energy consumption per sector

32% industry
38% buildings
29% transportation

source: www.greenoptimistic.com
waste production per sector

- 41.6% construction
- 33.2% commercial & industrial
- 13.9% households
- 7.3% agriculture
- 4% other

Source: http://www.europarl.europa.eu
linear economy
2050

9 billion
2050

9 billion

x 6
the circular approach
close the material loops
close the material loops

Emissions diminished

Waste reduced
main objective

Formation of the strategy for rating the Design for Disassembly in unitized curtain wall modules, with the focus on comparing 4 adaptive concepts for high-rise office buildings on temperate climate conditions for 2 different materials used for mullions: aluminum and timber.
main objective

Formation of the **strategy** for rating the Design for Disassembly in unitized curtain wall modules, with the focus on **comparing 4 adaptive concepts** for high-rise office buildings on temperate climate conditions for 2 different materials used for mullions: aluminum and timber.
main objective

Formation of the strategy for rating the Design for Disassembly in unitized curtain wall modules, with the focus on comparing 4 adaptive concepts for high-rise office buildings on temperate climate conditions for 2 different materials used for mullions: aluminum and timber.
1. DfD strategy
2. The 4 adaptive building envelopes
3. Environmental impact
4. Rating the DfD criteria
5. Final comparison
6. Conclusions & recommendations
the DfD strategy
the DfD strategy

2

the 4 adaptive building envelopes
the DfD strategy
the 4 adaptive building envelopes
environmental impact
rating the DfD criteria
the DfD strategy
the 4 adaptive building envelopes
environmental impact
rating the DfD criteria
final comparison

conclusions & recommendations

conclusions & recommendations

6
1. DESIGN FOR DISASSEMBLY: a strategy for unitized curtain walls
DfD guidelines

**Material-related**
- Environmental impact
- Durability of components
- Recycle/reuse potential

**Connection-related**
- Reversibility of connections
- Ease of (dis)assembly
- Speed of (dis)assembly
1. environmental impact

- OVERALL IMPACT

Cradle-to-gate assessment
2. durability of the components

- LIFE EXPECTANCY
- MAINTENANCE
- RESISTANCE TO WEAR
2. durability of the components

- LIFE EXPECTANCY
- MAINTENANCE
- RESISTANCE TO WEAR
2. durability of the components

- LIFE EXPECTANCY
- MAINTENANCE
- RESISTANCE TO WEAR
3. recycle/reuse potential

- END-OF-LIFE ACTIVITY
- SIDE EFFECTS WHEN REUSED/RECYCLED
3. recycle/reuse potential

- END-OF-LIFE ACTIVITY
- SIDE EFFECTS WHEN REUSED/RECYCLED
4. reversibility of connections

- REVERSIBLE JOINING TECHNIQUES
5. ease of (dis)assembly

- COMPLEXITY OF CONNECTION TECHNIQUES
- ACCESSIBILITY OF CONNECTIONS
5. ease of (dis)assembly

- COMPLEXITY OF CONNECTION TECHNIQUES
- ACCESSIBILITY OF CONNECTIONS
6. speed of (dis)assembly

- TOTAL AMOUNT OF CONNECTIONS
- DIFFERENT TYPES OF CONNECTIONS
6. speed of (dis)assembly

criteria:

- TOTAL AMOUNT OF CONNECTIONS
- DIFFERENT TYPES OF CONNECTIONS
other DfD guidelines that apply for unitized CW

- PREFABRICATION OF BUILDING COMPONENTS
- INDEPENDENCE OF BUILDING COMPONENTS
- COMPATIBILITY OF DIMENSIONING
other DfD guidelines that apply for unitized CW

- PREFABRICATION OF BUILDING COMPONENTS
- INDEPENDENCE OF BUILDING COMPONENTS
- COMPATIBILITY OF DIMENSIONING
other DfD guidelines that apply for unitized CW

- PREFABRICATION OF BUILDING COMPONENTS
- INDEPENDENCE OF BUILDING COMPONENTS
- COMPATIBILITY OF DIMENSIONING
other DfD guidelines that apply for unitized CW

- PREFABRICATION OF BUILDING COMPONENTS
- INDEPENDENCE OF BUILDING COMPONENTS
- COMPATIBILITY OF DIMENSIONING
## criteria weights

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<tr>
<td></td>
<td>resistance to wear extremely fragile --- extremely resistant</td>
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<td>3. recycle/reuse potential</td>
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<td>side effects when reused/recycled very toxic --- 100% safe</td>
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## Criteria Weights

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<td>every 1y. --- never</td>
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weight factors for design guidelines

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1: the assessed criterion is of less importance than the one compared to
2: the assessed criterion is of about equal importance to the one compared
3: the assessed criterion is of more importance than the one compared to
DfD strategy for Unitized CW

- Prefabrication of components
- Independence of components
- Compatibility of dimensioning
- Environmental impact
- Durability of the components
- Recycle/reuse potential
- Reversibility of connections
- Ease of (dis)assembly
- Speed of (dis)assembly

Criteria:

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<td>Maintenance</td>
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<td>Resistance to wear</td>
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<td>y4</td>
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<td>End-of-life activity</td>
<td>x5 0.8</td>
<td>y5</td>
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<tr>
<td>Side effects</td>
<td>x6 0.2</td>
<td>y6</td>
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<tr>
<td>Reversibility</td>
<td>x7 1</td>
<td>y7</td>
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<td>y9</td>
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<tr>
<td>Types of con.</td>
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</table>

Design guidelines:

- Weight factors: w1 = 10 + w2 = 10 + w3 = 13 + w4 = 15 + w5 = 7 + w6 = 5

Final rating = x1 * y1 + x2 * y2 + x3 * y3 + x4 * y4 + x5 * y5 + x6 * y6 + x7 * y7 + x8 * y8 + x9 * y9 + x10 * y10 + x11 * y11

Diagram:

- Design guidelines
- Overall impact
- Life expectancy
- Maintenance
- Resistance to wear
- End-of-life activity
- Side effects
- Reversibility
- Complexity
- Accessibility
- Amount of con.
- Types of con.
- Final rating
2. THE 4 ADAPTIVE BUILDING ENVELOPES
classification of relevant physics
classification of relevant physics

thermal, optical & electrical adaptation
energy consumption in a typical office

- Heating + Cooling: 1/3
- Others (Ventilation, etc.): 1/3
- Lighting: 1/3
the 4 adaptive concepts

<table>
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<tr>
<th>Horizontal</th>
<th>Rotating</th>
<th>Folding</th>
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<tr>
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<td>F1</td>
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<table>
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<th>Vertical</th>
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<tbody>
<tr>
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<td>R2</td>
<td>F2</td>
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</table>
application

Facade Module

Office Grid

1250 1250
2500 2500
3750
750
2250
750

2500 7500
curtain wall fixation

layout 1G
one level hanging

layout 2G
two level hanging

layout 1-0
one level bearing

layout 2-0
two level bearing
MODULE R2 – Horizontal Rotating Fins

SUMMER
save on cooling

WINTER
save on heating

vertical steel profile
split transom
supporting steel element
glass louvers
split mullion
exterior aluminum frame
MODULE F1 – Horizontally Folding Panels

**SUMMER**
save on cooling

**WINTER**
save on heating

- vertical steel profile
- split transom
- supporting steel element
- glass louvers
- split mullion
- exterior aluminum frame
MODULE F2 – Vertically Folding Panels

SUMMER
save on cooling

WINTER
save on heating

vertical steel profile
split transom
glass louvers
supporting steel element
split mullion
exterior aluminum frame
2 materials for mullions and transoms

aluminum

timber
1 prefabricated frame including the shading system
2 bolts
3 steel plate
4 bolts
5 steel T or L profile
6 rubber profile
7 prefabricated frame including the shading system
1 prefabricated frame
2 bolts
3 steel plate
4 bolts
5 steel T or L profile
6 rubber profile
7 prefabricated frame including the shading system

prefabrication
prefabricated frame including the shading system
prefabricated frame including the shading system

1 prefabricated
2 bolts
3 steel plate
4 bolts
5 steel T or L profile
6 rubber profile
7 prefabricated frame including the shading system
1 prefabricated
2 bolts
3 steel plate
4 bolts
5 steel T or L profile
6 rubber profile
7 prefabricated frame including the shading system

diagram:
- Prefabrication
- Transportation
- On-site connection
- On-site assembly
1 prefabricated
2 bolts
3 steel plate
4 bolts
5 steel T or L profile
6 rubber profile
7 prefabricated frame including the shading system
1 prefabricated frame including the shading system
2 bolts
3 steel plate
4 bolts
5 steel T or L profile
6 rubber profile
7 prefabricated frame including the shading system
1 prefabricated
2 bolts
3 steel plate
4 bolts
5 steel T or L profile
6 rubber profile
7 prefabricated frame including the shading system
1 prefabricated frame including the shading system
2 bolts
3 steel plate
4 bolts
5 steel T or L profile
6 rubber profile
7 prefabricated frame including the shading system
3. ENVIRONMENTAL IMPACT
The Life Cycle stages – EN standards

<table>
<thead>
<tr>
<th>A 1-3</th>
<th>A 4-5</th>
<th>B 1-7</th>
<th>C 1-4</th>
<th>D</th>
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<tbody>
<tr>
<td>PRODUCT stage</td>
<td>CONSTRUCTION PROCESS</td>
<td>USE stage</td>
<td>END OF LIFE stage</td>
<td>Benefits and loads beyond the system boundary</td>
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<td>A1</td>
<td>A2</td>
<td>A3</td>
<td>A4</td>
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cradle-to-gate
### Elements for Calculation

#### Aluminum CW

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<tr>
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<th>Part of the Module</th>
<th>Element Name</th>
<th>Material Name</th>
<th>Amount</th>
<th>Area</th>
<th>Height/Length</th>
<th>Volume</th>
<th>Density</th>
<th>Weight</th>
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<td>CW - A</td>
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<td>1625</td>
<td>3750</td>
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<td>2700</td>
<td>16.453125</td>
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<td>Transom (2)</td>
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#### Shading

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### Elements for Calculation

#### Aluminum CW

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74
results

Impact categories

shadow cost

Abiotic depletion
Global warming (ODP)
Ozone layer depletion (ODP)
Human toxicity
Fresh water aquatic ecotoxicity
Marine aquatic ecotoxicity
Terrestrial ecotoxicity
Photochemical oxidation
Acidification
Eutrophication

R1 - A
R2 - A
F1 - A
F2 - A
R1 - T
R2 - T
F1 - T
F2 - T
results

TOTAL IMPACT

module name

shadow cost

R1 - A
R2 - A
F1 - A
F2 - A
R1 - T
R2 - T
F1 - T
F2 - T
4. RATINGS FOR THE DFD CRITERIA
overview
Overview

**Rating System Overview**

**Overall Impact**
- Very low
- Low
- Medium
- High
- Very high

**Lif expectancy**
- 100y
- 75y
- 50y
- 25y
- 15y
- 5y
- 1y

**Maintenance**
- Never
- Every 50y
- Every 25y
- Every 15y
- Every 5y
- Every 1y

**Resistence to Wear**
- Extremely resistant
- Very resistant
- Resistant
- Fragile
- Very fragile
- Extremely fragile

**End of Life Activity**
- Reuse
- Remanufacture
- Recycle
- Recover
- Landfill

**Side Effects**
- 100% safe
- Sufficiently safe
- Not safe enough
- Dangerous
- Toxic
- Very toxic

**Reversibility**
- All constant, reversible
- 1 non-reversible
- 2 non-reversible
- 3 to 5 non-reversible
- More non-reversible

**Complexity**
- Extremely simple
- Very simple
- Simple
- Complicated
- Very complicated
- Extremely complicated

**Accessibility**
- Completely accessible
- Accessible
- Obscured
- Very obscured
- Completely obscured

**Amount of Connections**

**Types of Connections**
rating system

all con. reversible
1 non-reversible
2 non-reversible
3 to 5 non-reversible
more non-reversible
5. **FINAL COMPARISON**
1. env. impact
2. durability of the components
3. recycle/reuse potential
4. reversibility of con.
5. ease of (dis)assembly
6. speed of disassembly

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R2-A 1 3 3 5 3 4 4.2
F1-A 3 3 2 3 3 5 4 3 4 3
F2-A 3 3 2 3 3 5 4 3 4 3
R1-T 3 3 2 3 3 5 4 3 4 3
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F1-T 3 3 2 3 3 5 4 3 4 3
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1. env. impact
2. durability of the components
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Final ratings:
- 216.2
- 204.2
- 222.2
- 222.7
- 241.8
- 227.8
- 249.3
- 249.8
6. CONCLUSIONS & RECOMMENDATIONS
• A strategy was formed to aid DfD in unitized systems.
• a strategy was formed to aid DfD in unitized systems

• weight factors were applied according to importance
• a strategy was formed to aid DfD in unitized systems
• weight factors were applied according to importance
• demountable design for unitized & adaptive CW
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• demountable design for unitized & adaptive CW
• timber-framed modules perform better for DfD
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• weight factors were applied according to importance
• demountable design for unitized & adaptive CW
• timber-framed modules perform better for DfD
• top performing modules

CONCLUSIONS
• a strategy was formed to aid DfD in unitized systems
• weight factors were applied according to importance
• demountable design for unitized & adaptive CW
• timber-framed modules perform better for DfD
• top performing modules
  • other considerations which are also very crucial during the design phase, such as:
    • energy performance
    • life cycle costs
    • user comfort
    • aesthetics
    • maintenance
• development of a DfD strategy for the **stick system** in curtain walls

  usually used in smaller projects
• development of a DfD strategy for the stick system in curtain walls usually used in smaller projects

• simulations for energy performance
• development of a DfD strategy for the stick system in curtain walls usually used in smaller projects

• simulations for energy performance

• application on other adaptive concepts or static

thermal, optical & electrical adaptation
• development of a DfD strategy for the **stick system** in curtain walls
  
  usually used in smaller projects

• simulations for **energy performance**

• application on other **adaptive** concepts or **static**

• **steel** mullions and transoms
  
  heavy profiles → not used in high-rise buildings
• development of a DfD strategy for the **stick system** in curtain walls
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• simulations for **energy performance**

• application on other **adaptive** concepts or **static**

• **steel** mullions and transoms
  heavy profiles → not used in high-rise buildings
  customized profiles

SOURCE: www.tgpamerica.com
• development of a DfD strategy for the stick system in curtain walls
  usually used in smaller projects

• simulations for energy performance

• application on other adaptive concepts or static

• steel mullions and transoms
  heavy profiles → not used in high-rise buildings

• integration of costs
THANK YOU
QUESTIONS?