

The Future Building Envelope: Circular and Adaptive



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ir. Tom Huizer
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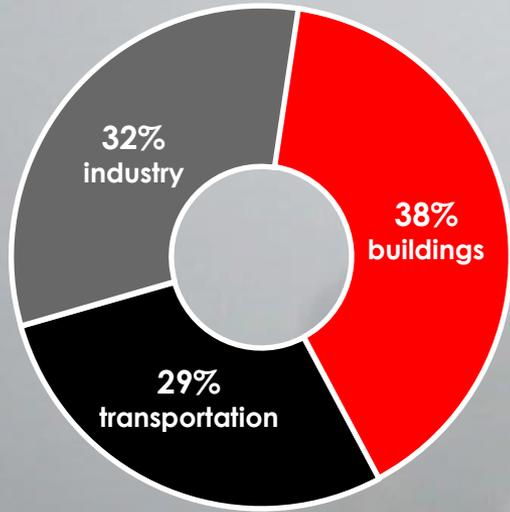
TU Delft
MSc Building Engineering

Nondas Ntailianas





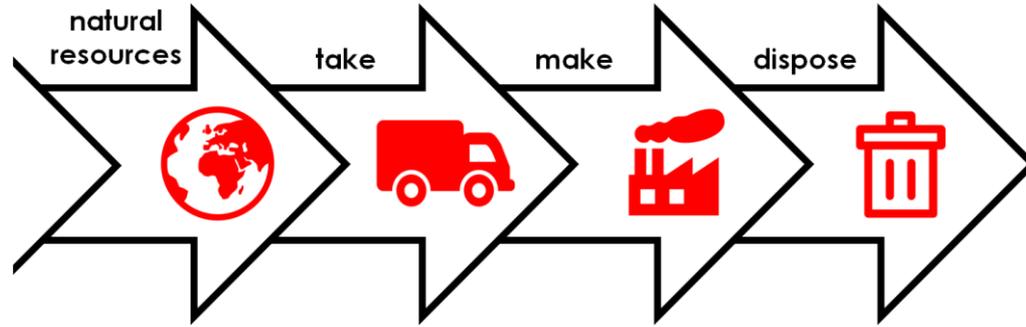
energy consumption per sector



waste production per sector



linear economy



2050



9 billion



2050

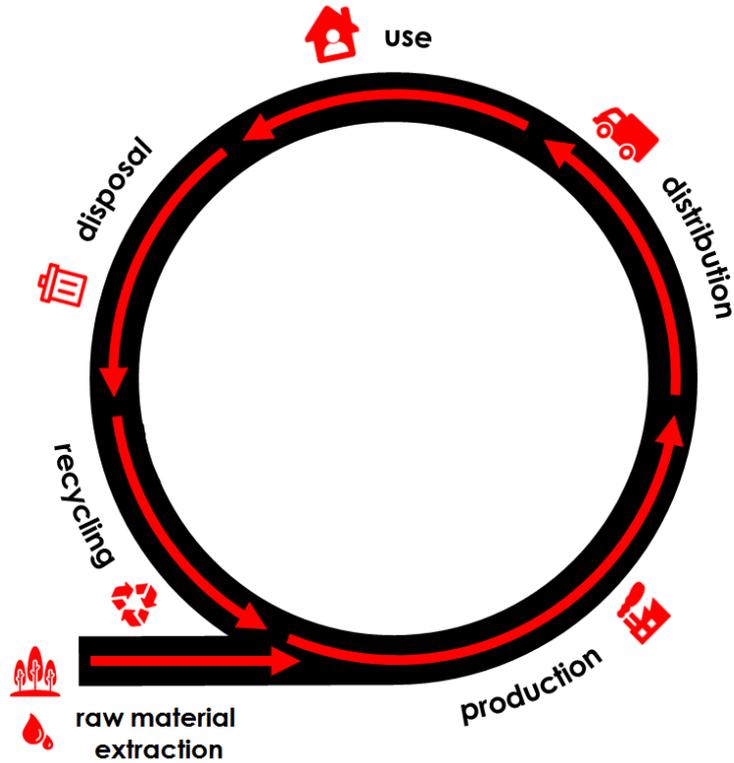


9 billion

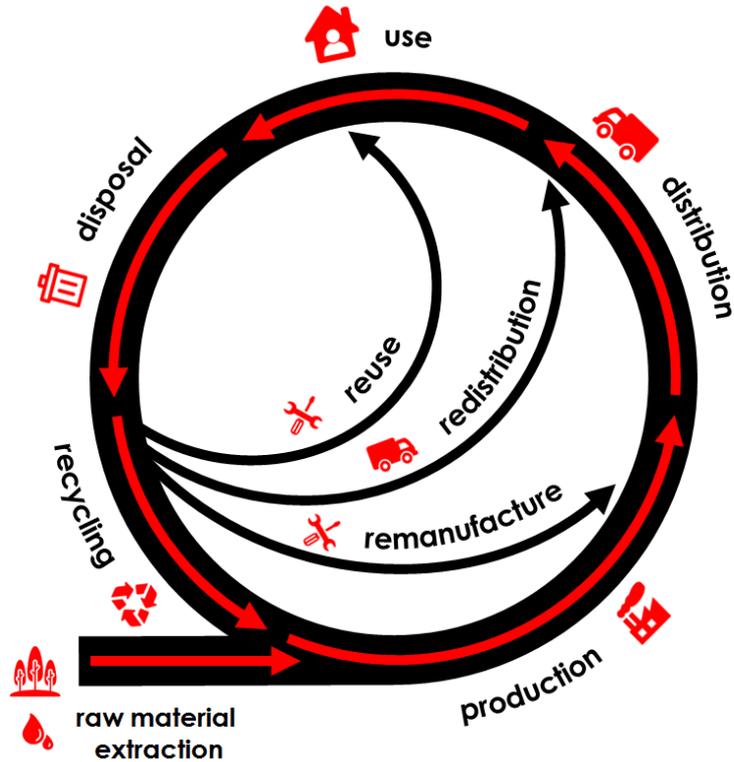


x 6

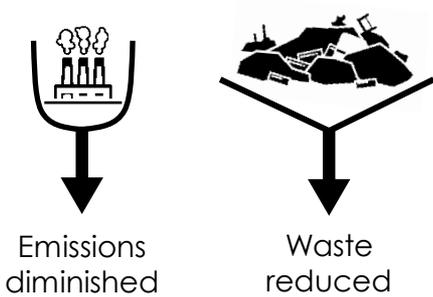
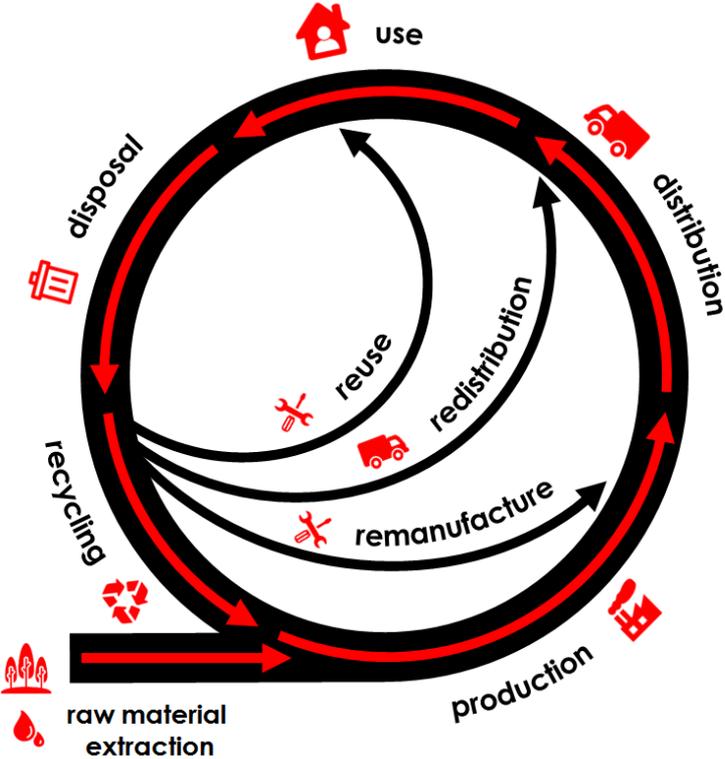
the circular approach



close the material loops



close the material loops



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.

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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.

STRATEGY DFD RATING



DESIGN 4 ADAPTIVE CONCEPTS



FINAL COMPARISON PERFORMANCE



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.**

STRATEGY
DFD RATING



DESIGN
4 ADAPTIVE CONCEPTS



FINAL COMPARISON
PERFORMANCE



FAÇADE SYSTEM
UNITIZED CW



CLIMATE
TEMPERATE



BUILDING TYPE
OFFICE



MATERIALS
TIMBER/ALUMINUM



contents

1

DfD strategy



2

the 4 adaptive building envelopes



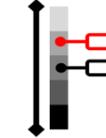
3

environmental impact



4

rating the DfD criteria



5

final comparison



6

conclusions & recommendations

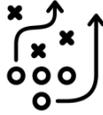


the DfD strategy

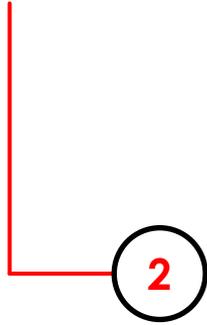


1

DfD strategy



the 4 adaptive
building envelopes



2

the 4 adaptive building envelopes



the DfD strategy

the 4 adaptive
building envelopes

environmental impact



the DfD strategy

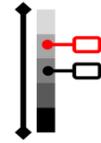
the 4 adaptive
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environmental impact

rating the DfD criteria

4

rating the DfD criteria



the DfD strategy

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building envelopes

environmental impact

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5

final comparison

■	■	■	■
■			
■			
■			

the DfD strategy

the 4 adaptive
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conclusions &
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6

conclusions & recommendations



the DfD strategy

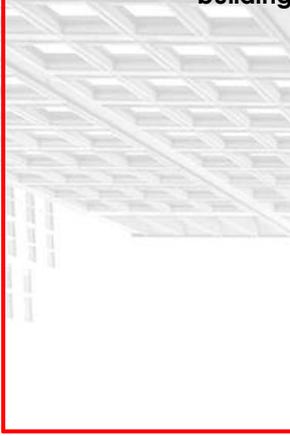
the 4 adaptive
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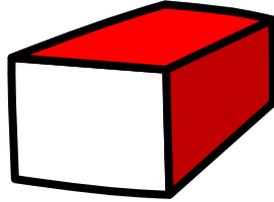
conclusions &
recommendations



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

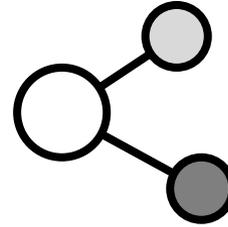
DfD guidelines

material-related



-  environmental impact
-  durability of components
-  recycle/reuse potential

connection-related



-  reversibility of connections
-  ease of (dis)assembly
-  speed of (dis)assembly



1



2



3



4



5



6

1. environmental impact

crit^{er}ion:

□ OVERALL IMPACT



cradle-to-gate
assessment



1



2



3



4



5



6

2. durability of the components

criteria:

- LIFE EXPECTANCY
- MAINTENANCE
- RESISTANCE TO WEAR



1



2



3



4



5



6

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1



2



3



4



5



6

2. durability of the components

criteria:

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- MAINTENANCE
- RESISTANCE TO WEAR



1



2



3



4



5



6

3. recycle/reuse potential

criteria:

- END-OF-LIFE ACTIVITY
- SIDE EFFECTS WHEN REUSED/RECYCLED



1



2



3



4



5



6

3. recycle/reuse potential

criteria:

- END-OF-LIFE ACTIVITY
- SIDE EFFECTS WHEN REUSED/RECYCLED



- 1 
- 2 
- 3 **
- 4 
- 5 
- 6 

4. reversibility of connections

critrion:

- ❑ REVERSIBLE JOINING TECHNIQUES



Project ABT/DAMEN OFFICES, Delft, by Bierman Henket architecten 2001
Photo Bierman Henket architecten.



1



2



3



4



5



6

5. ease of (dis)assembly

criteria:

- ❑ COMPLEXITY OF CONNECTION TECHNIQUES
- ❑ ACCESSIBILITY OF CONNECTIONS



1



2



3



4



5



6

5. ease of (dis)assembly

criteria:

- ❑ COMPLEXITY OF CONNECTION TECHNIQUES
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1



2



3



4



5

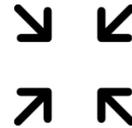


6

6. speed of (dis)assembly

criteria:

- TOTAL AMOUNT OF CONNECTIONS
- DIFFERENT TYPES OF CONNECTIONS



1



2



3



4



5

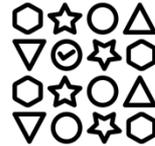


6

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1



2



3



4



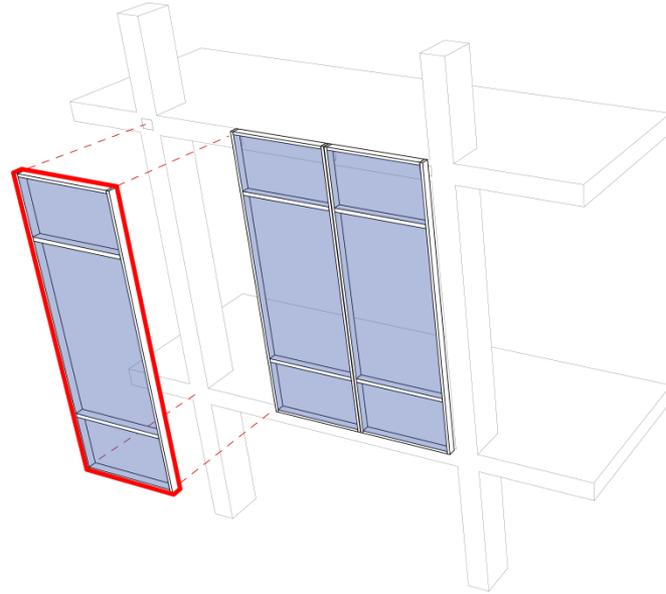
5



6

other DfD guidelines that apply for unitized CW

- ❑ PREFABRICATION OF BUILDING COMPONENTS
- ❑ INDEPENDENCE OF BUILDING COMPONENTS
- ❑ COMPATIBILITY OF DIMENSIONING



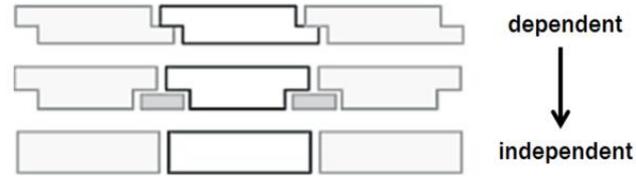
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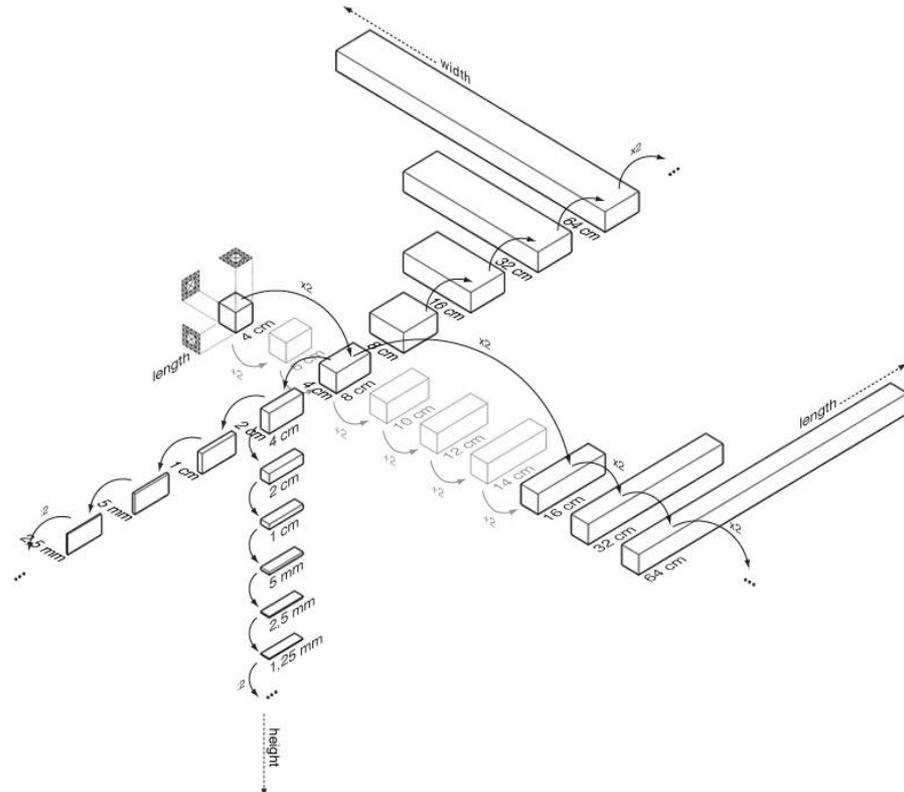
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other DfD guidelines that apply for unitized CW

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- ❑ COMPATIBILITY OF DIMENSIONING



criteria weights

Disassembly Criteria	Scale of rating	Weight
1. environmental impact		
overall impact (cradle-to-gate)	very high --- very low	1
2. durability of the components		
life expectancy	1y. --- 100y.	0.6
maintenance	every 1y. --- never	0.2
resistance to wear	extremely fragile --- extremely resistant	0.2
3. recycle/reuse potential		
end-of-life activity	landfill --- reuse	0.8
side effects when reused/recycled	very toxic --- 100% safe	0.2
4. reversibility of connections		
reversibility of connections	more non-reversible --- all con. reversible	1
5. ease of (dis)assembly		
complexity of the conn. techniques	extremely complicated --- extremely simple	0.5
accessibility of connections	completely obscured --- completely accessible	0.5
6. speed of (dis)assembly		
amount of connections	0 --- ∞	0.8
types of connections	1 --- ≥ 5	0.2

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1

1

1

1

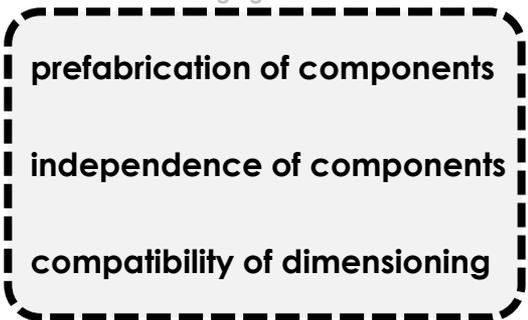
weight factors for design guidelines

		MATERIALS			CONNECTIONS			
		environmental impact	durability/lifespan	recycle/reuse potential	reversibility	ease of (dis)assembly	speed of (dis)assembly	
CONNECTIONS	MATERIALS	environmental impact	2	1	1	3	3	10
		durability/lifespan	2	1	1	3	3	10
		recycle/reuse potential	3	3	1	3	3	13
		reversibility	3	3	3	3	3	15
		ease of (dis)assembly	1	1	1	1	3	7
		speed of (dis)assembly	1	1	1	1	1	5

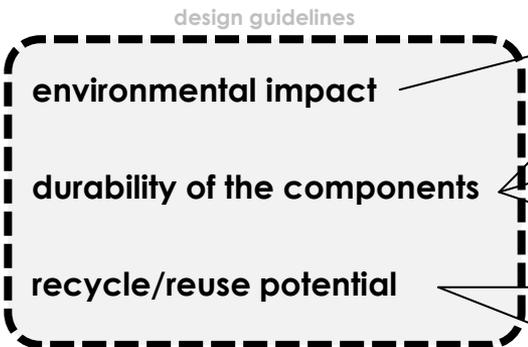
- 1: the assessed criterion is of less importance than the one compared to
- 2: the assessed criterion is of about equal importance to the one compared
- 3: the assessed criterion is of more importance than the one compared to

DfD strategy for Unitized CW

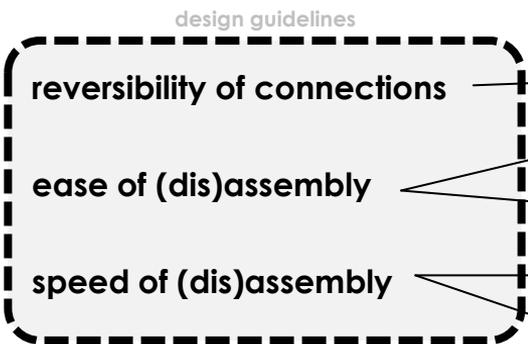
components



materials



connections



criteria	rating	specific weight	weighted rating	des. guid. rating	weight factors	weighted des. guid. rating
overall impact	x1	1	y1	z1	10	w1
life expectancy	x2	0.6	y2	z2	10	w2
maintenance	x3	0.2	y3			
resistance to wear	x4	0.2	y4	z3	13	w3
end-of-life activity	x5	0.8	y5			
side effects	x6	0.2	y6	z4	15	w4
reversibility	x7	1	y7			
complexity	x8	0.5	y8	z5	7	w5
accessibility	x9	0.5	y9			
amount of con.	x10	0.8	y10	z6	5	w6
types of con.	x11	0.2	y11			

final rating

the DfD strategy

the 4 adaptive
building envelopes

environmental impact

rating the DfD criteria

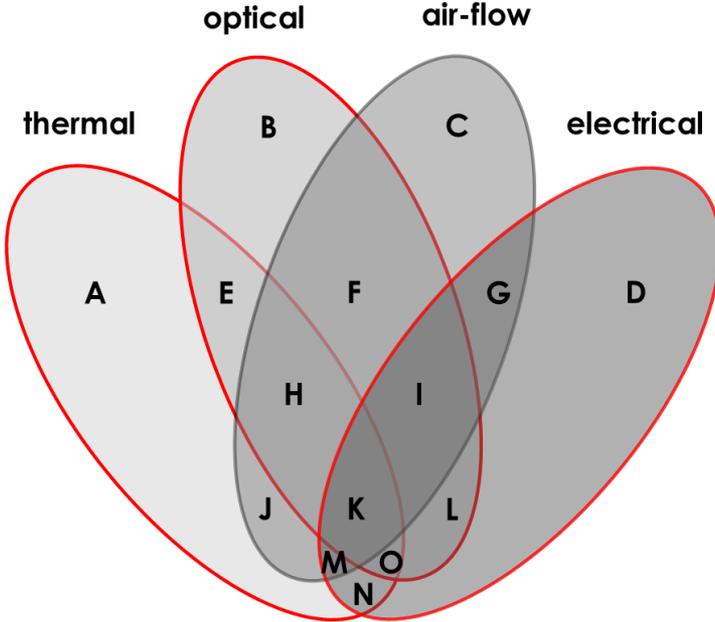
final comparison

conclusions &
recommendations

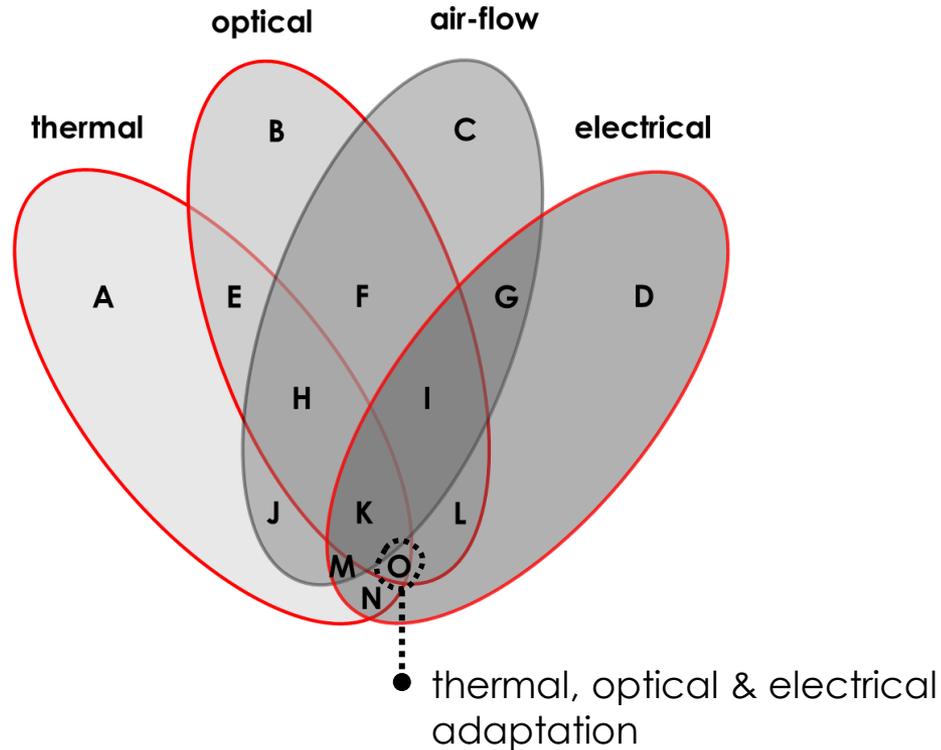


2. THE 4 ADAPTIVE BUILDING ENVELOPES

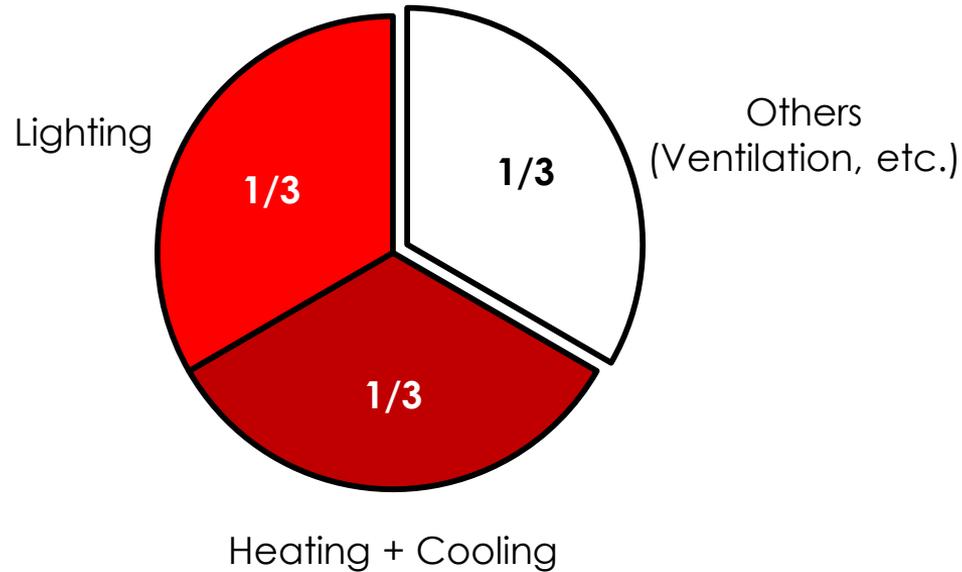
classification of **relevant physics**



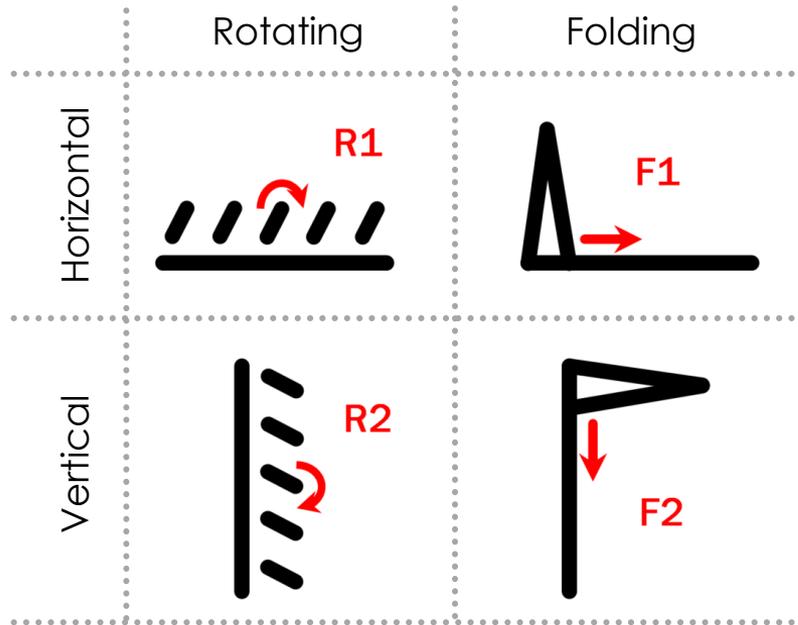
classification of **relevant physics**



energy consumption in a typical office

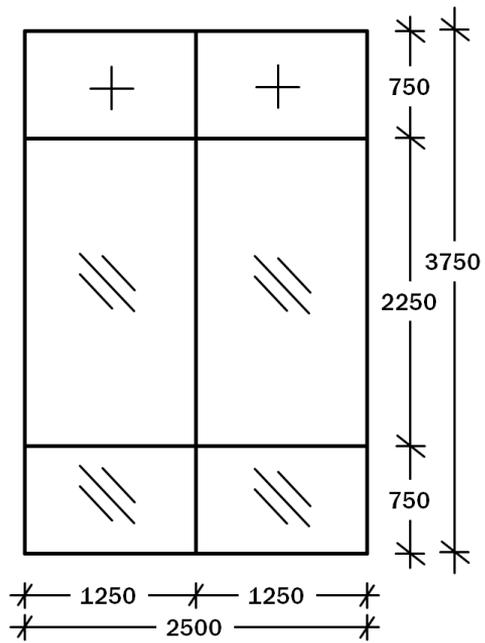


the 4 adaptive concepts

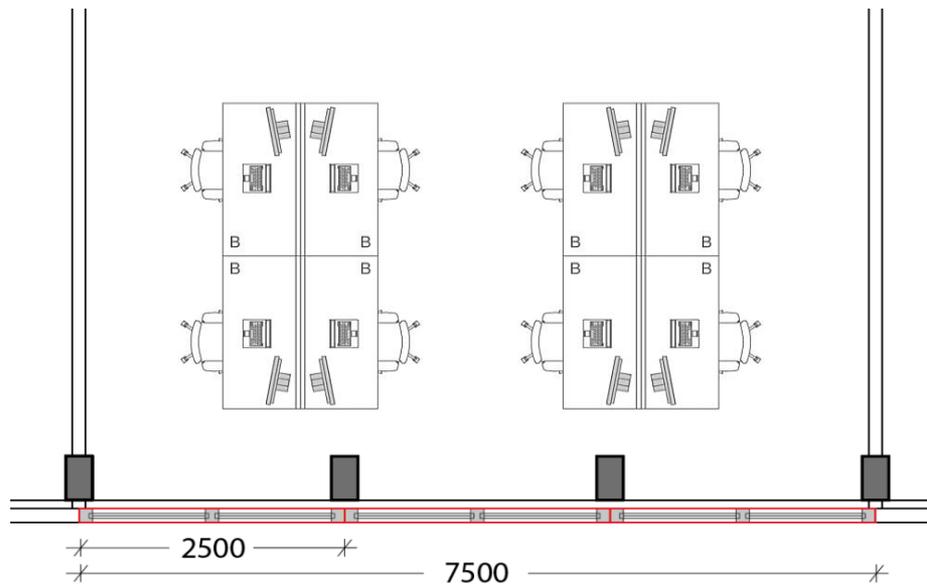


application

Facade Module

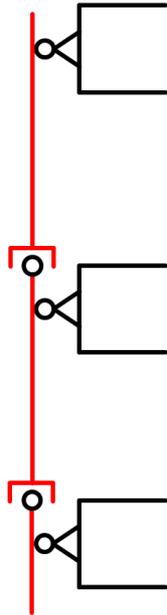


Office Grid

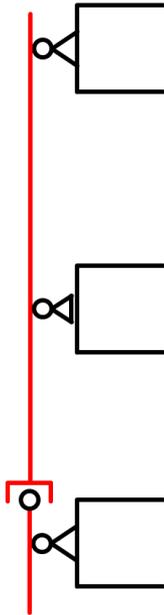


curtain wall fixation

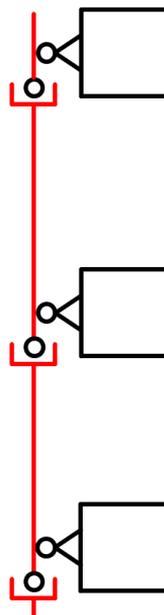
layout 1G
one level hanging



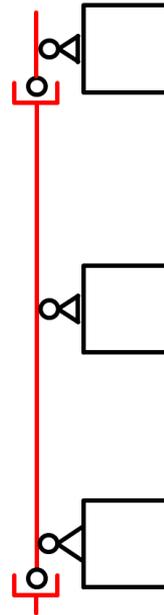
layout 2G
two level hanging



layout 1-0
one level bearing

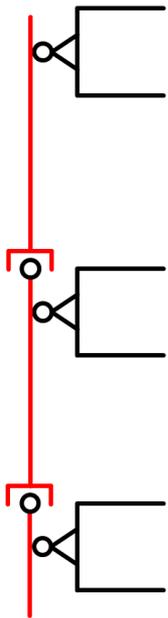


layout 2-0
two level bearing

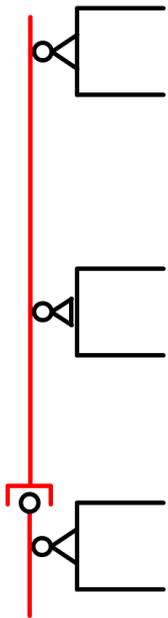




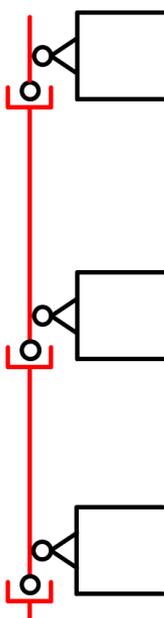
layout 1G
one level hanging



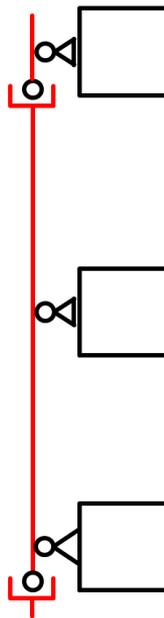
layout 2G
two level hanging



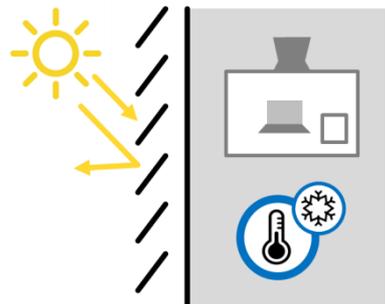
layout 1-0
one level bearing



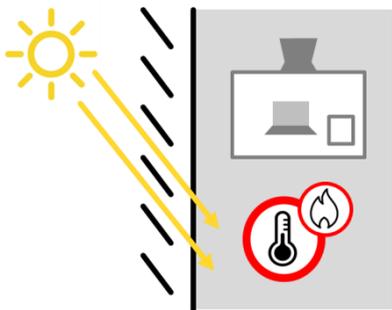
layout 2-0
two level bearing



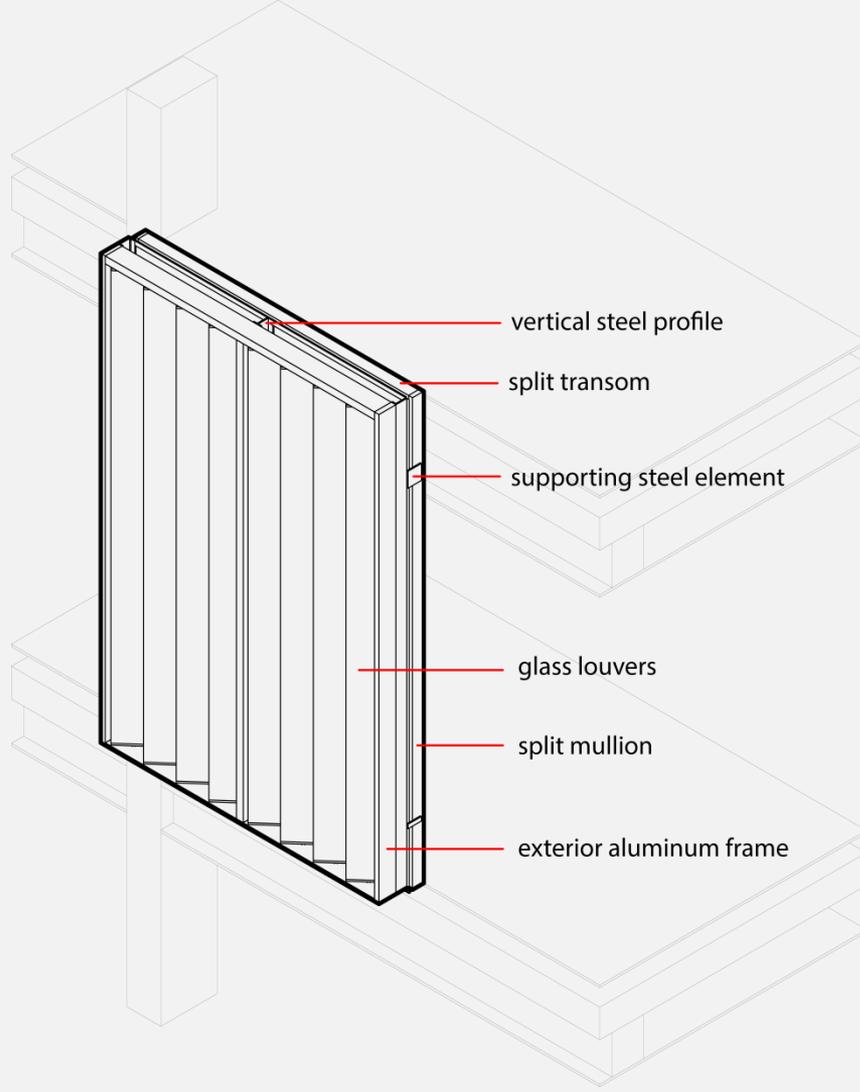
MODULE R1 – Vertical Rotating Fins



SUMMER
save on cooling



WINTER
save on heating



vertical steel profile

split transom

supporting steel element

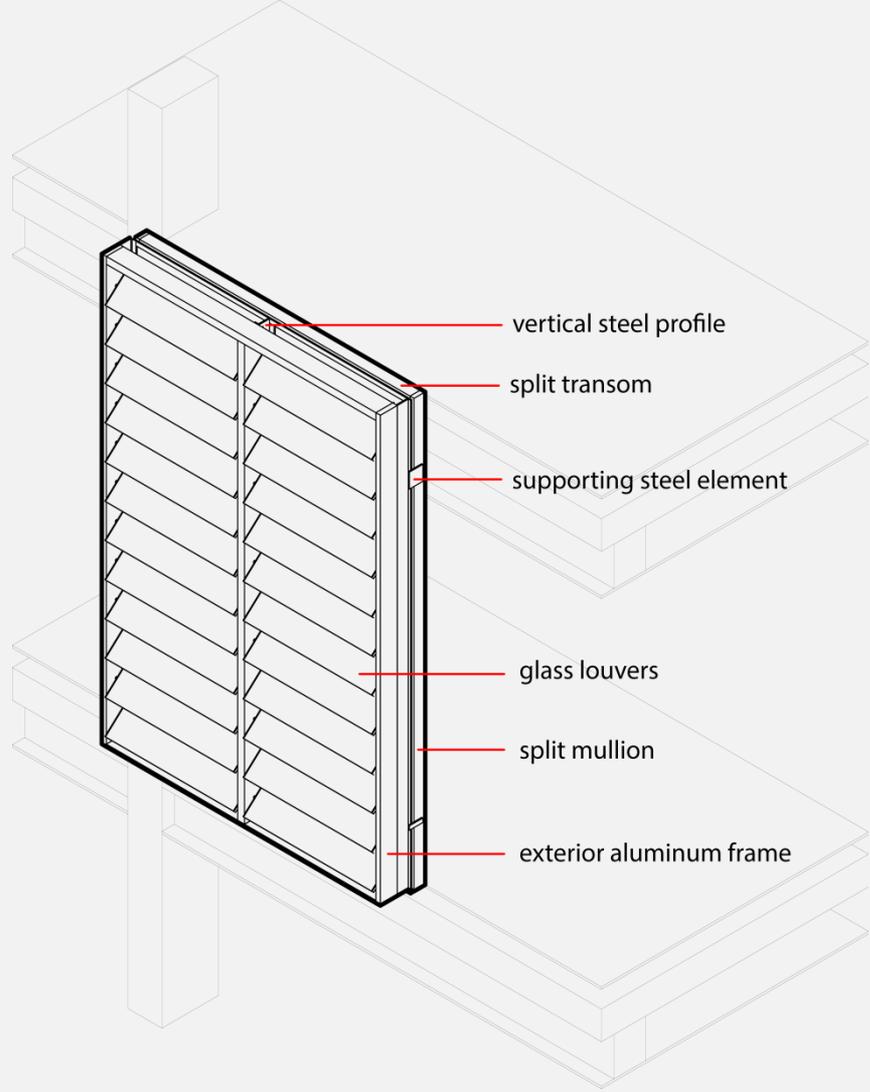
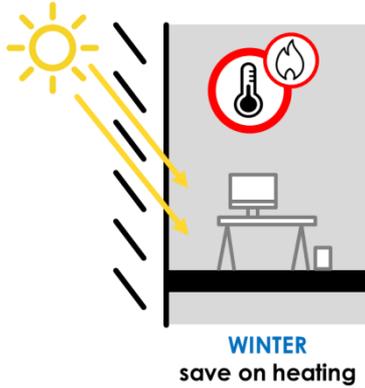
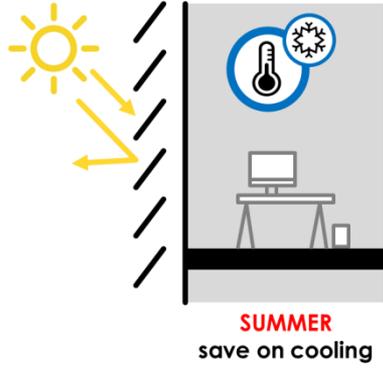
glass louvers

split mullion

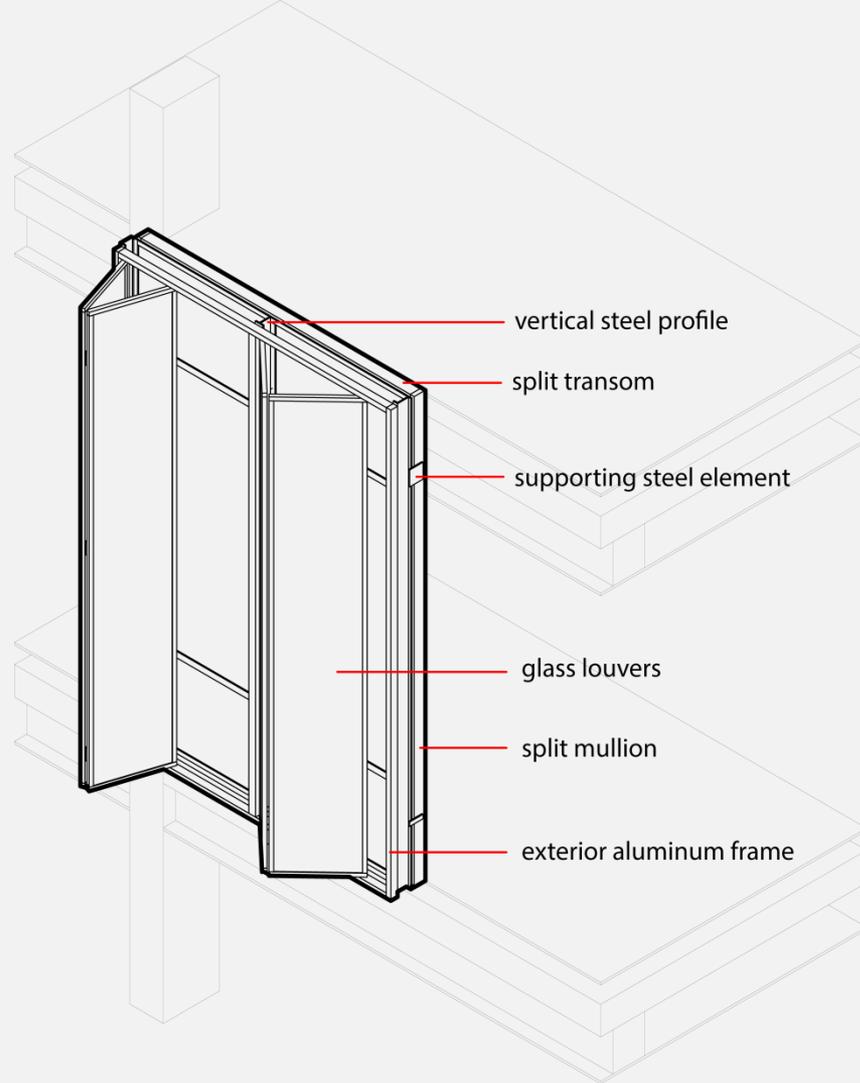
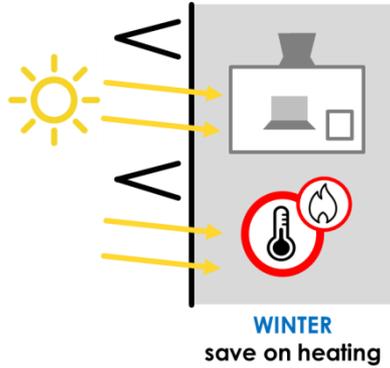
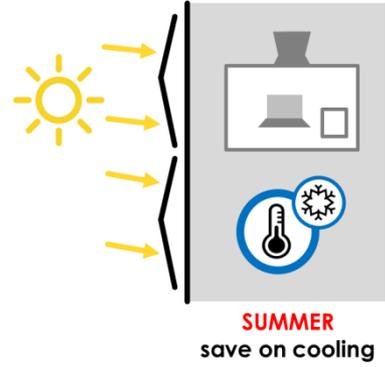
exterior aluminum frame



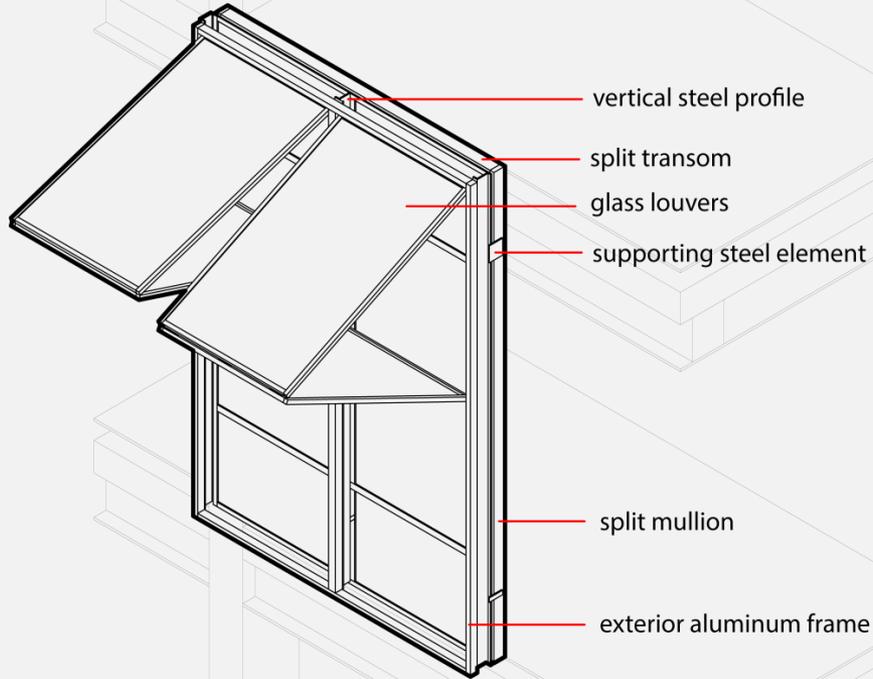
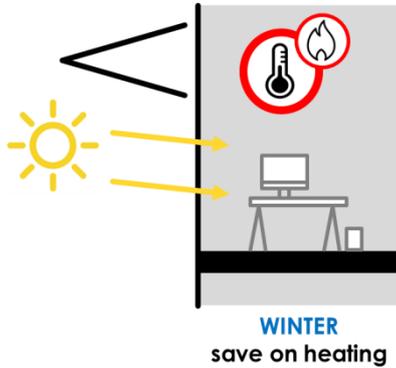
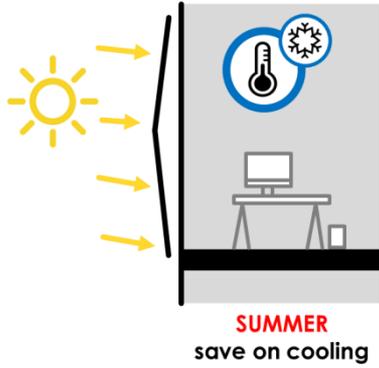
MODULE R2 – Horizontal Rotating Fins



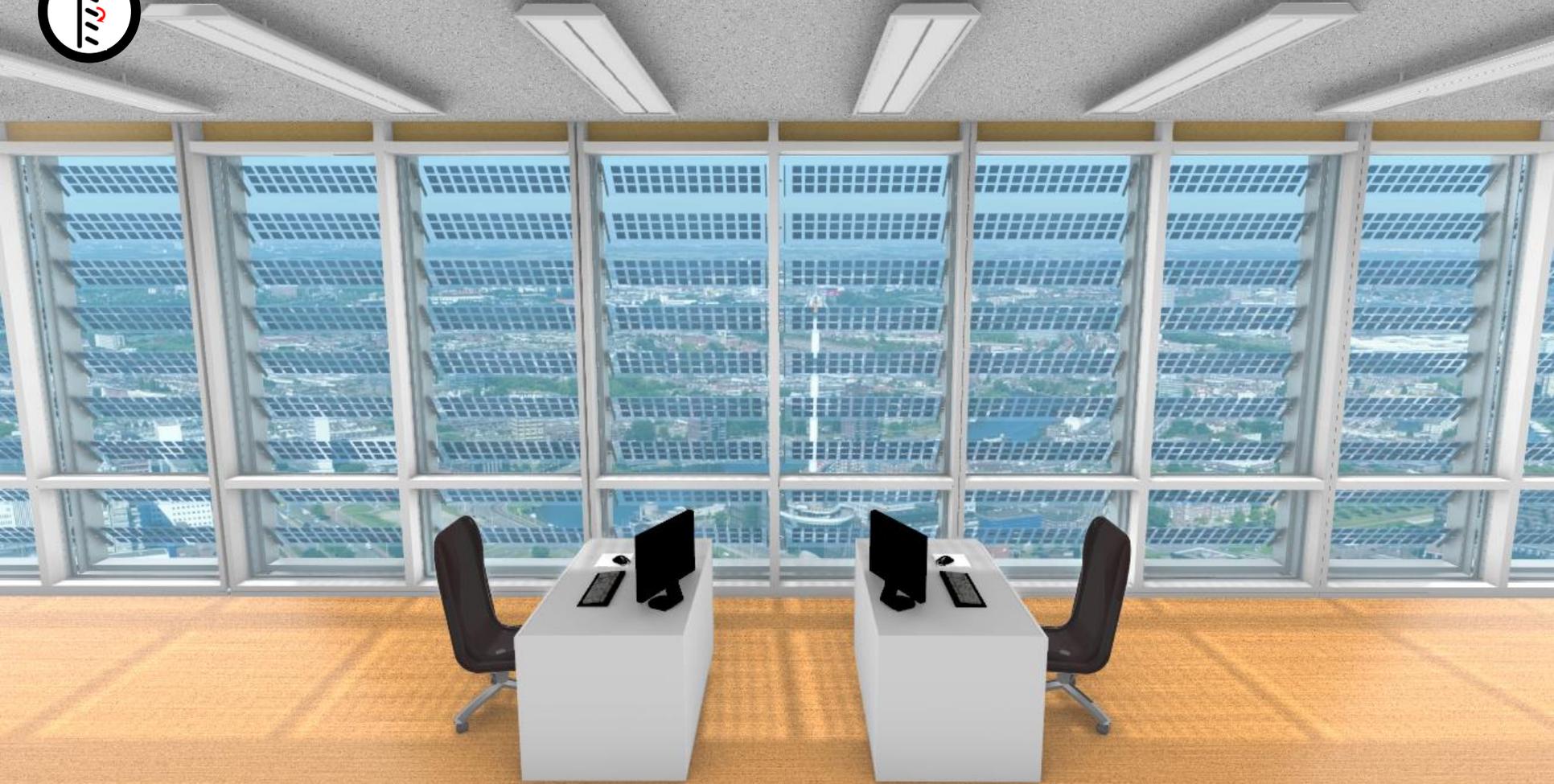
MODULE F1 – Horizontally Folding Panels



MODULE F2 – Vertically Folding Panels



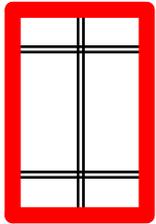
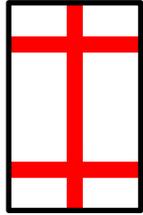








2 materials for mullions and transoms

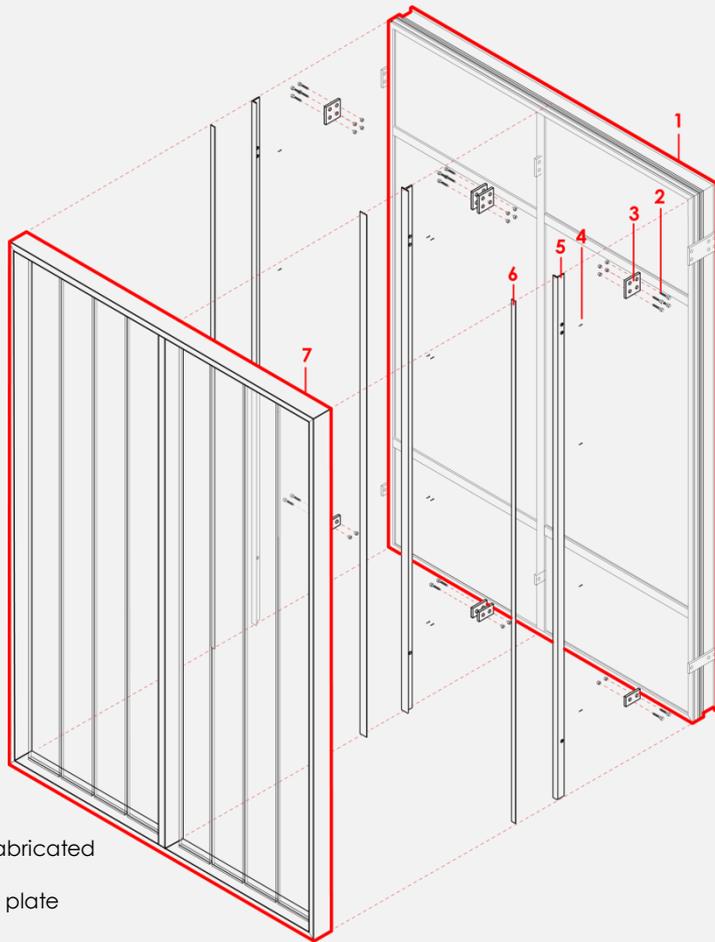


aluminum

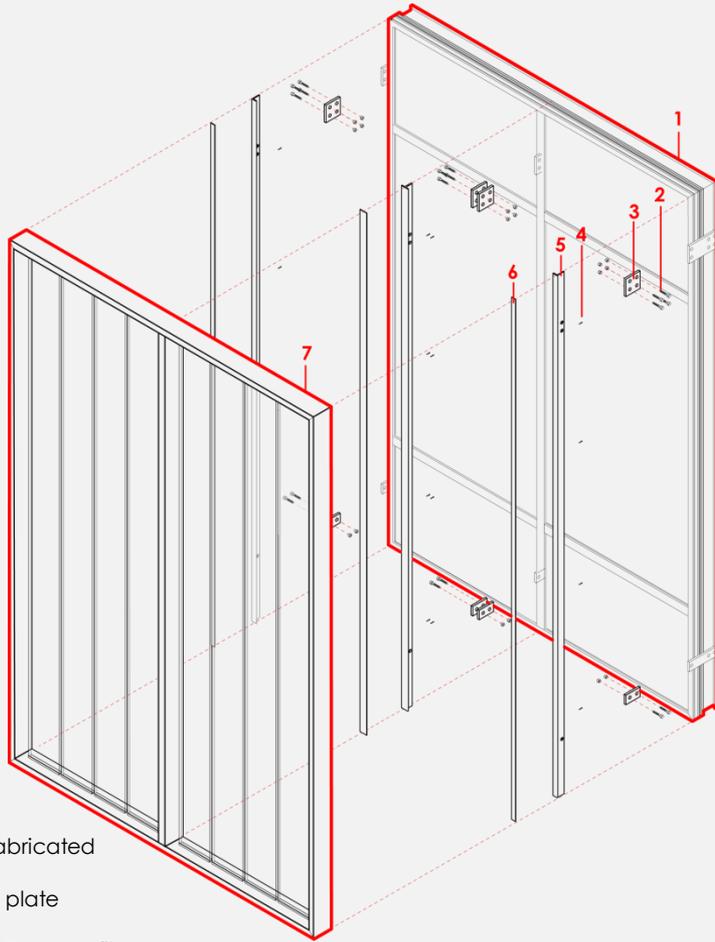


timber



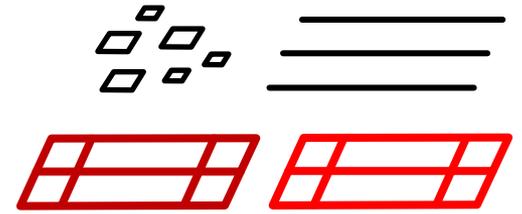


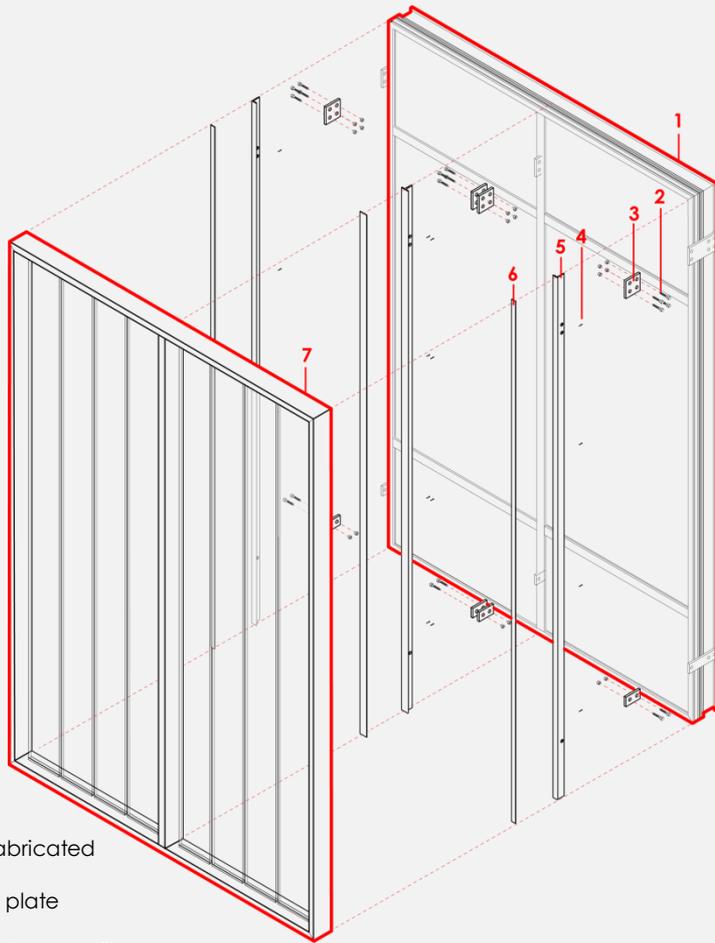
- 1 prefabricated
- 2 bolts
- 3 steel plate
- 4 bolts
- 5 steel T or L profile
- 6 rubber profile
- 7 prefabricated frame including the shading system



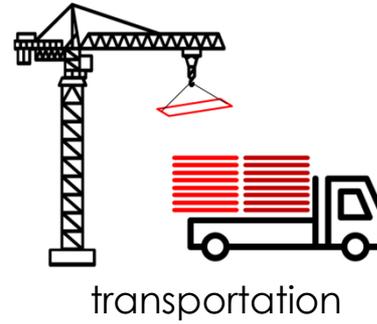
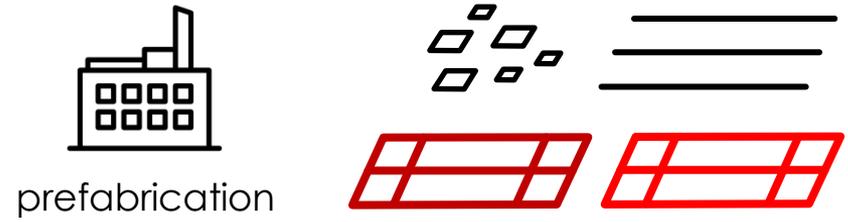
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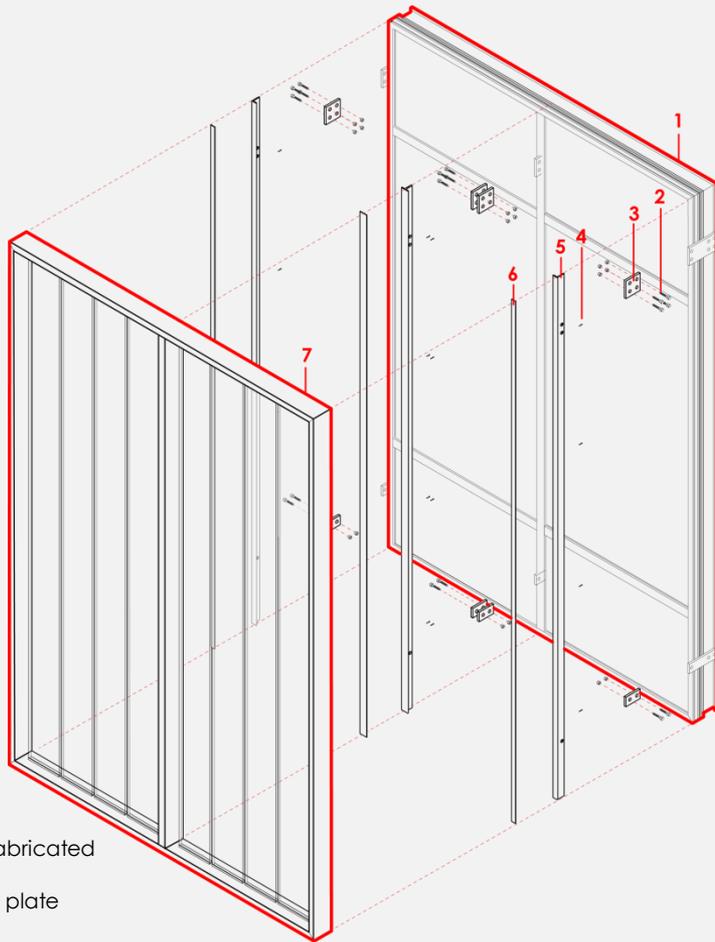

prefabrication





- 1 prefabricated
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- 3 steel plate
- 4 bolts
- 5 steel T or L profile
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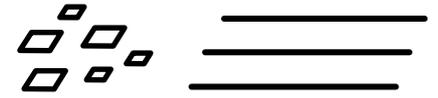




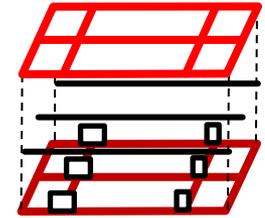
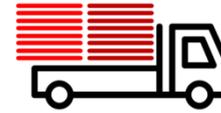
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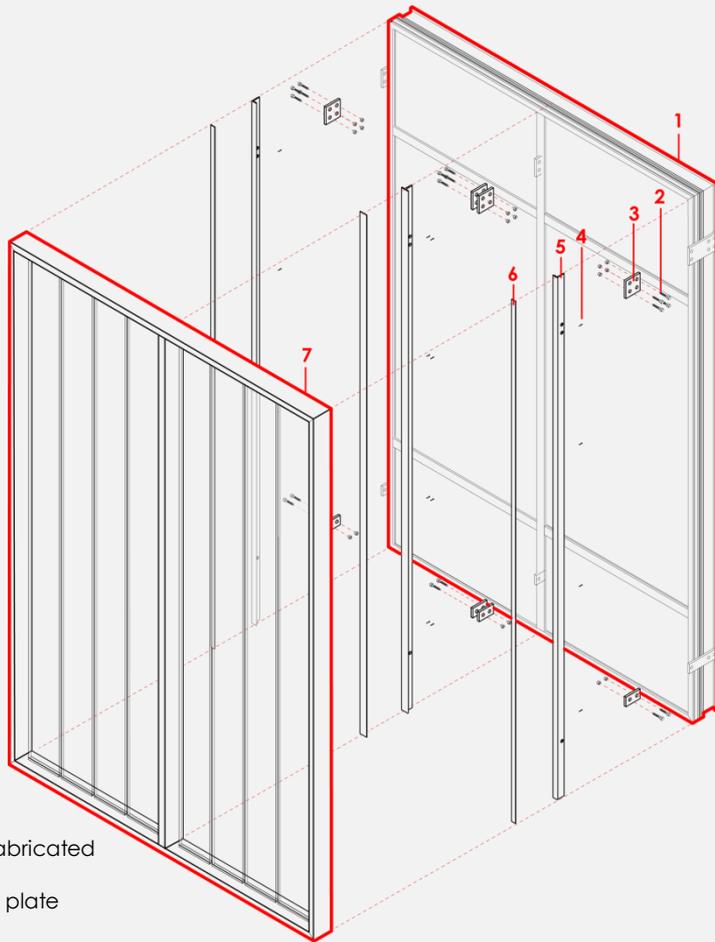
prefabrication



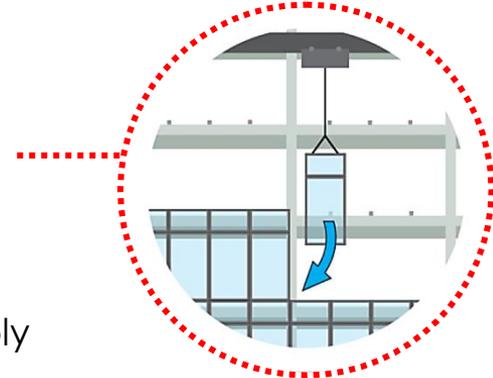
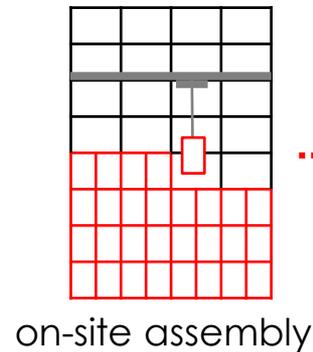
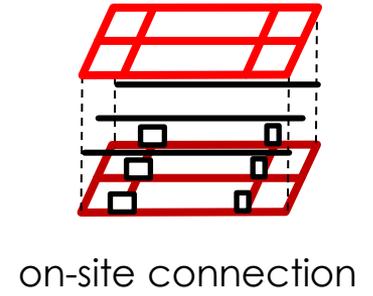
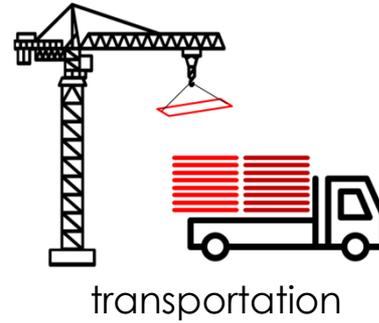
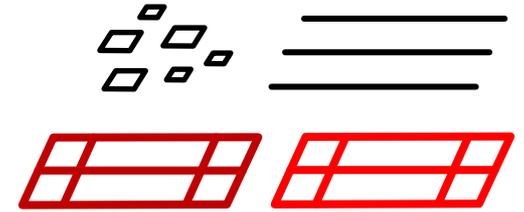
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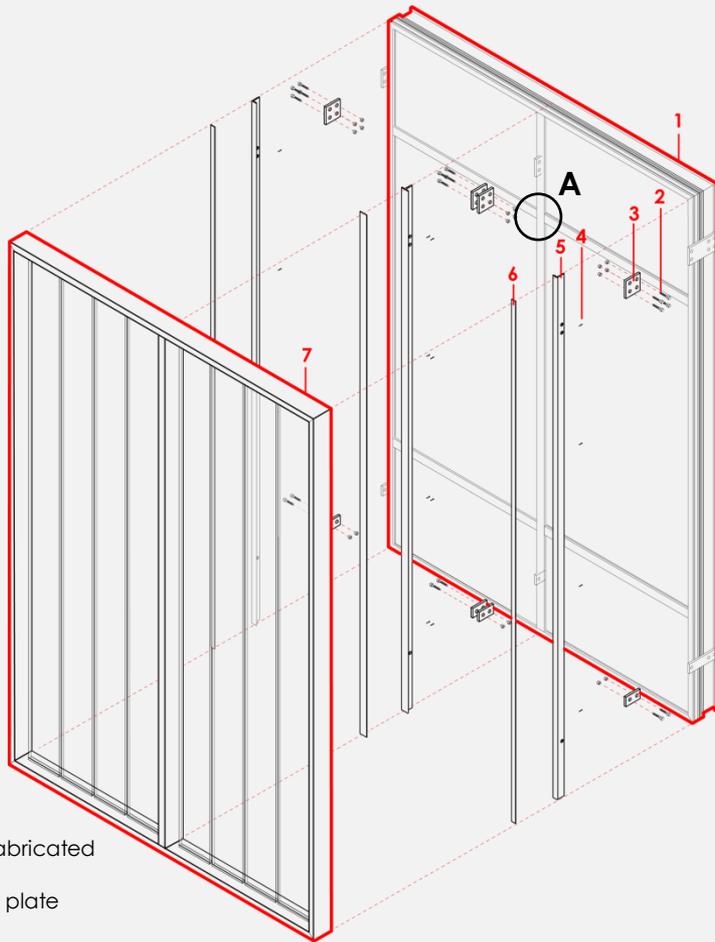


on-site connection

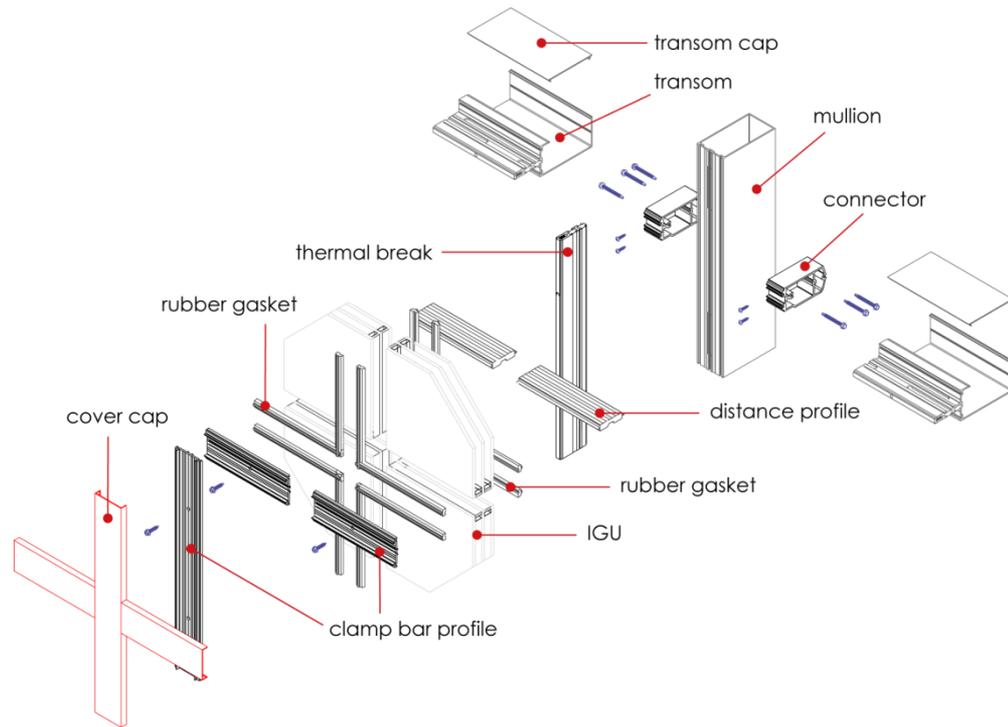


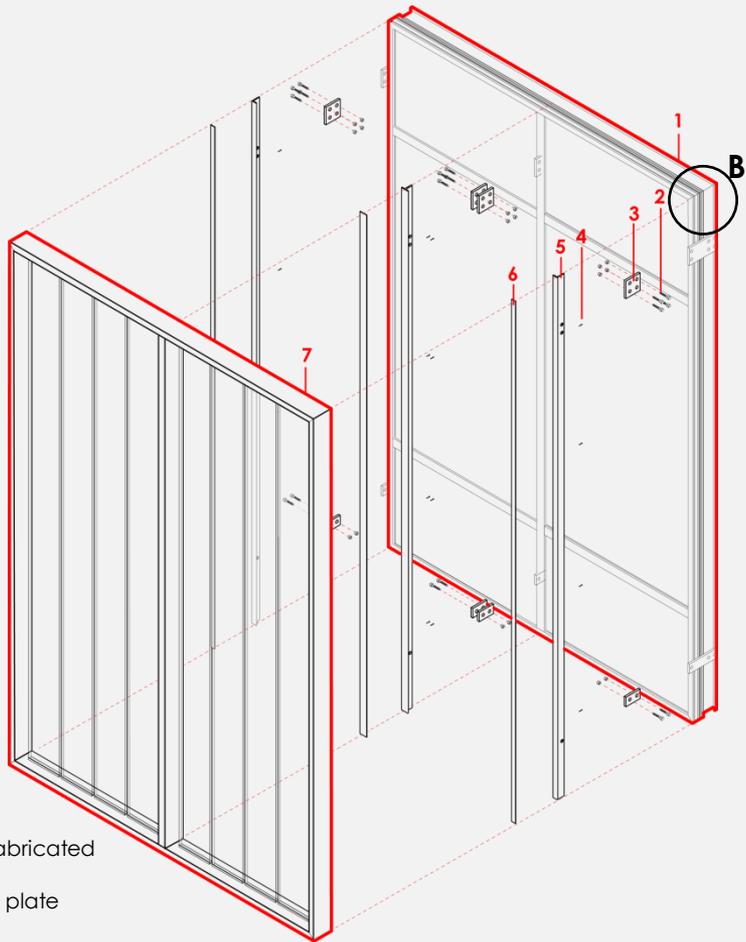
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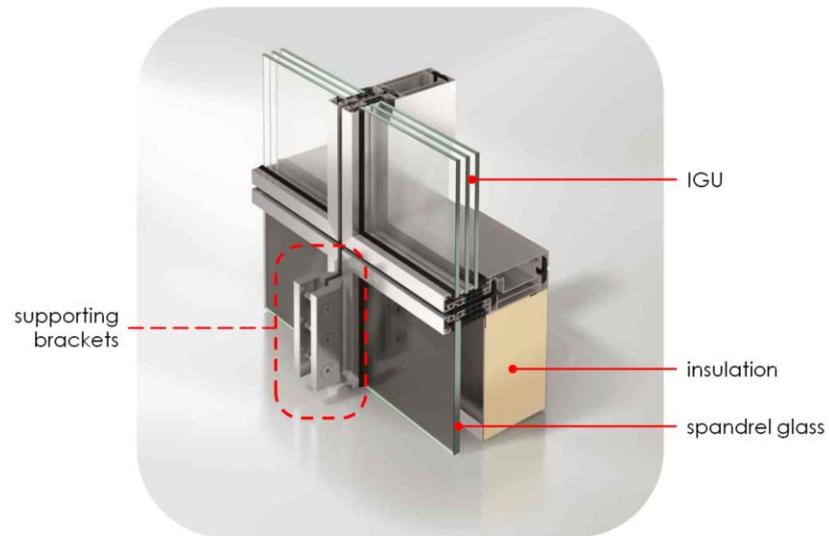


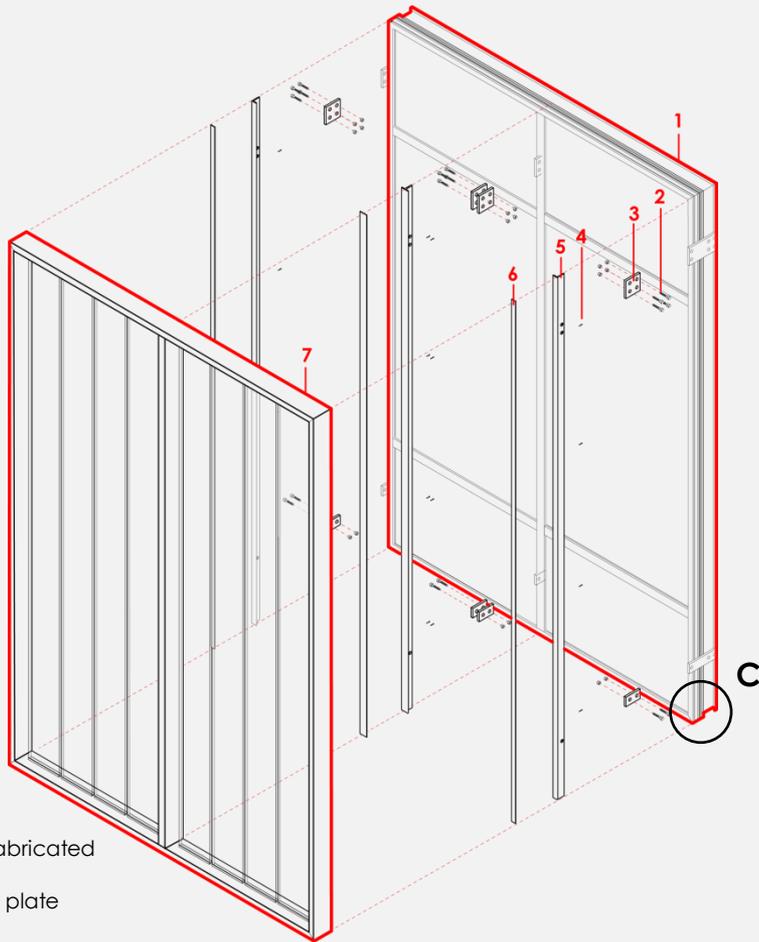
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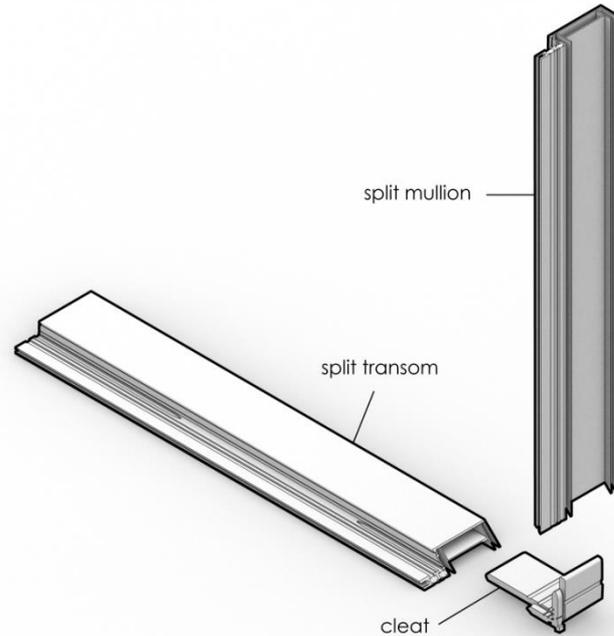


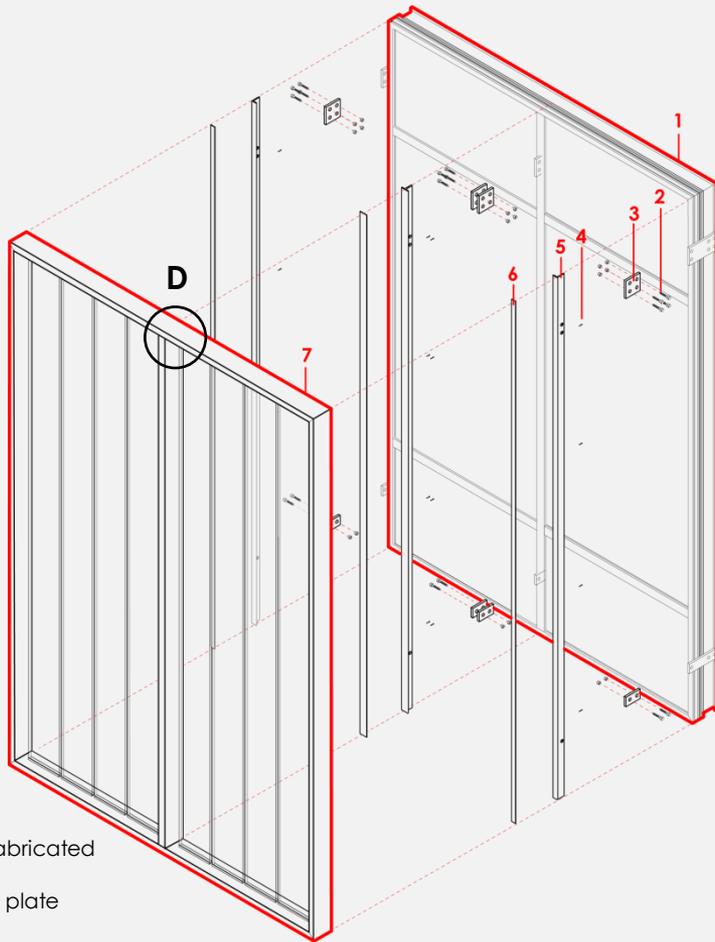
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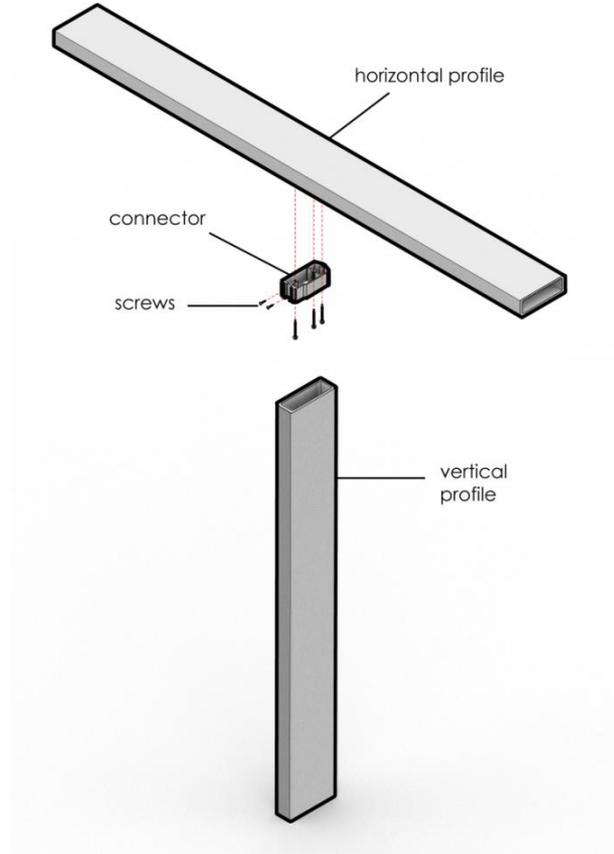


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- 5 steel T or L profile
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the DfD strategy

the 4 adaptive
building envelopes

environmental impact

rating the DfD criteria

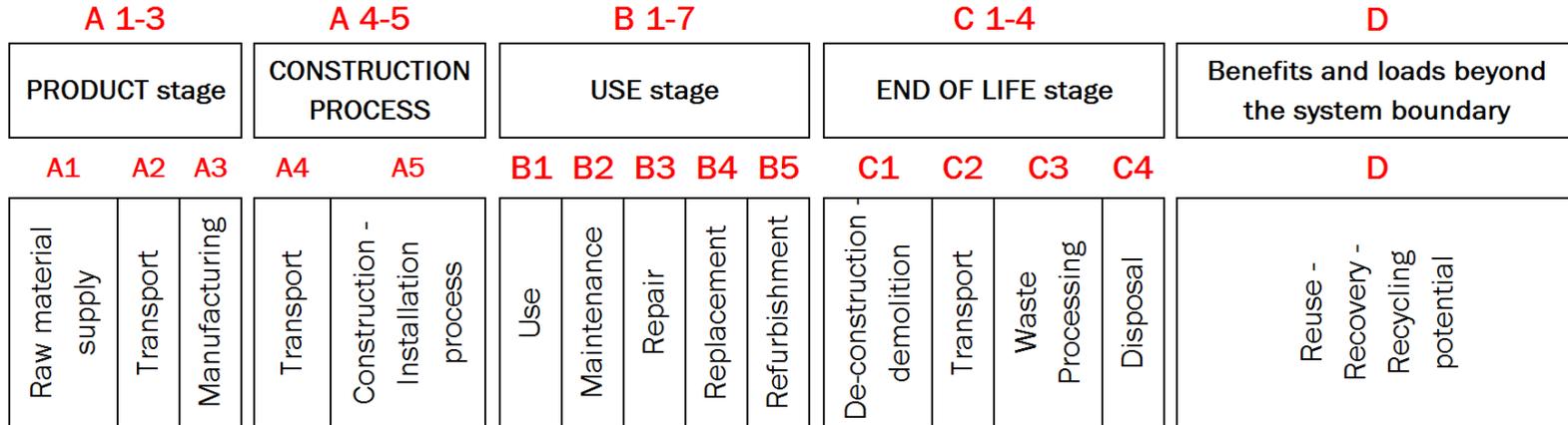
final comparison

conclusions

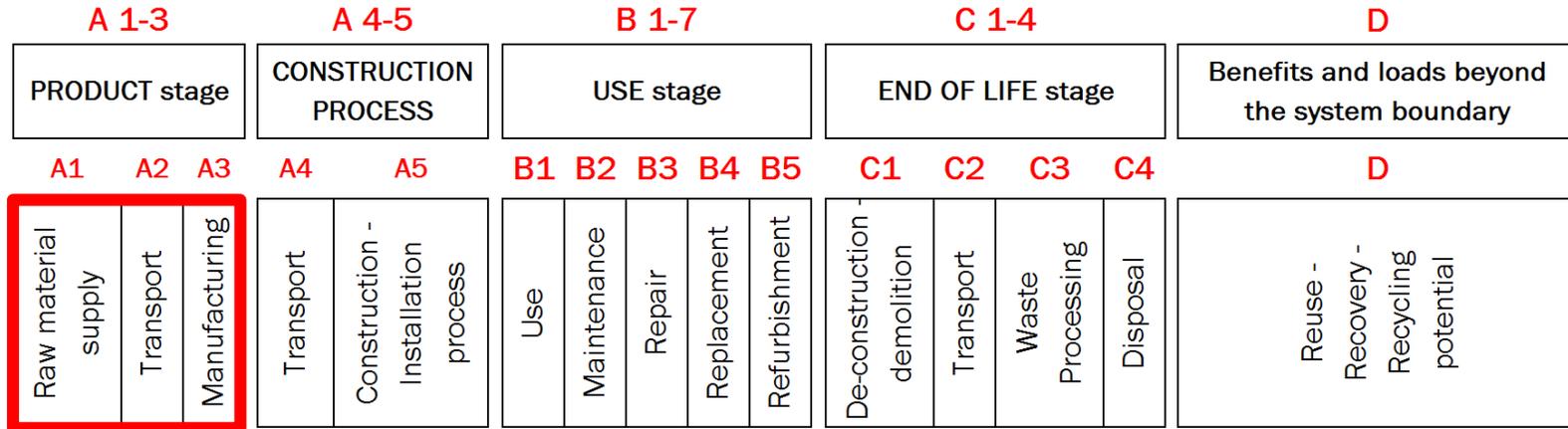


3. ENVIRONMENTAL IMPACT

The Life Cycle stages – EN standards



cradle-to-gate



elements for calculation

ALUMINUM CW									
concept	part of the module	element name	material name	amount nr.	area mm2	height/length mm	volume m3	density kg/m3	weight kg
R1 - A	CW - A	mullion (1)	aluminum	1	1625	3750	0.00609375	2700	16.453125
		transom (2)	aluminum	4	6500	1250	0.008125	2700	21.9375
		split mullion (3)	aluminum	2	2100	3750	0.007875	2700	21.2625
		split transom (4)	aluminum	2	2100	2500	0.00525	2700	14.175
	SHADING	exterior mullion (5)	aluminum	1	1800	3750	0.00675	2700	18.225
		exterior split mullion (6)	aluminum	2	3600	3750	0.0135	2700	36.45
		exterior split transom (7)	aluminum	2	3600	2500	0.009	2700	24.3
R2 - A	CW - A	mullion (1)	aluminum	1	1625	3750	0.00609375	2700	16.453125
		transom (2)	aluminum	4	6500	1250	0.008125	2700	21.9375
		split mullion (3)	aluminum	2	2100	3750	0.007875	2700	21.2625
		split transom (4)	aluminum	2	2100	2500	0.00525	2700	14.175
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		split transom (4)	aluminum	2	2100	2500	0.00525	2700	14.175
	SHADING	exterior mullion (5)	aluminum	1	720	3750	0.0027	2700	7.29
		exterior split mullion (6)	aluminum	2	960	3750	0.0036	2700	9.72
		exterior split transom (7)	aluminum	2	960	2500	0.0024	2700	6.48
F2 - A	CW - A	mullion (1)	aluminum	1	1625	3750	0.00609375	2700	16.453125
		transom (2)	aluminum	4	6500	1250	0.008125	2700	21.9375
		split mullion (3)	aluminum	2	2100	3750	0.007875	2700	21.2625
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		exterior split transom (7)	aluminum	2	960	2500	0.0024	2700	6.48

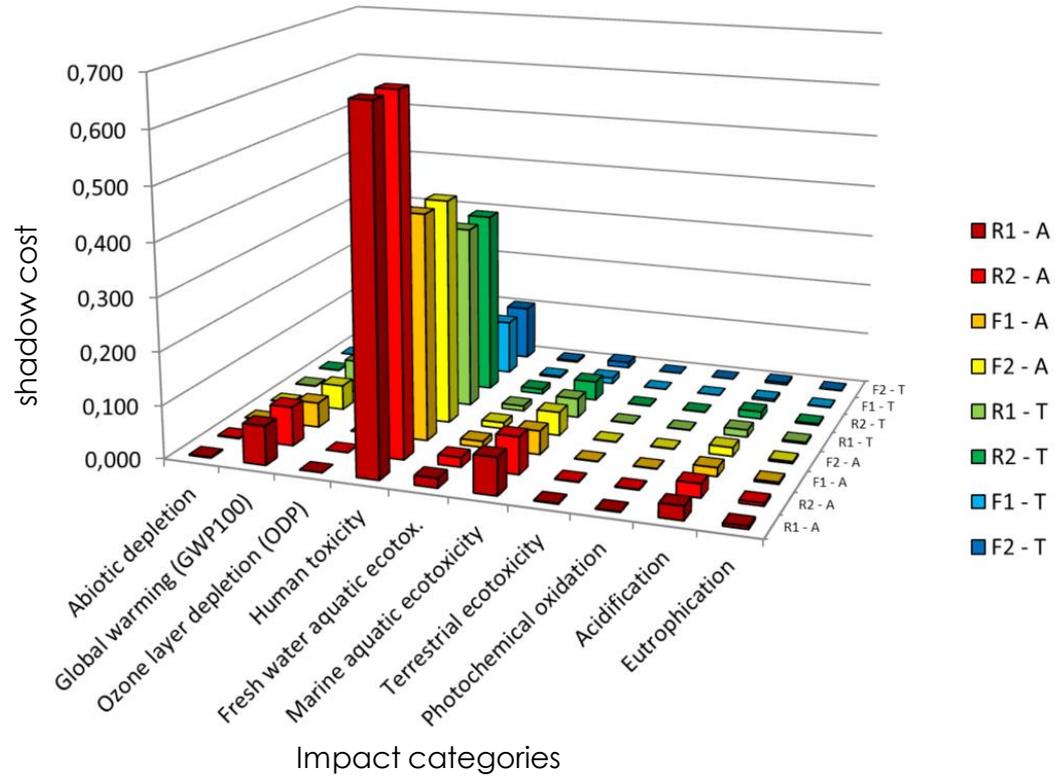
TIMBER CW									
concept	part of the module	element name	material name	amount nr.	area mm2	height/length mm	volume m3	density kg/m3	weight kg
R1 - T	CW - T	mullion (1)	timber	1	8125	3750	0.03046875	380	11.578125
		transom (2)	timber	4	32500	1250	0.040625	380	15.4375
		split mullion (3)	timber	2	7000	3750	0.02625	380	9.975
		split transom (4)	timber	2	7000	2500	0.0175	380	6.65
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		exterior split transom (7)	aluminum	2	960	2500	0.0024	2700	6.48

elements for calculation

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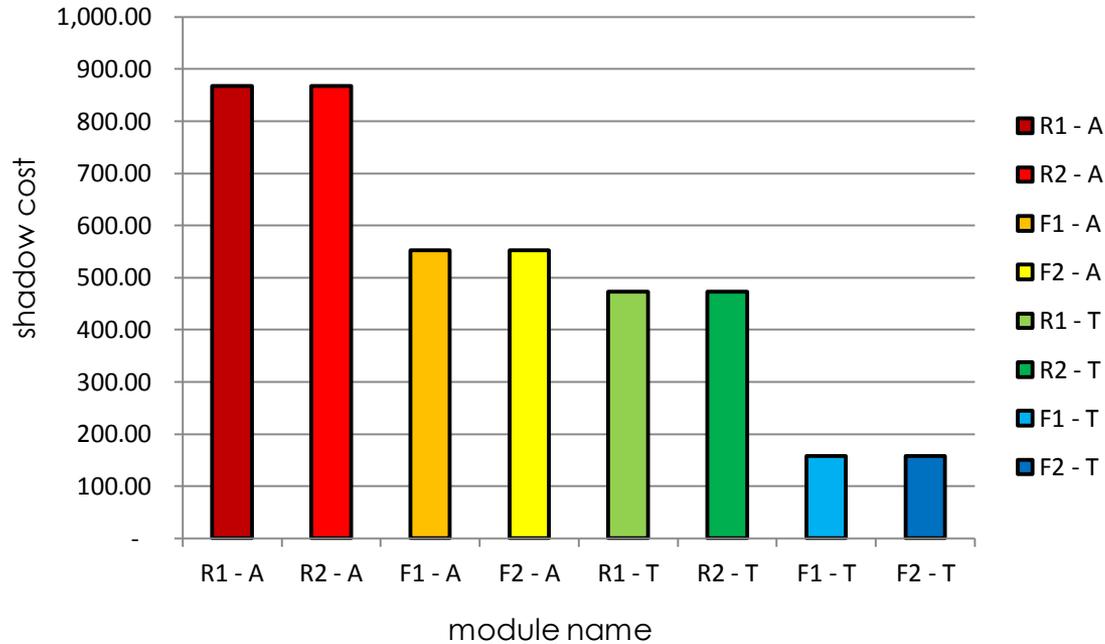
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results



results

TOTAL IMPACT



the DfD strategy

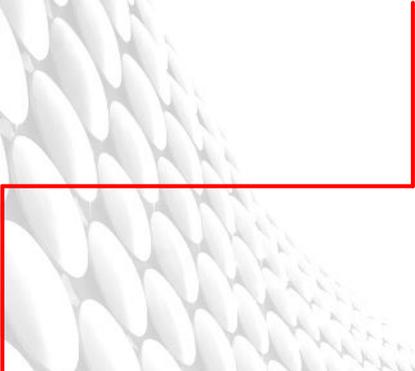
the 4 adaptive
building envelopes

environmental impact

rating the DfD criteria

final comparison

conclusions &
recommendations

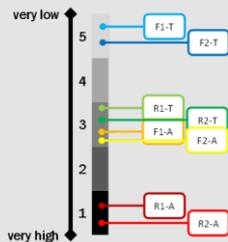


4. RATINGS FOR THE DFD CRITERIA

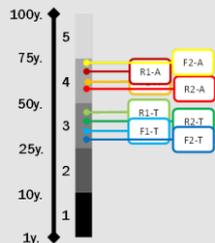
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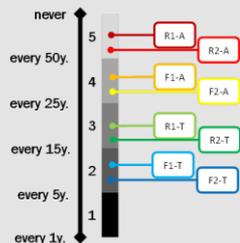
OVERALL IMPACT



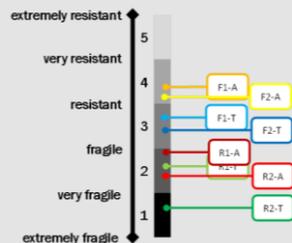
LIFE EXPECTANCY



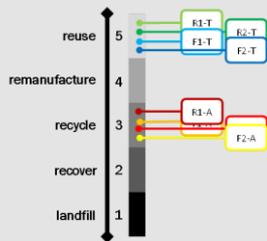
MAINTENANCE



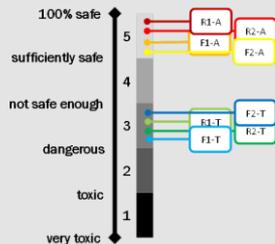
RESISTANCE TO WEAR



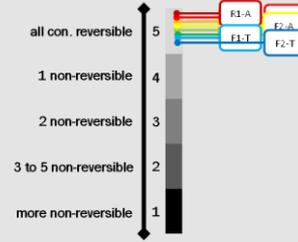
END-OF-LIFE ACTIVITY



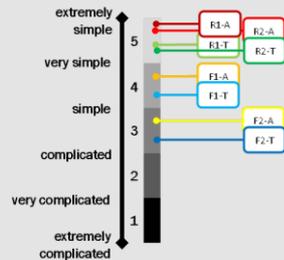
SIDE EFFECTS



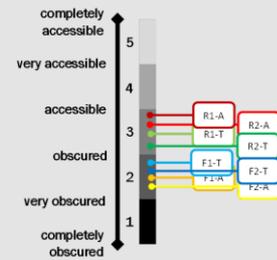
REVERSIBILITY



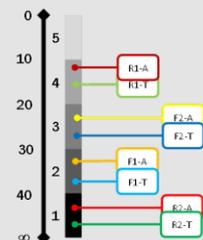
COMPLEXITY



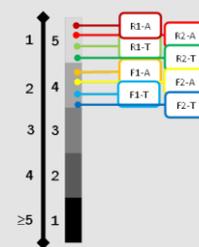
ACCESSIBILITY



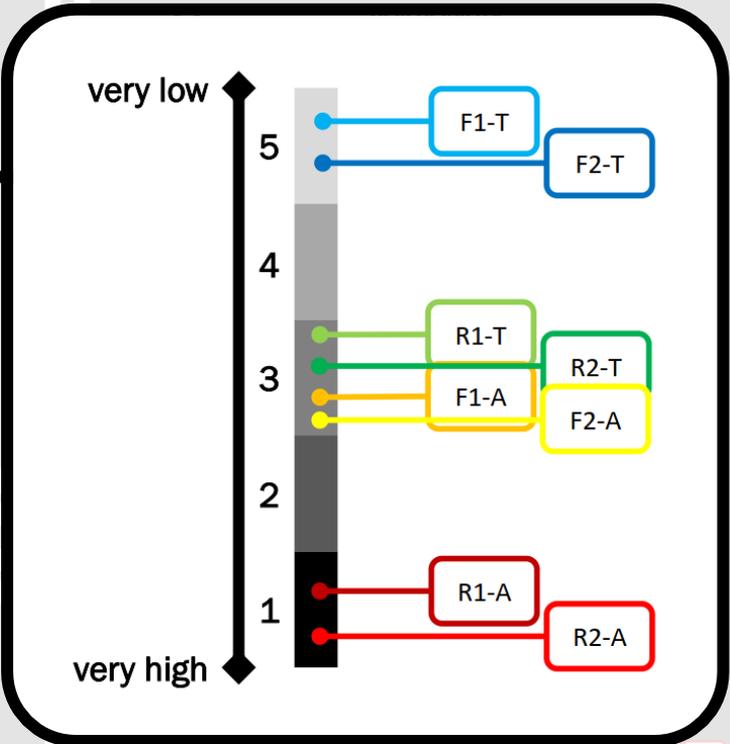
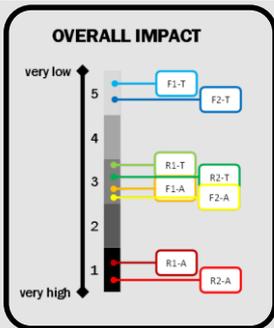
AMOUNT OF CONNECTIONS



TYPES OF CONNECTIONS



overview



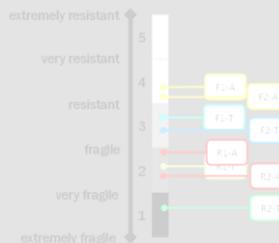
LIFE EXPECTANCY



MAINTENANCE



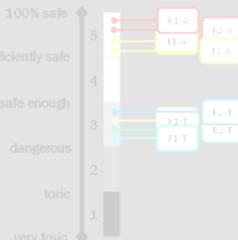
RESISTANCE TO WEAR



END-OF-LIFE ACTIVITY



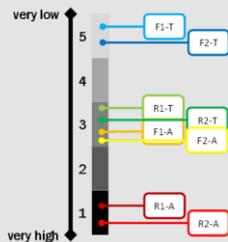
SIDE EFFECTS



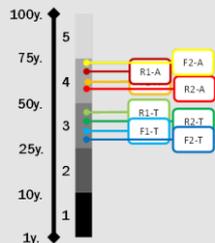
overview



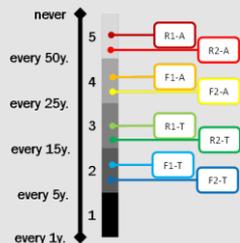
OVERALL IMPACT



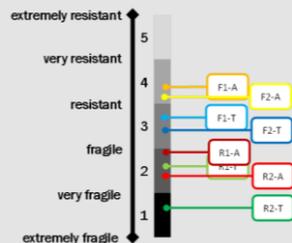
LIFE EXPECTANCY



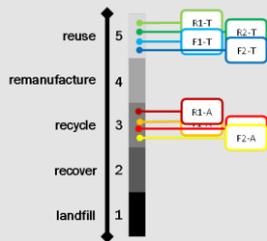
MAINTENANCE



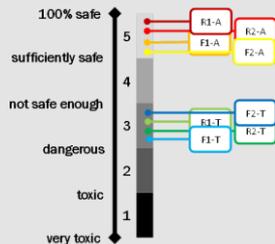
RESISTANCE TO WEAR



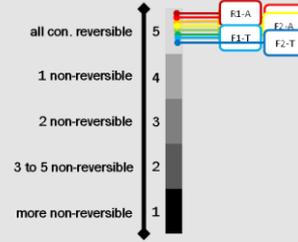
END-OF-LIFE ACTIVITY



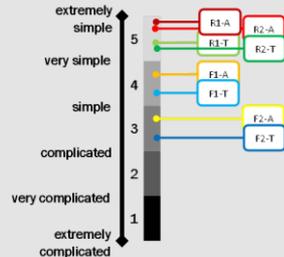
SIDE EFFECTS



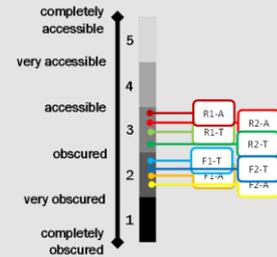
REVERSIBILITY



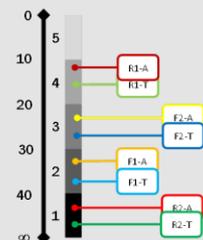
COMPLEXITY



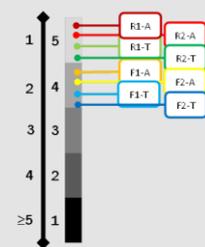
ACCESSIBILITY

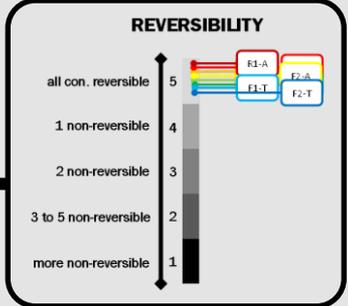
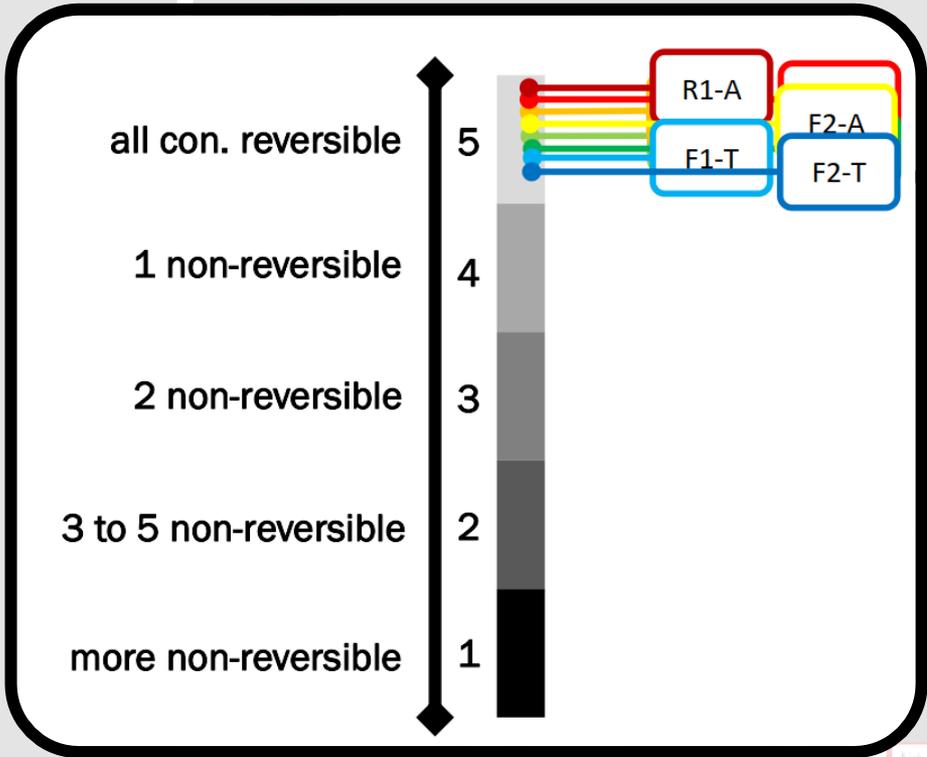


AMOUNT OF CONNECTIONS



TYPES OF CONNECTIONS

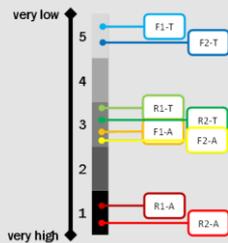




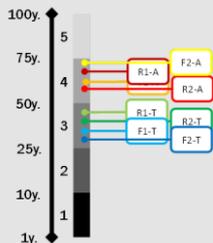
overview



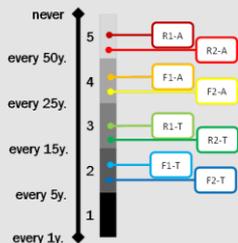
OVERALL IMPACT



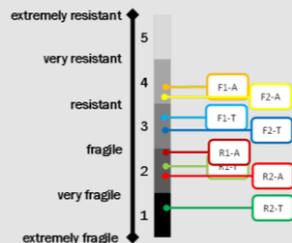
LIFE EXPECTANCY



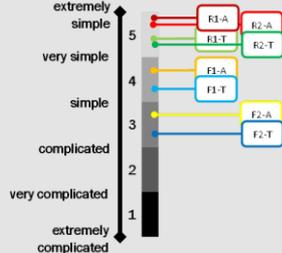
MAINTENANCE



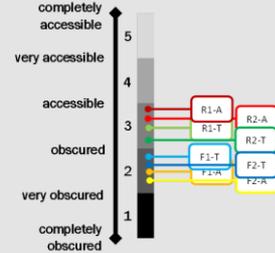
RESISTANCE TO WEAR



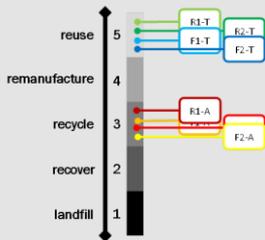
COMPLEXITY



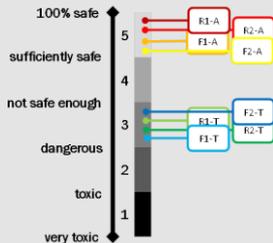
ACCESSIBILITY



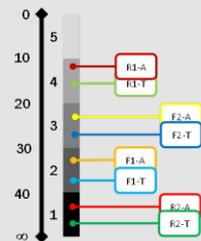
END-OF-LIFE ACTIVITY



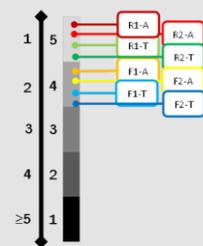
SIDE EFFECTS



AMOUNT OF CONNECTIONS



TYPES OF CONNECTIONS



the DfD strategy

the 4 adaptive
building envelopes

environmental impact

rating the DfD criteria

final comparison

conclusions &
recommendations



5. FINAL COMPARISON

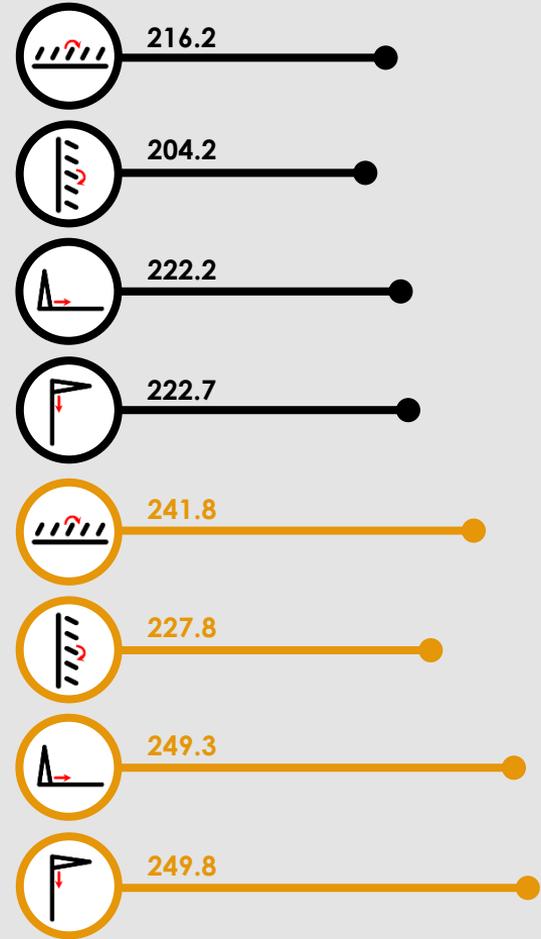
	1. env. impact	2. durability of the components			3. recycle/reuse potential		4. reversibility of con.	5. ease of (dis)assembly		6. speed of disassembly	
	OVERALL IMPACT	LIFE EXPECT.	MAINTENANCE	RES. TO WEAR	END-OF-LIFE ACTIVITY	SIDE EFFECTS	REVERSIBILITY	COMPLEXITY	ACCESSIBILITY	AMOUNT OF CON.	TYPES OF CON.
R1-A	1	4	5	2	3	5	5	5	3	4	5
R2-A	1	4	5	2	3	5	5	5	3	1	5
F1-A	3	4	4	4	3	5	5	4	2	2	4
F2-A	3	4	4	4	3	5	5	3	2	3	4
R1-T	3	3	3	2	5	3	5	5	3	4	5
R2-T	3	3	3	1	5	3	5	5	3	1	5
F1-T	5	3	2	3	5	3	5	4	3	2	4
F2-T	5	3	2	3	5	3	5	3	3	3	4



	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
R1-A	1	3.8	3.4	5	4	4.2
R2-A	1	3.8	3.4	5	4	1.8
F1-A	3	4	3.4	5	3	2.4
F2-A	3	4	3.4	5	2.5	3.2
R1-T	3	2.8	4.6	5	4	4.2
R2-T	3	2.6	4.6	5	4	1.8
F1-T	5	2.8	4.6	5	3.5	2.4
F2-T	5	2.8	4.6	5	3	3.2



final ratings



the DfD strategy

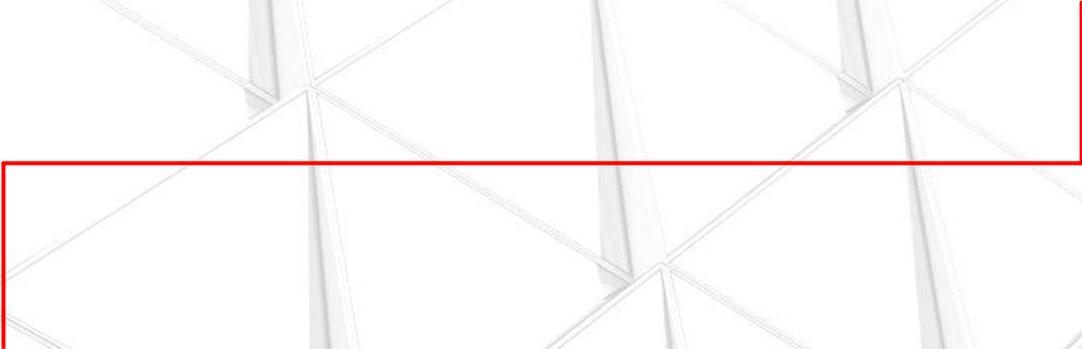
the 4 adaptive
building envelopes

environmental impact

rating the DfD criteria

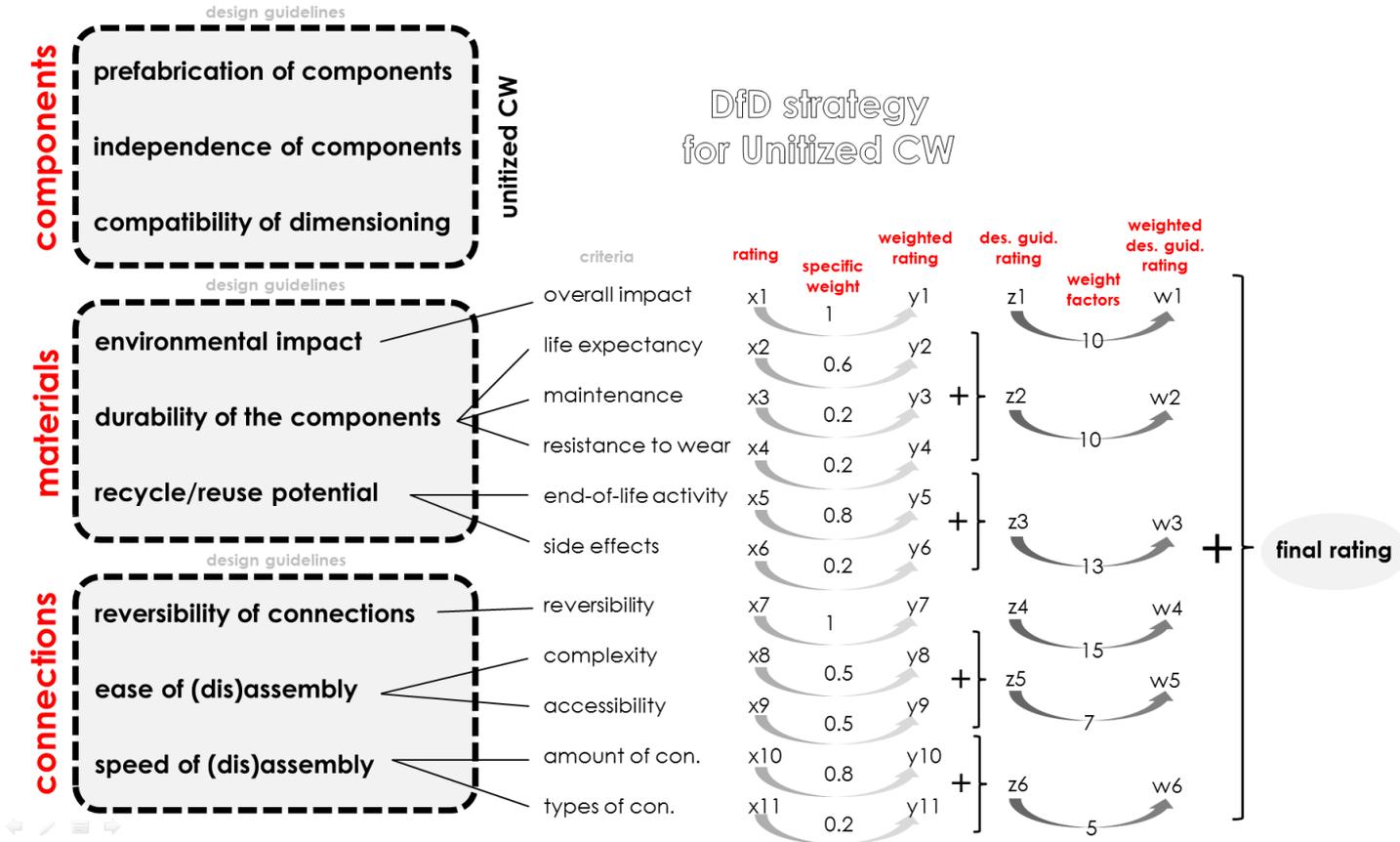
final comparison

conclusions &
recommendations

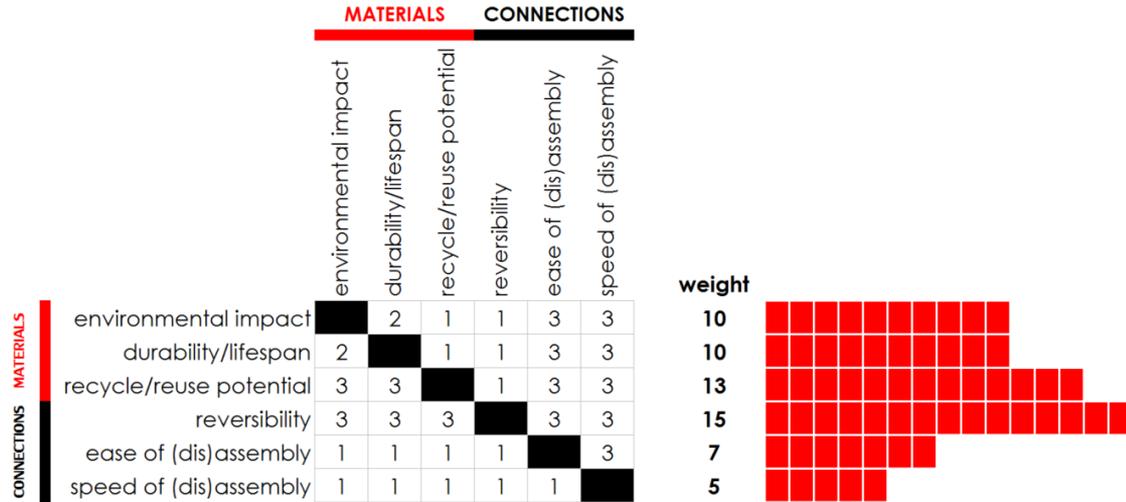


6. CONCLUSIONS & RECOMMENDATIONS

- a strategy was formed to aid DfD in unitized systems

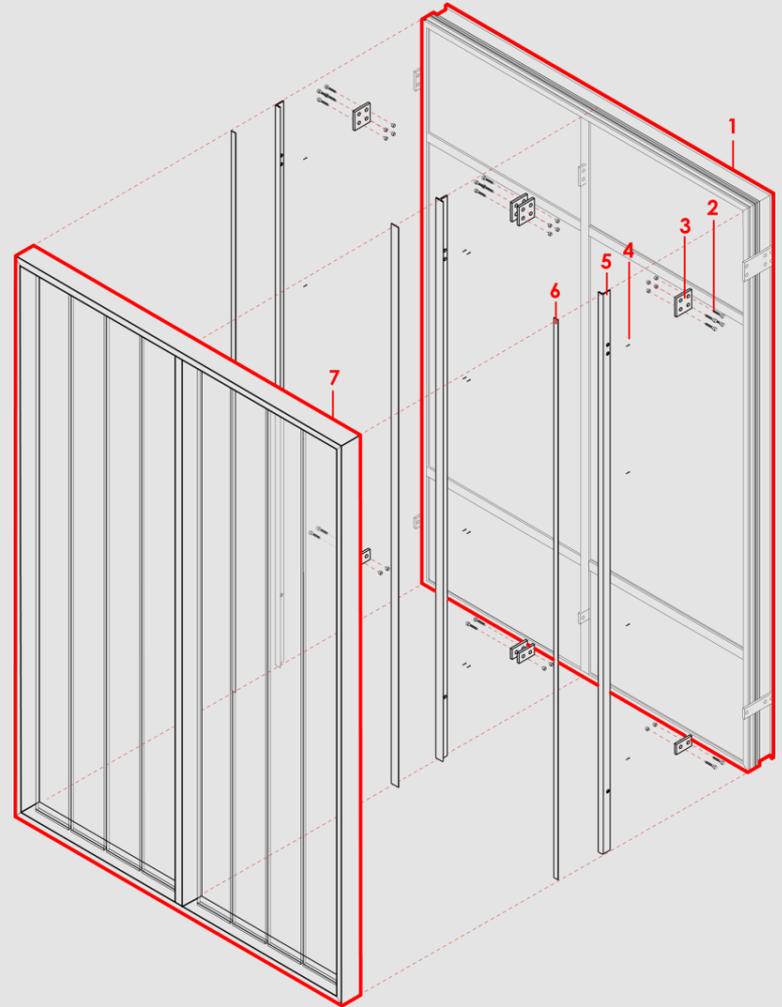


- a strategy was formed to aid DfD in unitized systems
- weight factors were applied according to importance



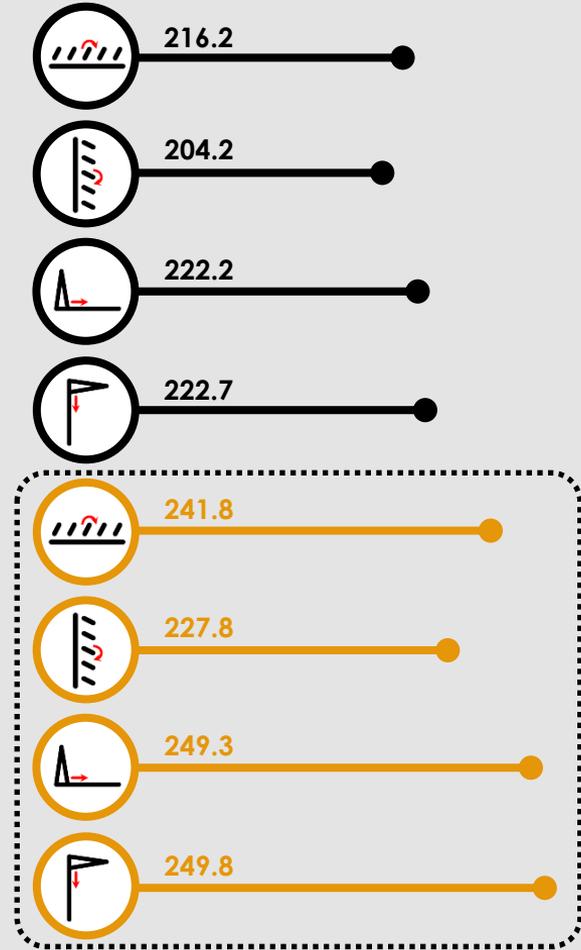
- 1: the assessed criterion is of less importance than the one compared to
- 2: the assessed criterion is of about equal importance to the one compared
- 3: the assessed criterion is of more importance than the one compared to

- a strategy was formed to aid DfD in unitized systems
- weight factors were applied according to importance
- demountable design for unitized & adaptive CW



- 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

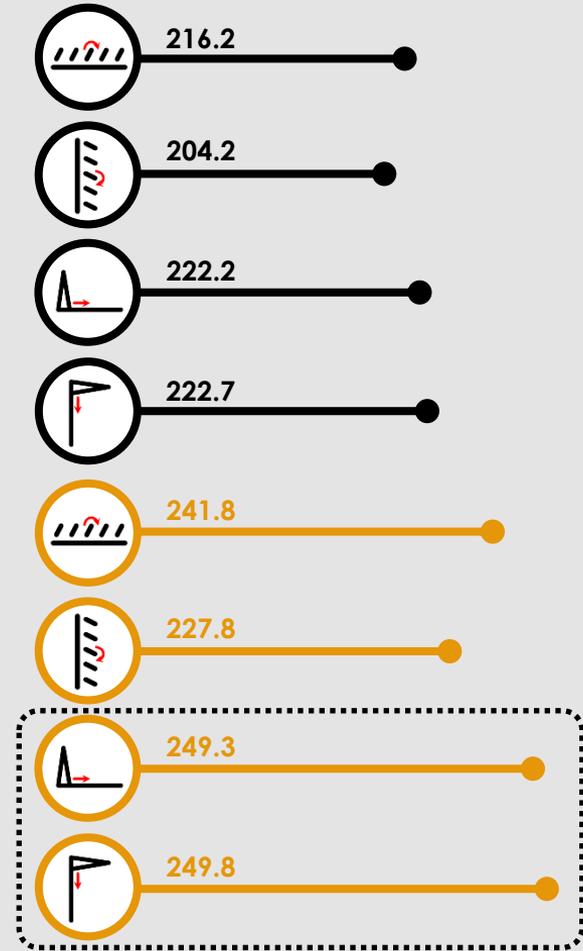
final ratings



- 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



final ratings



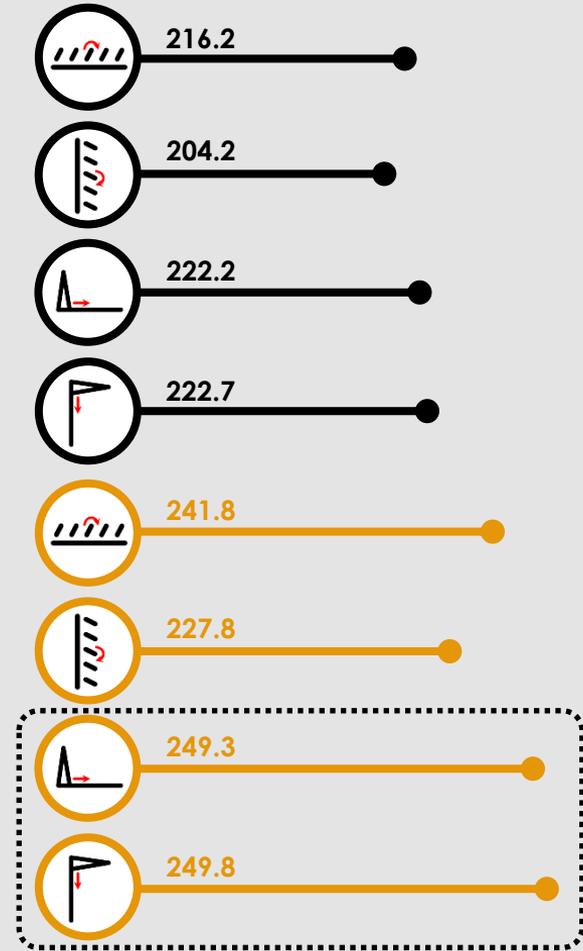
- a strategy was formed to aid DfD in unitized systems
- weight factors were applied according to importance
- demountable design for unitized & adaptive CW
- timber-framed modules perform better for DfD
- top performing modules



- other considerations which are also very crucial during the design phase, such as:

- ⚡ energy performance
- 💰 life cycle costs
- 😊 user comfort
- 🖼️ aesthetics
- 🔧 maintenance

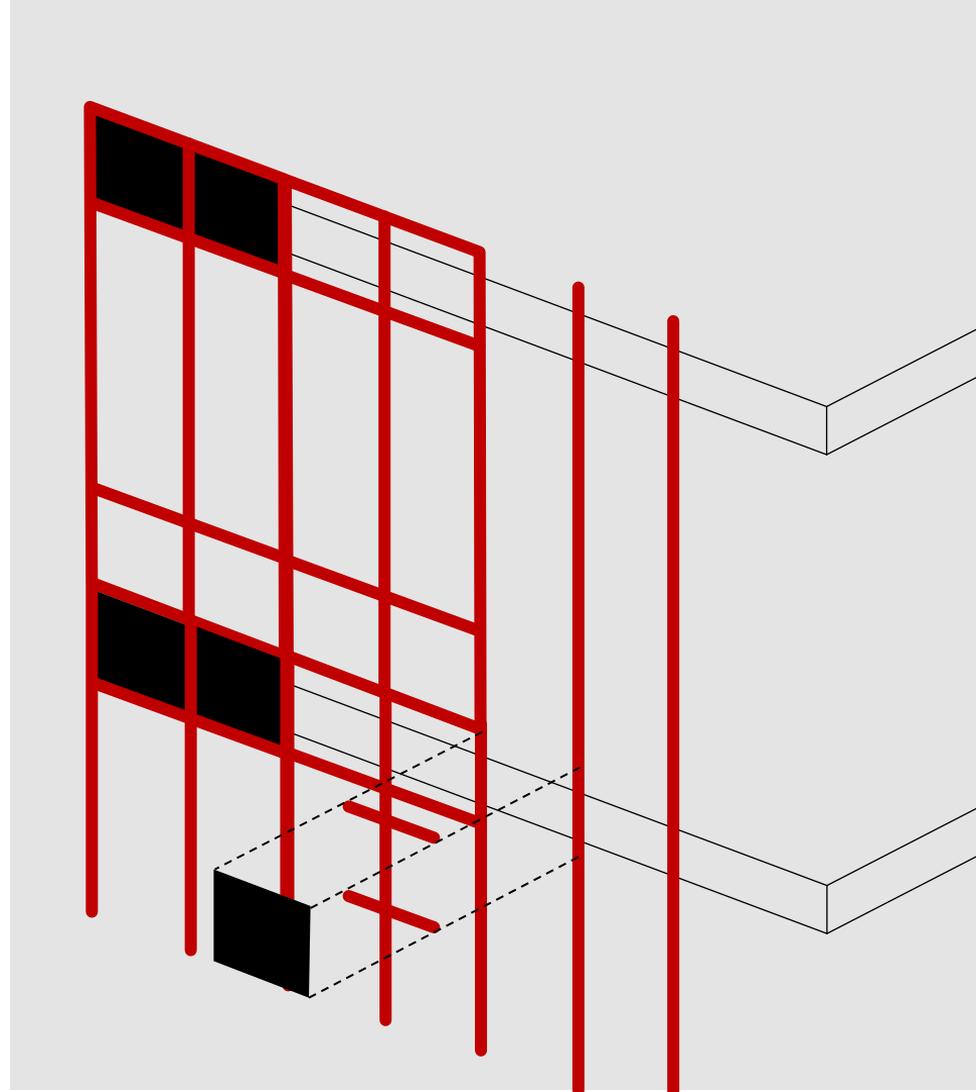
final ratings



RECOMMENDATIONS

- development of a DfD strategy for the **stick system** in curtain walls

usually used in smaller projects

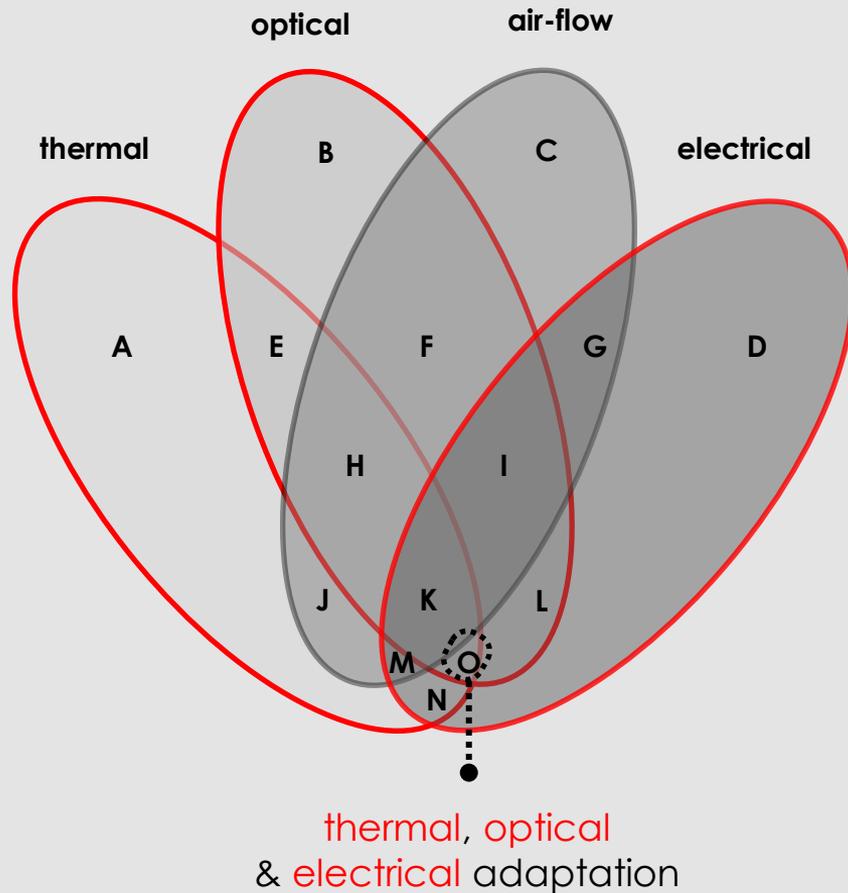


- development of a DfD strategy for the **stick system** in curtain walls

usually used in smaller projects

- simulations for **energy performance**

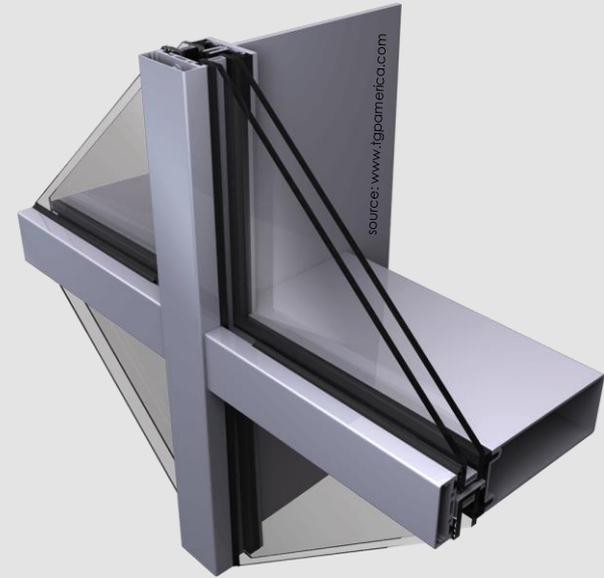
- development of a DfD strategy for the **stick system** in curtain walls
 - usually used in smaller projects
- simulations for **energy performance**
- application on other **adaptive** concepts or **static**



- 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

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

customized profiles



- 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

A modern office interior with two white desks, each with a black office chair and a computer monitor. The desks are positioned in front of a large window that offers a panoramic view of a city. The ceiling features several recessed fluorescent light fixtures. The floor is covered with a light-colored, textured carpet.

QUESTIONS?