVC</th>
<th>GRP</th>
<th>Al/Wood</th>
<th>Al/PVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightness</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Durability</td>
<td>3</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>3</td>
<td>7</td>
<td>7</td>
<td>7</td>
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<tr>
<td>Cyclability</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td>4</td>
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<tr>
<td>High strength</td>
<td>2</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>2</td>
<td>7</td>
<td>6</td>
<td>7</td>
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<tr>
<td>Low maintenance</td>
<td>4</td>
<td>7</td>
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<td>3</td>
<td>6</td>
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<td>7</td>
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<tr>
<td>Low thermal conductivity</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Low initial cost</td>
<td>3</td>
<td>6</td>
<td>3</td>
<td>7</td>
<td>7</td>
<td>1</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Complex shapes</td>
<td>1</td>
<td>7</td>
<td>5</td>
<td>3</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Low primary embodied energy</td>
<td>4</td>
<td>1</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Reusable</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>4</td>
<td>1</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Ease of repairness</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>6</td>
<td>4</td>
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<tr>
<td>No need for a thermal break</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5.68</td>
<td>5.60</td>
<td>5.47</td>
<td>4.27</td>
<td>4.37</td>
<td>5.96</td>
<td>5.17</td>
<td></td>
</tr>
</tbody>
</table>

(1) RT 82 HI + Optimization

(2) Hybrid System Variant A

(3) Hybrid System Variant B
(1) RT 82 HI + Optimization

Small improvements for circularity

- Vulcanized gaskets
- Pulverized or beaded form AlcoaTherm insulation
- Removable thermal break
- Castor Oil based thermal break
NEW ARCHITECTURE?
Video derived from footage by Anderson (2019)
Figure 8.8 Side view of the profile for Hybrid System Variant A. Image by author.
(2) Hybrid Variant A
Side View in Brick Cavity Wall Construction
(2) Hybrid Variant A

Isometric View

Legend
(1) IGU
(2) WPC extruded profile
(3) Aluminium weatherboard
(4) Aluminium extruded profile
(5) Castor oil thermal break
(6) Insulation beads
(2) Hybrid Variant A

Exploded Isometric View

Legend
(1) IGU
(2) WPC extruded profile
(3) Aluminium weatherboard
(4) Aluminium extruded profile
(5) Castor oil thermal break
(6) Insulation beads

Figure 8.10 Exploded isometric view of the Hybrid System Variant A. Image by author.
(2) Hybrid Variant A

Assessment Results Comparison

DfD Assessment
- Original RT 82 HI +
- Hybrid System Variant A

DfA Assessment
- Original RT 82 HI +
- Hybrid System Variant A

DfRem Assessment
- Original RT 82 HI +
- Hybrid System Variant A

Research Framework  Literature Review  Company Analysis  Case Study Analysis  Design  Conclusions
(3) Hybrid Variant B

Side View

- WPC extruded profile
- Aluminium weatherboard
- Pulverized or beaded form AlcoaTherm insulation
- Vulcanized gaskets
(3) Hybrid Variant B
Side View in Brick Cavity Wall Construction
(3) Hybrid Variant B

Isometric View

Legend
(1) IGU
(2) WPC extruded profile
(3) Aluminium weatherboard
(4) Insulation beads
(3) Hybrid Variant B

Legend
(1) IGU
(2) WPC extruded profile
(3) Aluminium weatherboard
(4) Insulation beads

Exploded Isometric View
(3) Hybrid Variant B
Assessment Results Comparison

DfD Assessment
- Functional independence
- Type of connection
- Interface geometry
- Assembly sequence
- Open vs. closed hierarchy

DfA Assessment
- Versatile
- Reusable
- Base element specification
- Life cycle coordination
- Moveable

DfRem Assessment
- Durability
- Access to spare parts
- Consumer acceptance
- Stable product technology
- Affordable Cores
- Product functionality can be recovered
- Standardization & Interchangeability
- High remaining value

Research Framework  Literature Review  Company Analysis  Case Study Analysis  Design  Conclusions
Improvements in Hardware & Connections

- 2 x .25 panhead bolt
- Extruded aluminium corner cleat
Reuse Scenarios

Attachment to four different types of façade systems

Brick Cavity Wall Construction

Optimization RT 82 HI +
Hybrid System Variant A
Hybrid System Variant B

Research Framework  Literature Review  Company Analysis  Case Study Analysis  Design  Conclusions
Reuse Scenarios
Attachment to four different types of façade systems
Passive House Façade System and Construction

Optimization RT 82 HI +  

Hybrid System Variant A 

Hybrid System Variant B
Reuse Scenarios

Attachment to four different types of façade systems

Residential Storey Floor Longitudinal Façade System and Construction

Hybrid System Variant B

Hybrid System Variant A

Optimization RT 82 HI +
Reuse Scenarios
Attachment to four different types of façade systems
Non-Residential Building with Metal Cladding Façade System and Construction

Optimization RT 82 HI +

Hybrid System Variant A

Hybrid System Variant B
Adaptability Scenarios

Change of Window Area

Change of aesthetics

Change of Function
Adaptability Scenarios

Change of Window Area (+/-)

Figure 8.33 Convertible conceptual designs for the window systems.
Adaptability Scenarios

Change of Aesthetics
Adaptability Scenarios
Change of Function

- Glass
- Climate Components
- Biodiversity
- Active technology

Research Framework | Literature Review | Company Analysis | Case Study Analysis | Design | Conclusions
Remanufacturing Scenarios

(5) Key Activities
Remanufacturing Scenarios
(5) Key Activities

1. Reman. Admin. Centre
2. Market + Customer
3. Product DfRem
4. Parts are brought in
5. Manufacturing
6. Product integrator
Remanufacturing Scenarios

(5) Key Activities

- Reman. Admin. Centre
- Market + Customer
- Product DfRem
- Parts are brought in
- Manufacturing
- Product integrator

- Maintenance Repair
- Product is in use
- Installation
- Distribution (logistics)
- Pack
- Sales (pre & post)
Remanufacturing Scenarios
(5) Key Activities

Reman. Admin. Centre > Market + Customer > Product DfRem > Parts are brought in > Manufacturing > Product integrator

? Maintenance Repair > Product is in use > Installation > Distribution (logistics) > Pack > Sales (pre & post)

? Assess in situ (contact reman. admin) > Remove > Repack > Back to company (logistics) > Reman. Admin Centre

Research Framework  Literature Review  Company Analysis  Case Study Analysis  Design  Conclusions
Remanufacturing Scenarios

(5) Key Activities

Reman. Admin. Centre > Market + Customer > Product DfRem > Parts are brought in > Manufacturing > Product integrator

Maintenance Repair < Product is in use < Installation < Distribution (logistics) < Pack < Sales (pre & post)

Assess in situ (contact reman. admin) > Remove > Repack > Back to company (logistics) > Reman. Admin Centre > Collection of cores (customers)

Bill of Materials (new parts might be added) < Detailed inspection of parts < Disassembly < Cleaning < Inspection & testing < Unpack

Reassemble > Test
Conclusions
Closing the Loop

Raw Materials
(Alcoa, WPC company)

- Wood Fibres
- PVC/PP/PT
- Aluminium
Closing the Loop

Raw Materials (Alcoa, WPC company)
- Wood Fibres
- PVC/PP/PT
- Aluminium

Parts fabrication (Kawneer)
- WPC ext. profiles
- Al. ext. profiles
- Al. cover caps
Closing the Loop

Raw Materials
(Alcoa, WPC company)
- Wood Fibres
- PVC/PP/PT
- Aluminium

Parts fabrication
(Kawneer)
- WPC ext. profiles
- Al. ext. profiles
- Al. cover caps

Product Assembly
(Façade Manufacturer)
- Optimization RT 82
- Hybrid Variant A
- Hybrid Variant B
Closing the Loop

Raw Materials
(Alcoa, WPC company)
- Wood Fibres
- PVC/PP/PT
- Aluminium

Parts fabrication
(Kawneer)
- WPC ext. profiles
- Al. ext. profiles
- Al. cover caps

Product Assembly
(Façade Manufacturer)
- Optimization RT 82
- Hybrid Variant A
- Hybrid Variant B

Distribution
(Contractor)
- Façade Manufacturer
Closing the Loop

Raw Materials (Alcoa, WPC company)
- Wood Fibres
- PVC/PP/PT
- Aluminium

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- WPC ext. profiles
- Al. ext. profiles
- Al. cover caps

Product Assembly (Façade Manufacturer)
- Optimization RT 82
- Hybrid Variant A
- Hybrid Variant B

Distribution (Contractor)
- Façade Manufacturer

User
Closing the Loop

Raw Materials (Alcoa, WPC company)
- Wood Fibres
- PVC/PP/PT
- Aluminium

Parts fabrication (Kawneer)
- WPC ext. profiles
- Al. ext. profiles
- Al. cover caps

Product Assembly (Façade Manufacturer)
- Optimization RT 82
- Hybrid Variant A
- Hybrid Variant B

Distribution (Contractor)
- Façade Manufacturer

Service
- Maintenance
- Repair

User
Closing the Loop

Raw Materials
(Alcoa, WPC company)
- Wood Fibres
- PVC/PP/PT
- Aluminium

Parts fabrication
(Kawneer)
- WPC ext. profiles
- Al. ext. profiles
- Al. cover caps

Product Assembly
(Façade Manufacturer)
- Optimization RT 82
- Hybrid Variant A
- Hybrid Variant B

Distribution
(Contractor)

User

Service
- Maintenance
- Repair

Direct Reuse/Resale
Closing the Loop

Raw Materials (Alcoa, WPC company)
- Wood Fibres
- PVC/PP/PT
- Aluminium

Parts fabrication (Kawneer)
- WPC ext. profiles
- Al. ext. profiles
- Al. cover caps

Product Assembly (Façade Manufacturer)
- Optimization RT 82
- Hybrid Variant A
- Hybrid Variant B

Distribution (Contractor)

User

Service
- Maintenance
- Repair

Recycling
- Direct Reuse/Resale
- Refurbishing
- Remanufacturing

Research Framework
- Literature Review
- Company Analysis
- Case Study Analysis
- Design
- Conclusions
Closing the Loop

Raw Materials (Alcoa, WPC company)
- Wood Fibres
- PVC/PP/PT
- Aluminium

Parts fabrication (Kawneer)
- WPC ext. profiles
- Al. ext. profiles
- Al. cover caps

Product Assembly (Façade Manufacturer)
- Optimization RT 82
- Hybrid Variant A
- Hybrid Variant B

Distribution (Contractor)
- Façade Manufacturer

User

Service
- Maintenance
- Repair

Recycling
- Direct Reuse/Resale
- Refurbishing
- Remanufacturing

(open loop)
- Incineration
- Landfill
- *insulation
- *EPDM gaskets, etc

Research Framework  Literature Review  Company Analysis  Case Study Analysis  Design  Conclusions
Is the System Ready?

Business Models

Reverse Logistics

DfD
DfA
DfRem

Research Framework  Literature Review  Company Analysis  Case Study Analysis  Design  Conclusions
Is the System Ready?

MARKET DEMAND

Business Models

Reverse Logistics

DfD
DfA
DfRem
Possible Circularity Scenarios

- **Direct reuse of window as a full component**
  - Change of location
  - Change of aesthetics
  - Change of infill

- **Breakdown of elements for new/reman. windows**
  - Disassembly
  - Remanufacture (elements are cores)
  - New Product
Assessments
RT 82 HI + Optimization

Hybrid Variant A

Hybrid Variant B
Limitations

Design focus on frames product arch.

Focus on DfD, DfA, DfRem

Material flows briefly analysed

Testing through physical prototypes

Limited research warranties & serv.

Analysis on thermal transmittance
Limitations

Design focus on frames product arch.

Focus on DfD, DfA, DfRem

Material flows briefly analysed

Testing through physical prototypes

Limited research warranties & serv.

Analysis on thermal transmittance
Further Research
Further Research

Analysis on other **window components**

Focus on **other circularity scenarios**

Analysis at a larger scale **Circular BE**

Ellaborate **physical prototypes for testing**

Development of **Warranties & Serv.**

Improvement of **U-value (passive house)**
WHAT'S NEXT?
RemanWindows 2.0

Understand the Potential for Rem. other BP

Development of Circular Business Models

Focus on Warranty & Service

Improvement on Product Architecture

Focus on Tolerances & Movements

Learn from Other Industries...

Research Framework  Literature Review  Company Analysis  Case Study Analysis  Design  Conclusions
Thank you.

questions + feedback?