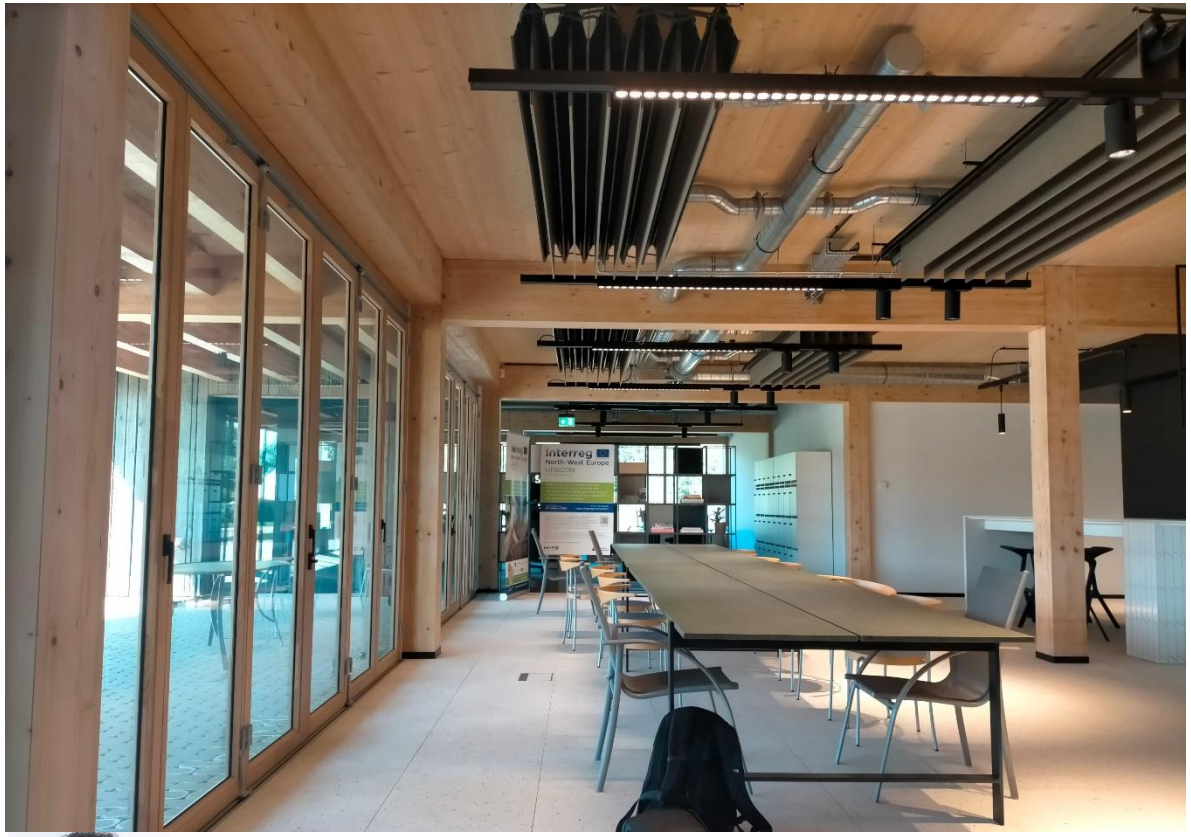
Decision Support for Circularity in Office Building Design



Prof. Dr. Shady Attia
Sustainable Building Design Lab, UEE,
Applied Sciences, University of Liège, Belgium
shady.attia@uliege.be

/in/shady-attia-14352a7
/www.shadyattia.org

LIÈGE université
SBD Lab

Outline

How to design, build and operate circular buildings?

1. **Circularity Definition** (EN pren17980)
2. **Circularity Principles** (EN pren17980)
3. **Multi-objective approach with multiple KPI**

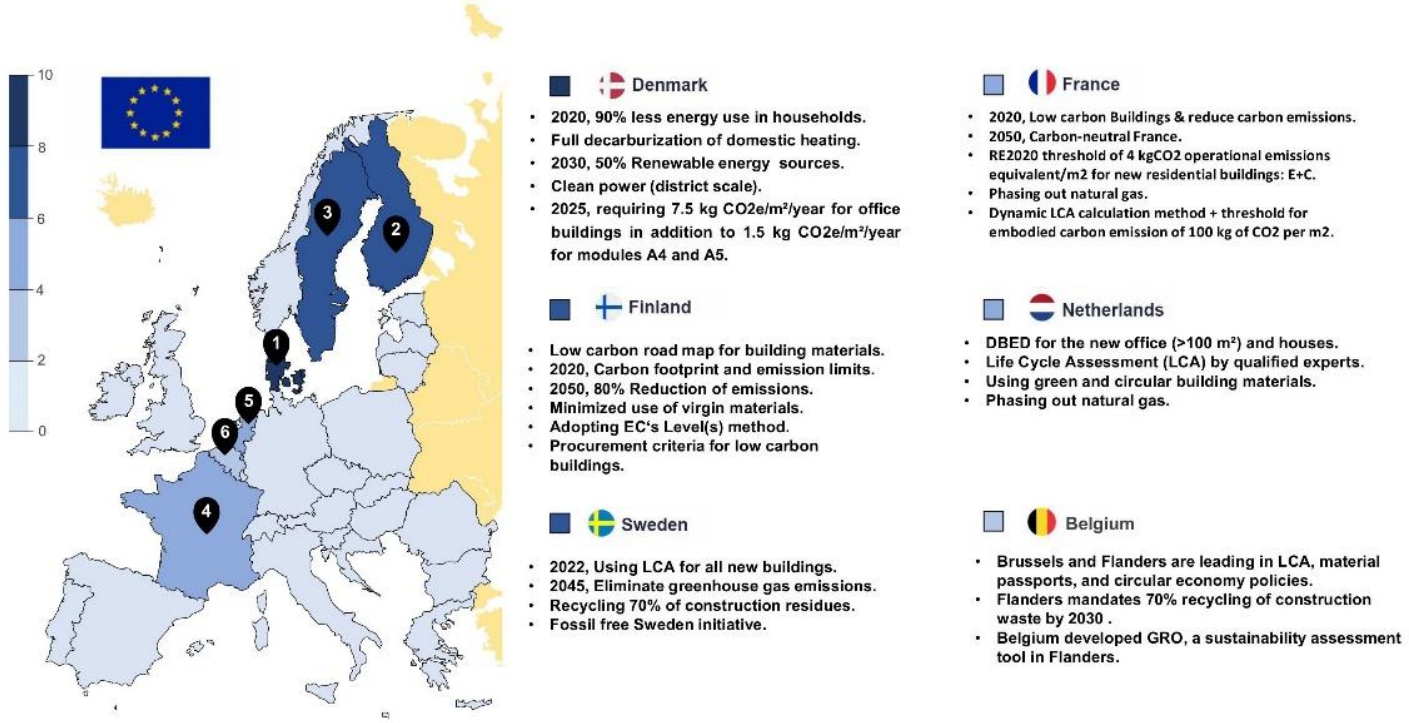


Figure 1.2. Ranking of EU leading member states that couple carbon neutrality and circularity requirements for new constructions

LIÈGE université SBD Lab

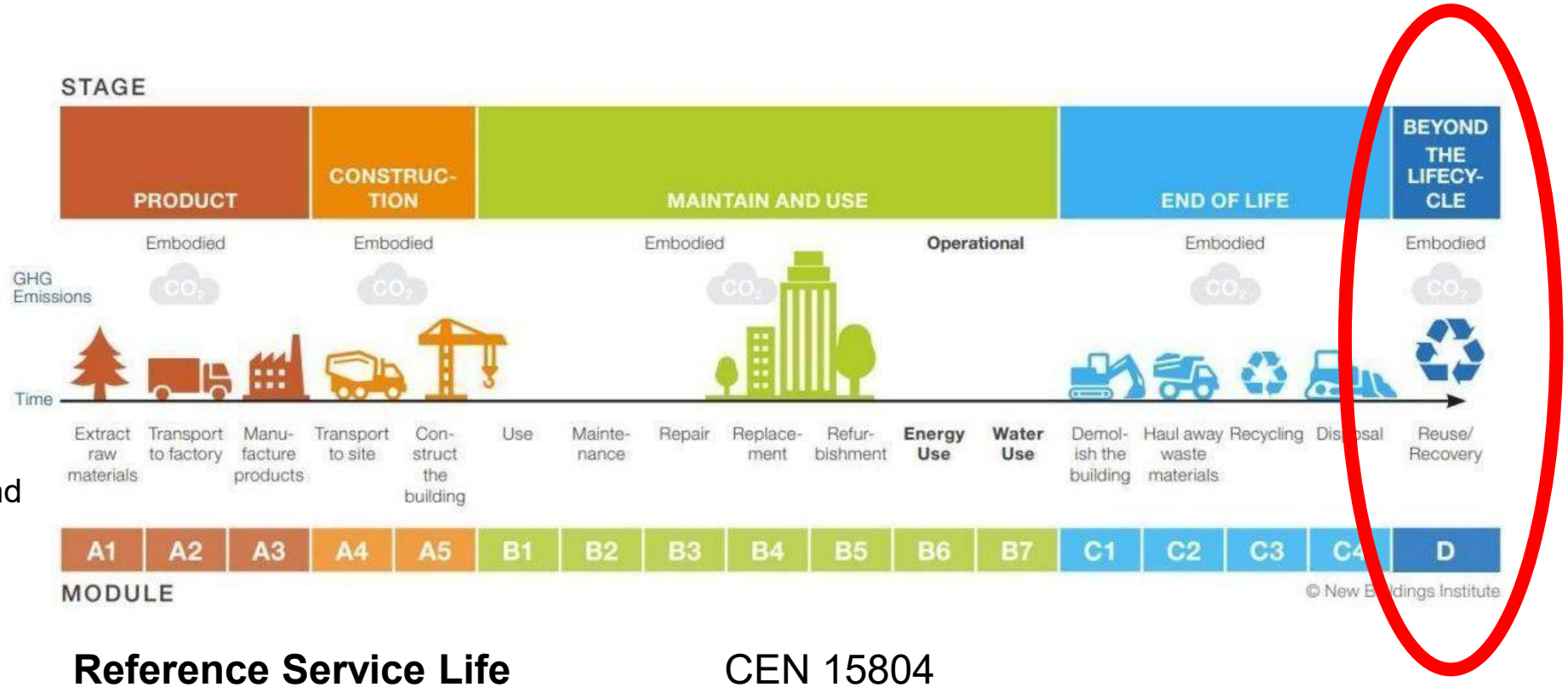
CEN 350: prenEN 18177 What is Circularity

Circular Economy

Target: The contribution of construction sector to circular economy. However, circular economy deals with macro economic aspects.

Circularity of Buildings

Is an attribute to assess the buildings, building elements and product level.



Reference Service Life CEN 15804

Circularity of Buildings

1) Circularity of materials & products
2) Circularity of building components
3) Circularity of construction works

LIÈGE université SBD Lab

CEN 350: prenEN 18177 **What is Circularity**

Circular Economy

Target: The contribution of construction sector to circular economy. However, circular economy deals with macro economic aspects.

Circularity of Buildings

Is an attribute to assess the buildings, building elements and product level.

Circularity of Buildings

1) Circularity of materials & products
2) Circularity of building components
3) Circularity of construction works

LIÈGE université SBD Lab

Circularity Definitions

Definitions, Metrics and Key Performance Indicators

According to prenEN 18177:

Circularity in buildings refers to the degree to which a building and its components are aligned with the principles of a circular economy, by being designed, used, maintained, adapted, and deconstructed in ways that:

1. **Minimize resource extraction and waste,**

2. **Extend the useful life of components and materials, and**

3. **Enable high-value reuse, remanufacturing, or recycling through multiple life cycles.**

Circularity Definitions

European Commission, CPR, and CEN

Life Extension (Slowing the loop)

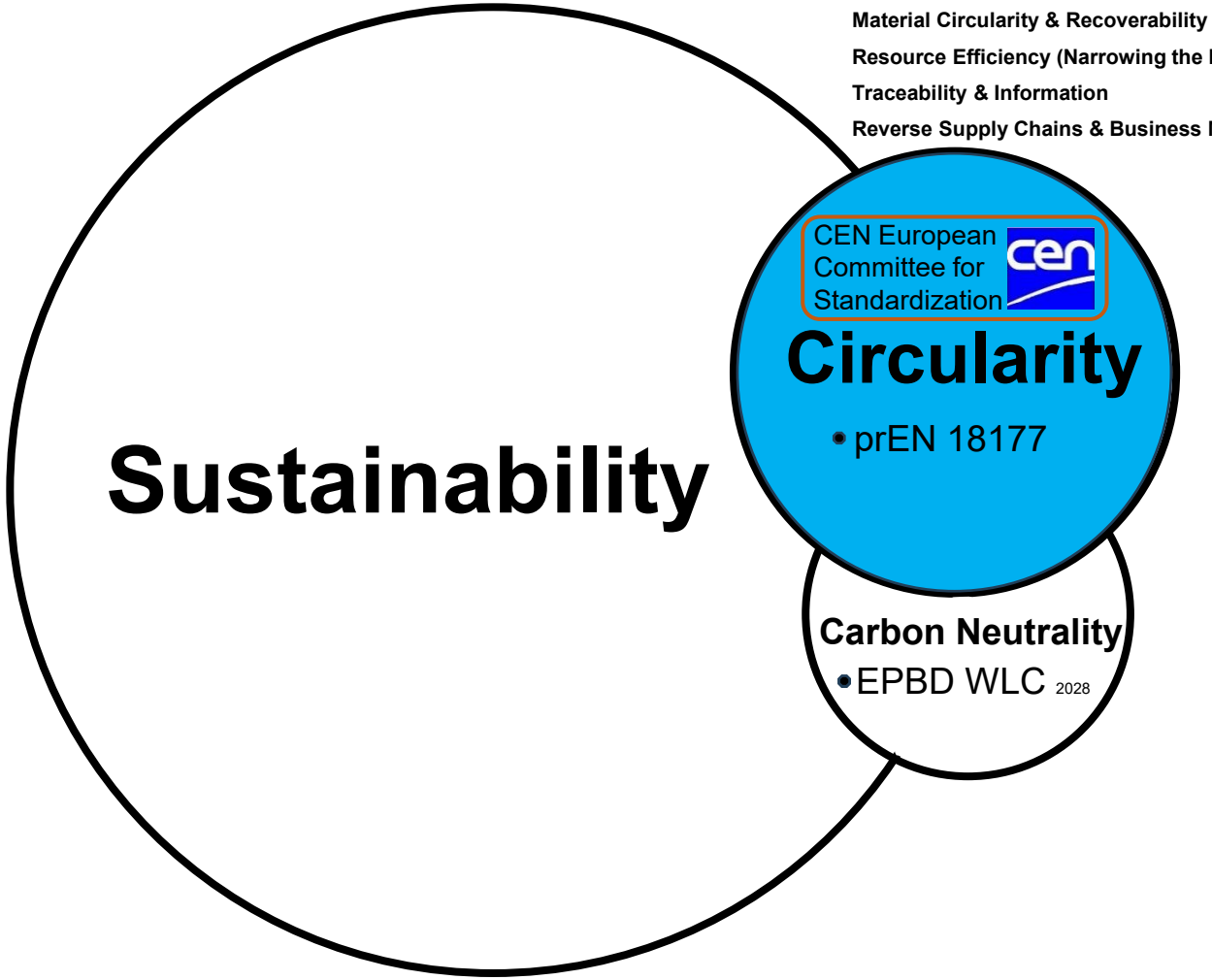
Disassembly & Reversible Assembly (closing the loop)

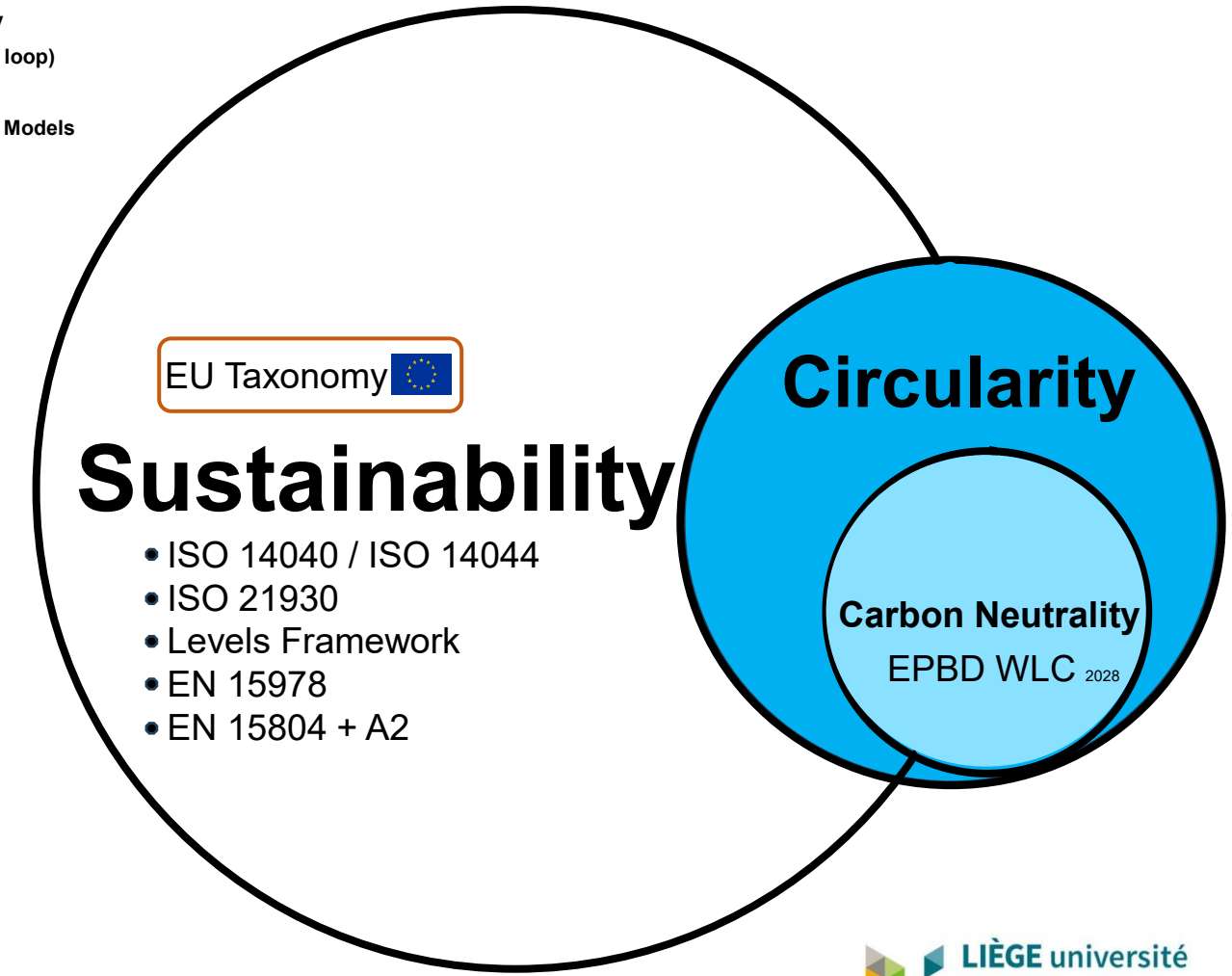
Material Circularity & Recoverability

Resource Efficiency (Narrowing the loop)

Traceability & Information

Reverse Supply Chains & Business Models





The Four Main Streams of Circularity in Construction

1. EU policy & standardization (governance spine)

•European Commission (CPR, EPBD recast, Green Deal).

2. Rating systems & applied schemes (market translators)

•Actors: Level(s) (EU JRC), BREEAM, DGNB/BNB, LEED, GRO (BE), klimaaktiv (AT).

3. LCA / Environmental Product Declarations (impact accounting)

•Core: EN 15804+A2 (EPDs), EN 15978 (building LCA), ISO 14040/44.

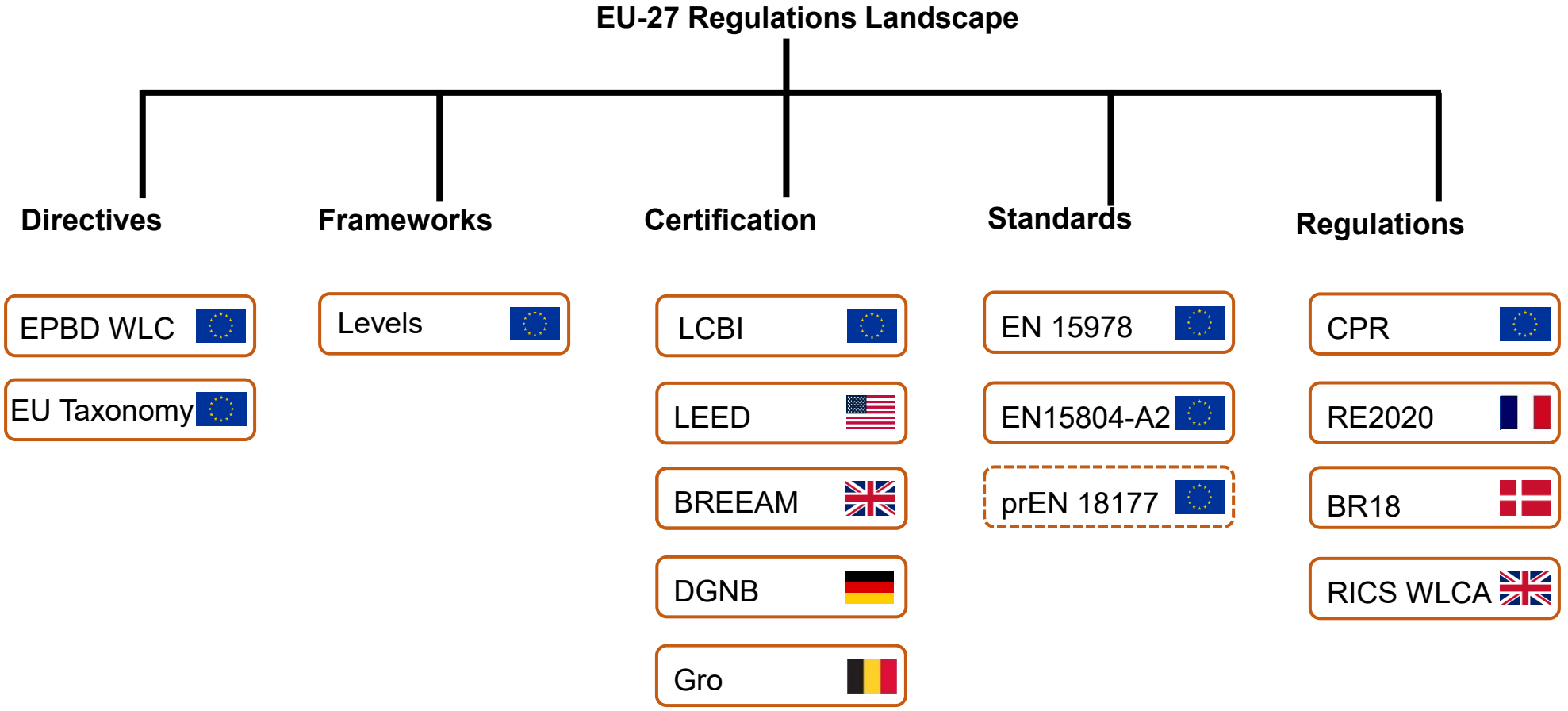
4. MFA & footprint logic (resource efficiency)

•MFA scholars, PEF (Product Environmental Footprint), Circular Footprint Formula (CFF).

LIÈGE université SBD Lab

EU-27 Regulations

Directives, Certifications and Standards



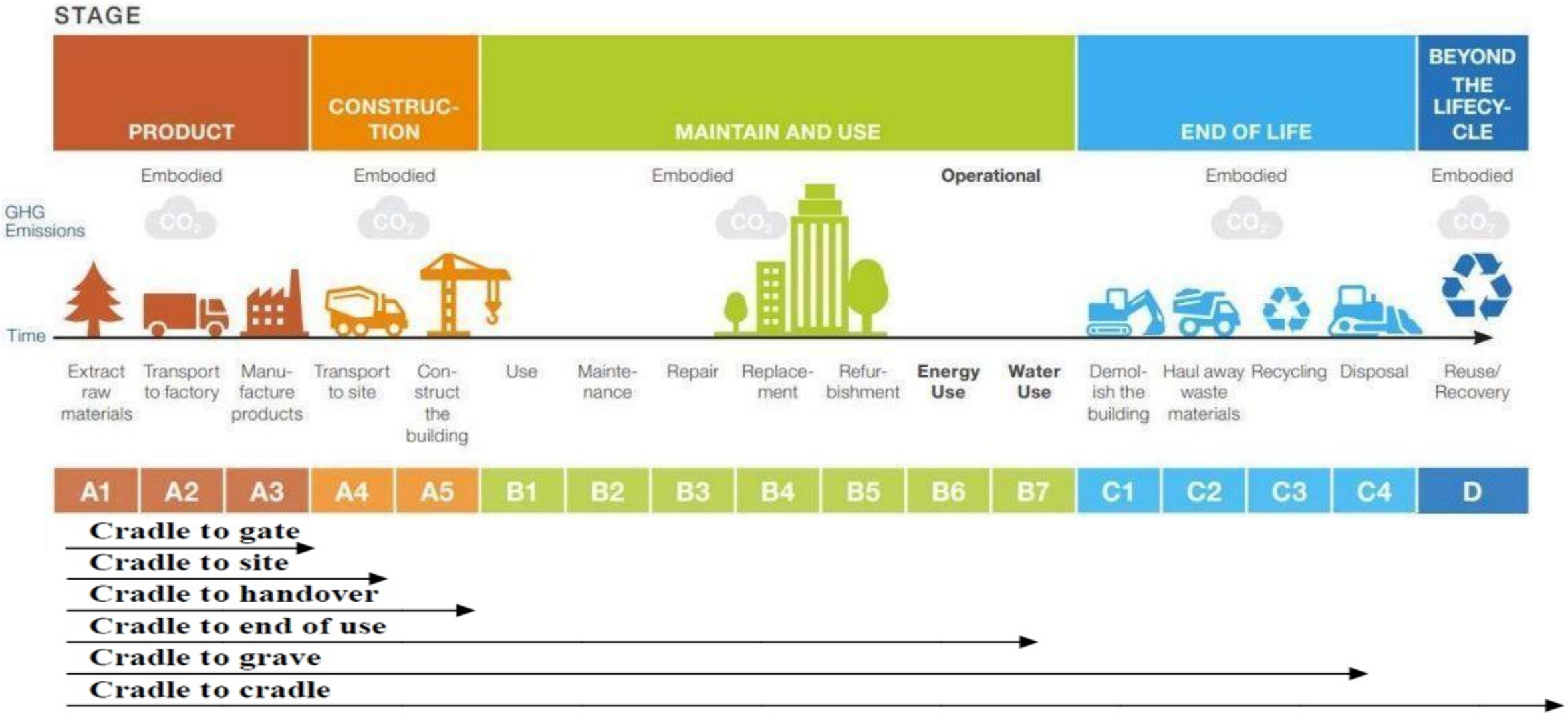
CEN/TC 350/SC 1 – Circular Economy in Construction
prEN 18177

- **WG 1 – Framework, Principles & Definitions:** Establishes common terminology, KPIs, and a guiding framework for circularity.
- **WG 2 – Gap Analysis, Conclusions & Recommendations** Identifies current practice gaps and proposes standardization priorities.
- **WG 3 – Chair's Advisory Group** Provides strategic coordination and oversight across WGs.
- **WG 4 – Circular Information in Construction Works:** Focuses on building/material passports, data transparency, BIM integration.
- **WG 5 – Circularity Assessment** Develops methodologies and metrics for evaluating circularity.
- **WG 6 – Reuse of Construction Products/Materials:** Sets standards and guidance for reusing materials and product take-back.
- **WG 7 – Circular Design for the Construction Sector** Promotes design strategies for adaptability, disassembly, and reuse.
- **WG 8 – Pre-Demolition/Pre-Redevelopment Audits & Evaluation:** Standardizes procedures for assessing materials before demolition or refurbishment

LIÈGE université SBD Lab

Lifecycle Stages of Building Products

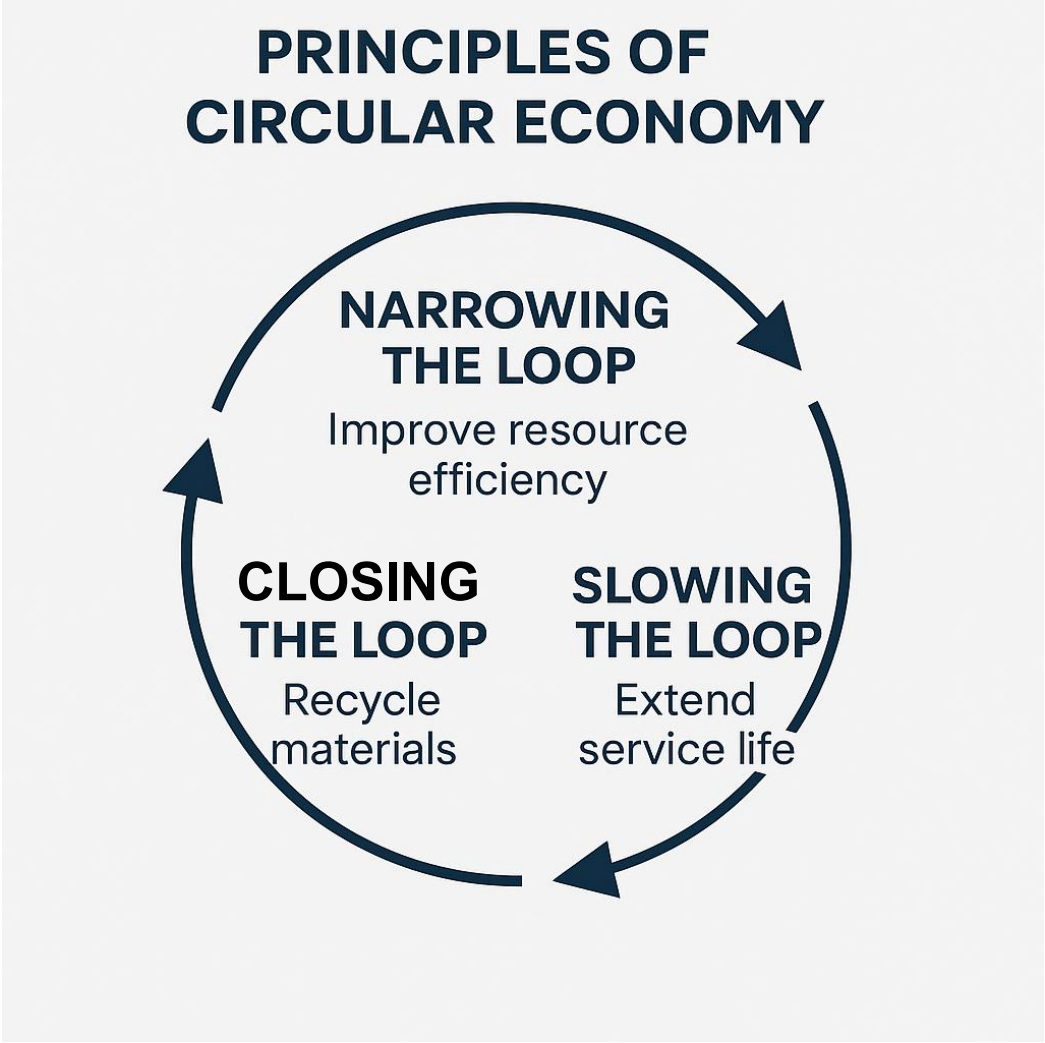
CEN 15978:2018+A2



The Science behind it

Metrics and Key Performance Indicators

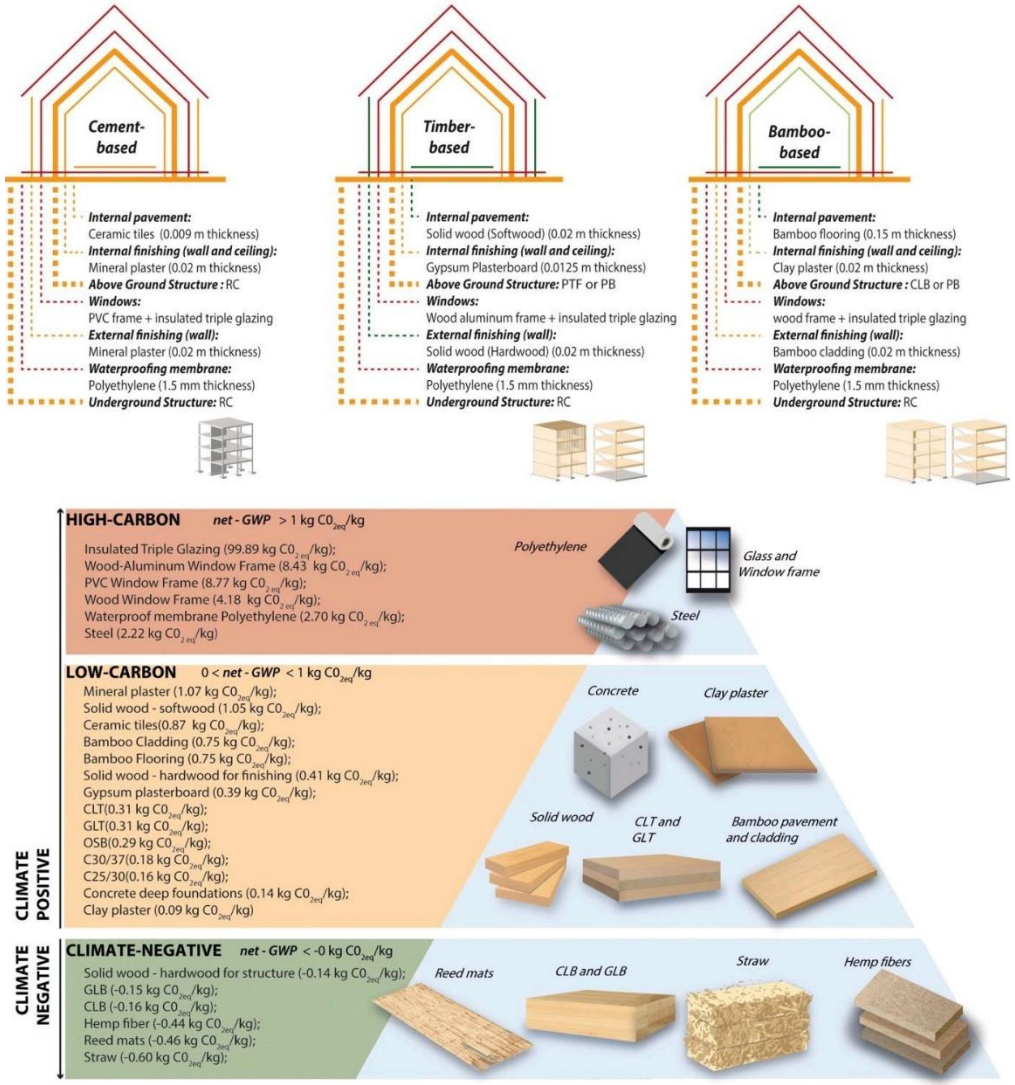
Material Flow Analysis
Resource Flow Analysis
Life Cycle Impact Assessment
Building Performance Simulation

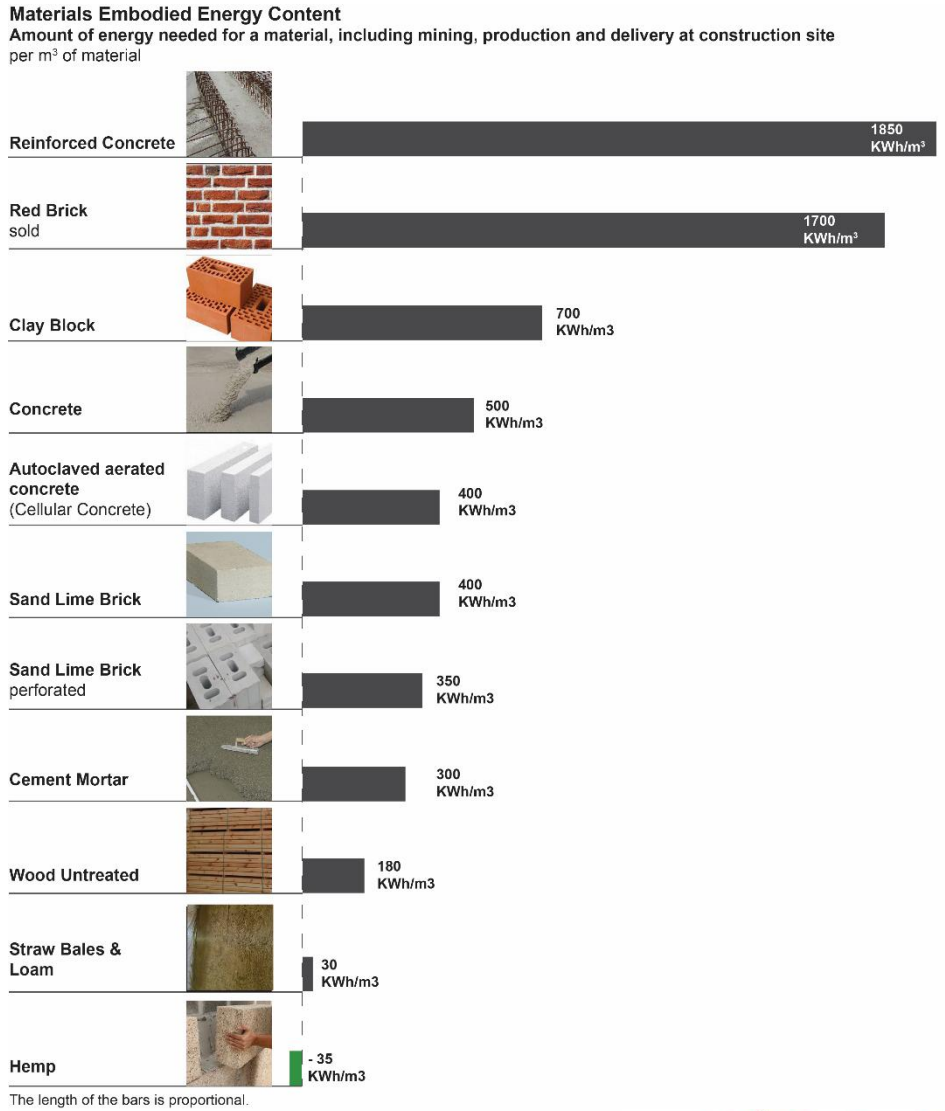


LIÈGE université
SBD Lab

The Science behind it

Materials Environmental Impact



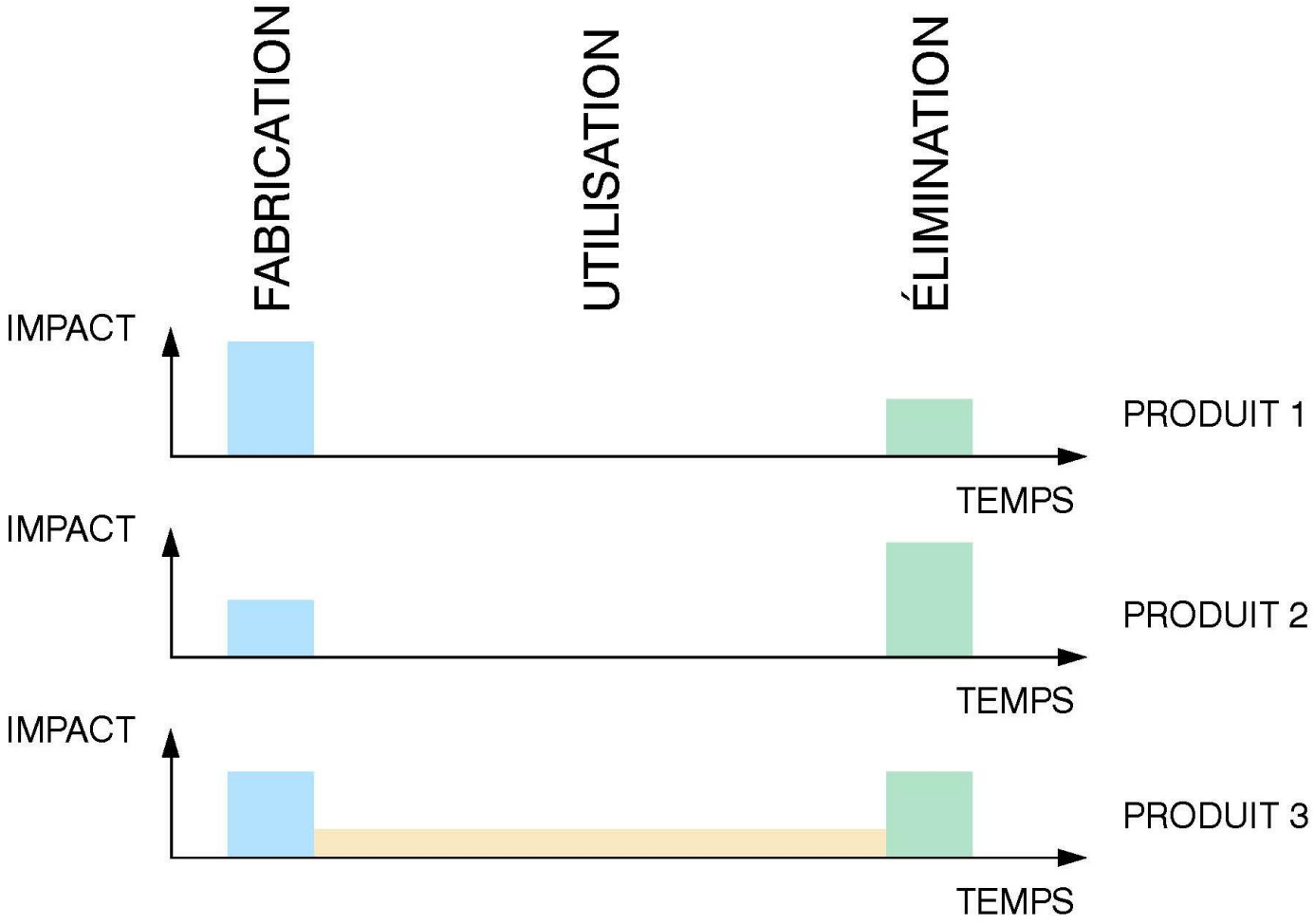


Source: Jan Slagman

LIÈGE université SBD Lab

The Science behind it

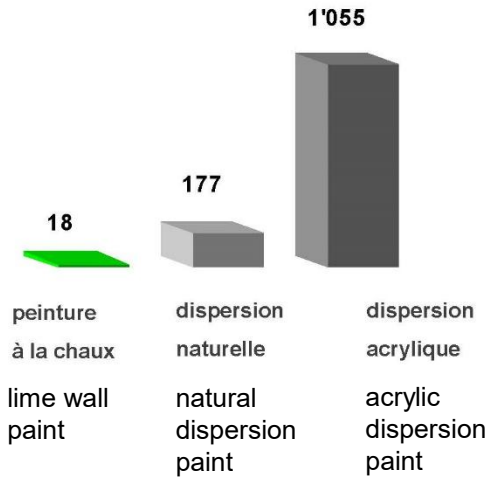
Life Cycle Assessment



énergies grises embedded energy

- peinture murale Walls paint

consommation en kWh
pour 100 m2 de peinture
murale



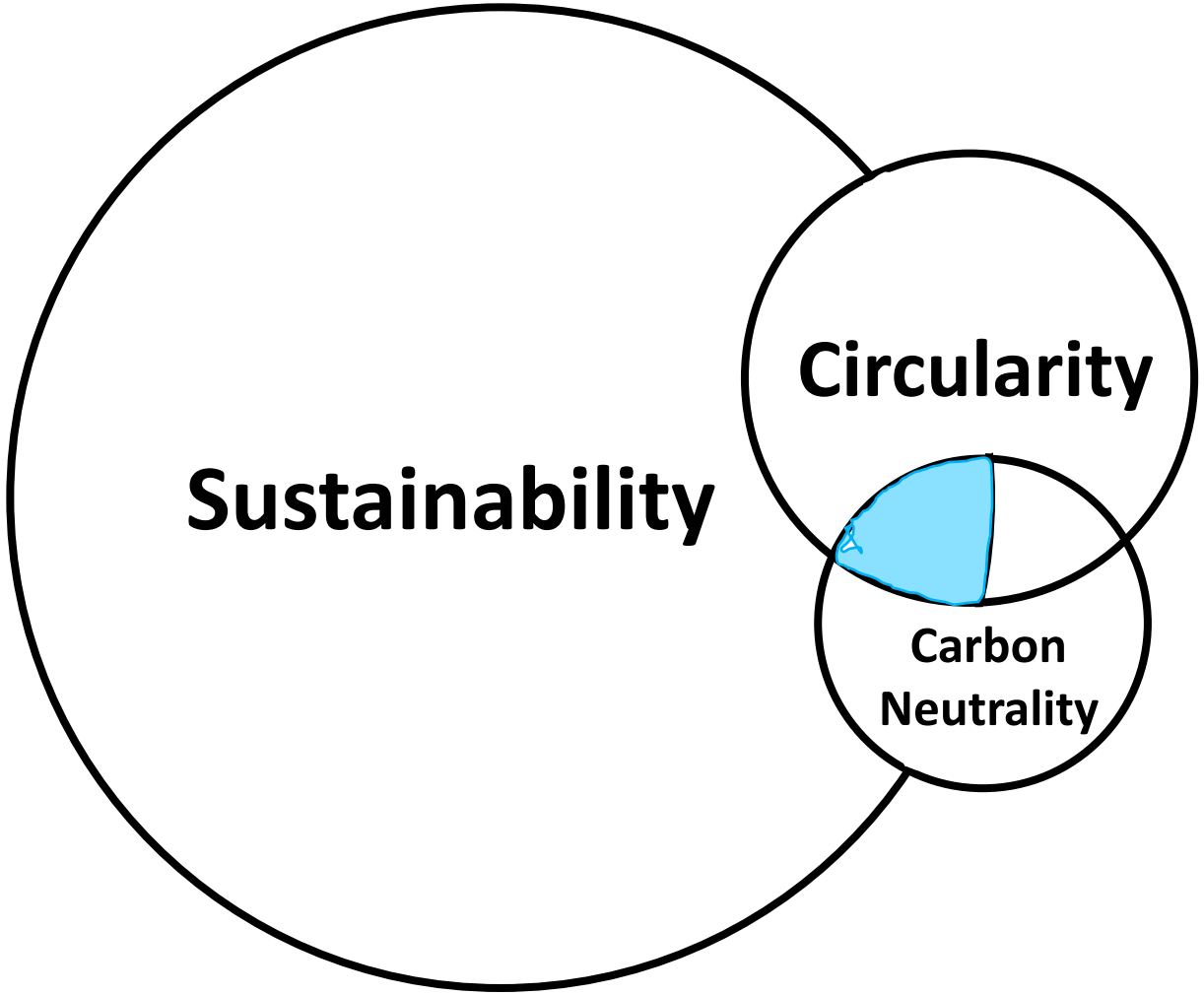
LIÈGE université SBD Lab

Multi-objective approach with multiple KPIs

LIÈGE université

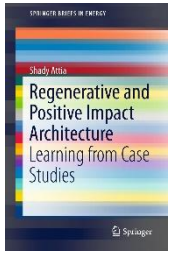
Building Circularity Framework

Directives, Certifications and Standards



Designers

Circular, Cradle to Cradle, Regenerative and Bio-based buildings



a) Fokker 7+8 Distrib.Centre

b) 't Centrum

c) Green Offices

d) Iewan Social Housing

e) Circl: ABN Circular Pavillon

f) Circular retrofit lab (VUB)

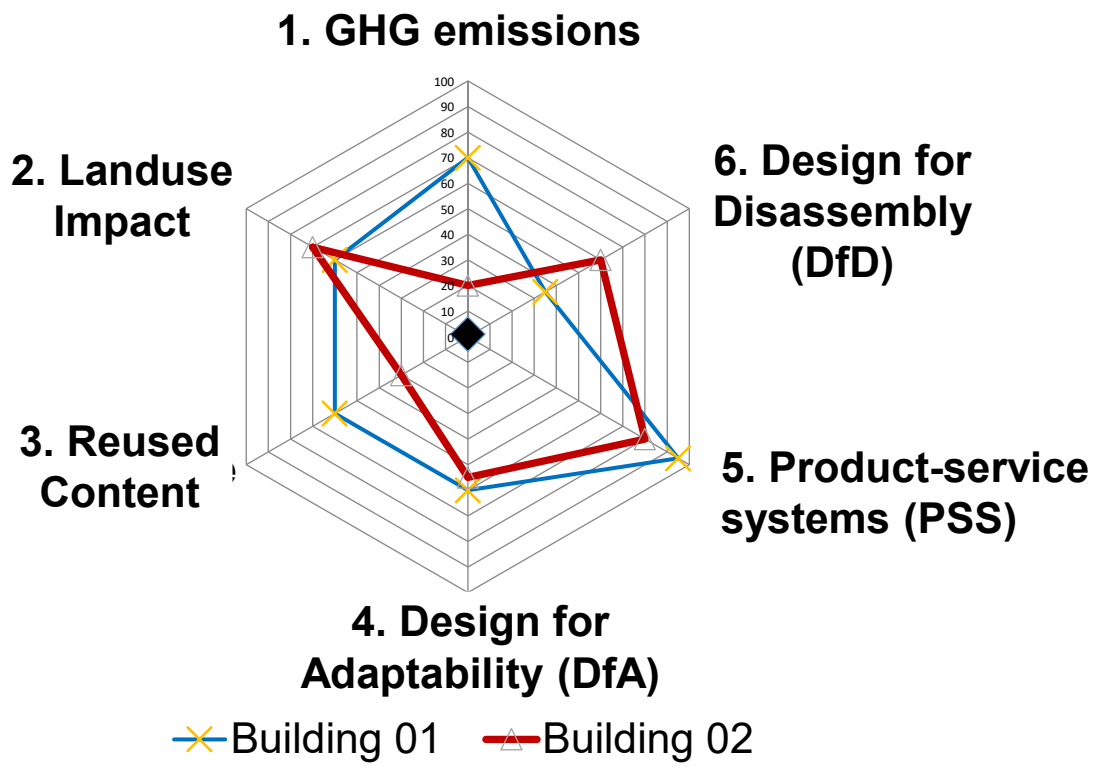
Photos of the selected projects studies (Attia and Al-Obaidy 2021)

Six demonstration projects were selected based on their carbon footprint and circularity features

LIÈGE université SBD Lab

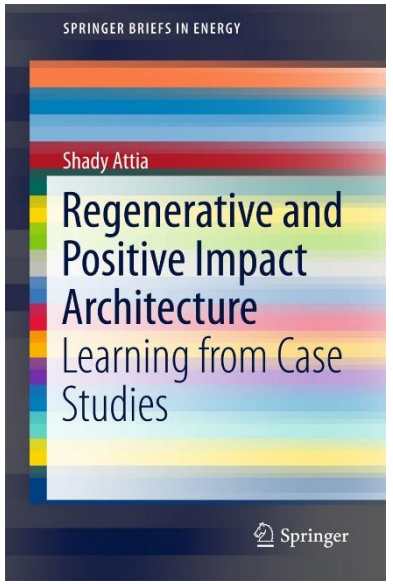
Circularity Evaluation Framework

Circular and bio-based buildings



Audit Sheet

Circularity criteria	%	Evaluation
1. **Carbon footprint (According to TOTEM indicators)**	%100	
1.1 Global warming	%10	
1.2 Ozone depletion	%10	
1.3 Acidification for soil and water	%10	
1.4 Eutrophication	%10	
1.5 Photochemical ozone creation	%10	
1.6 Depletion of abiotic resources: elements and fossil fuels	%10	
1.7 Human toxicity: cancer and non-cancer effects	%10	
1.8 Particulate matter	%10	
1.9 Ionizing radiation: human health effects	%5	
1.10 Ecotoxicity: freshwater	%5	
1.11 Water resource depletion	%5	
1.12 Land use: occupation and transformation (soil organic matter and biodiversity).	%5	
2. **Reuse content**	%100	
2.1 History of bearing load		
2.2 Reused content	%80	
2.3 Recycled content (by products)	%20	
2.4 Compliance with construction code		
3. **Disassembly potential**	%100	
3.1 Connections	%40	
3.2 Material passport	%30	
3.3 Tag & Track	%30	
4. **Design for flexible**	%100	
4.1 Modularity	%50	
4.2 Standardization of building elements	%50	
5. **Land use**	%100	
5.1 Land use footprint	%60	
5.2 Person per m^2	%40	
6. **Circular Economy Services Companies CESCO**	%100	
6.1 Construction elements	%30	
6.2 Energy	%30	
6.3 Heating and Cooling system	%20	
6.4 Lighting	%20	



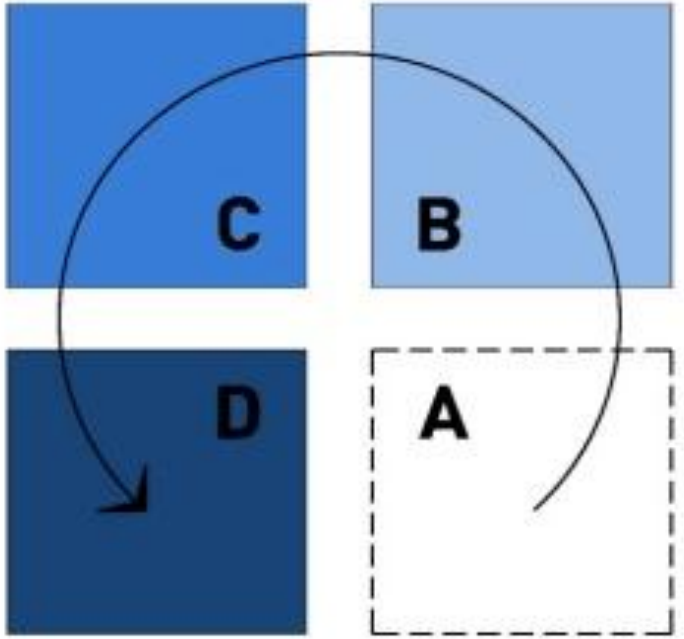
LIÈGE université SBD Lab

Het Centrum, Westerlo, Belgium

Design and Build Team

On the 7th of February 2021, SBD Lab signed an agreement with Kamp C to be a part of the consortium, doing LCA, and providing consultancy on the design for disassembly

Architect	Design & engineering	Structural engineering	Constructor	Constructing with green & natural elements	Geothermal energy	EPB reporting	Concrete technology	Research
West Architecture	TEN-agency	Streng-th	Beneens	Muurtuin	Tenerga	VESTAD	ResourceFull	VITO

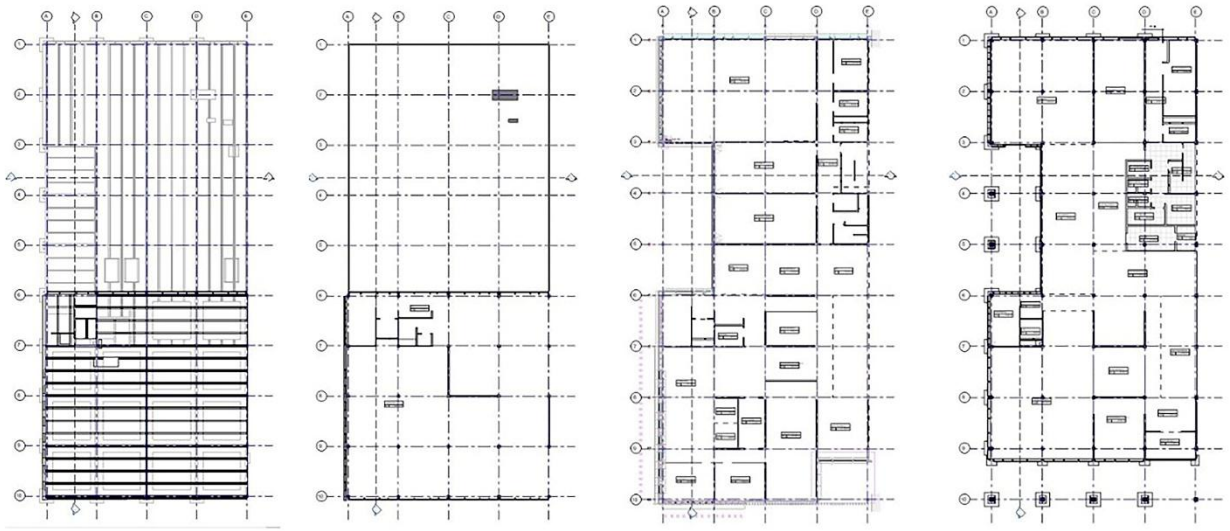


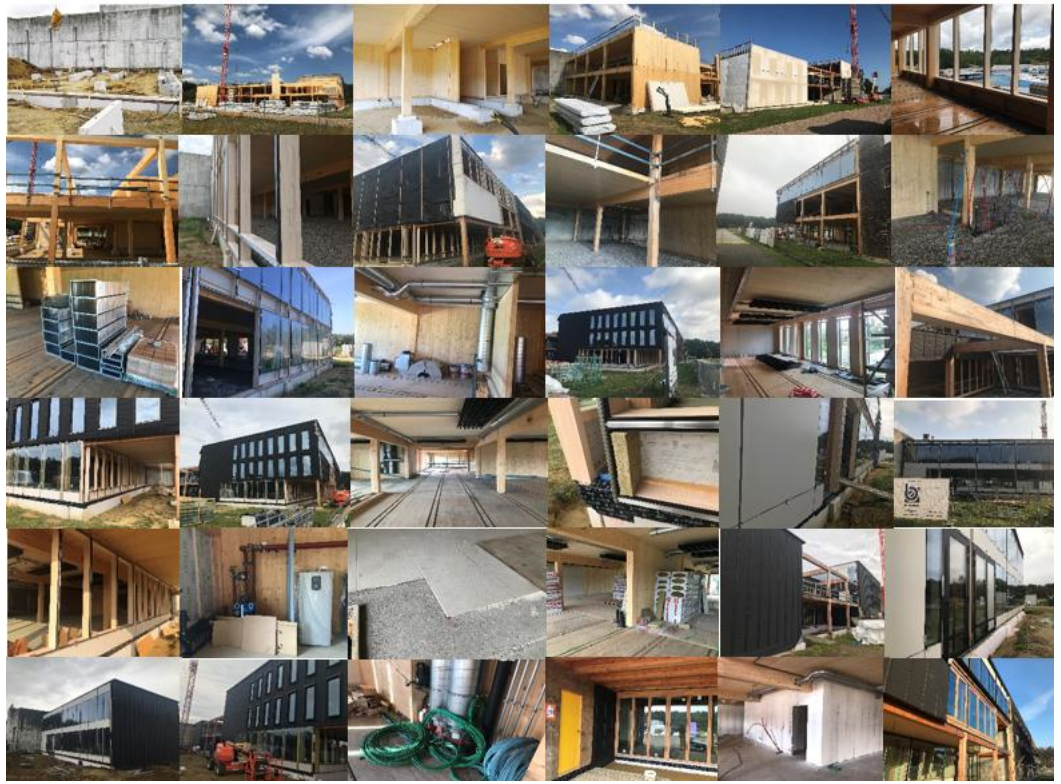
LIÈGE université SBD Lab

Het Centrum, Westerlo, Belgium

Documentation

On the 7th of February 2021, SBD Lab signed an agreement with Kamp C to be a part of the consortium, doing LCA, and providing consultancy on the design for disassembly

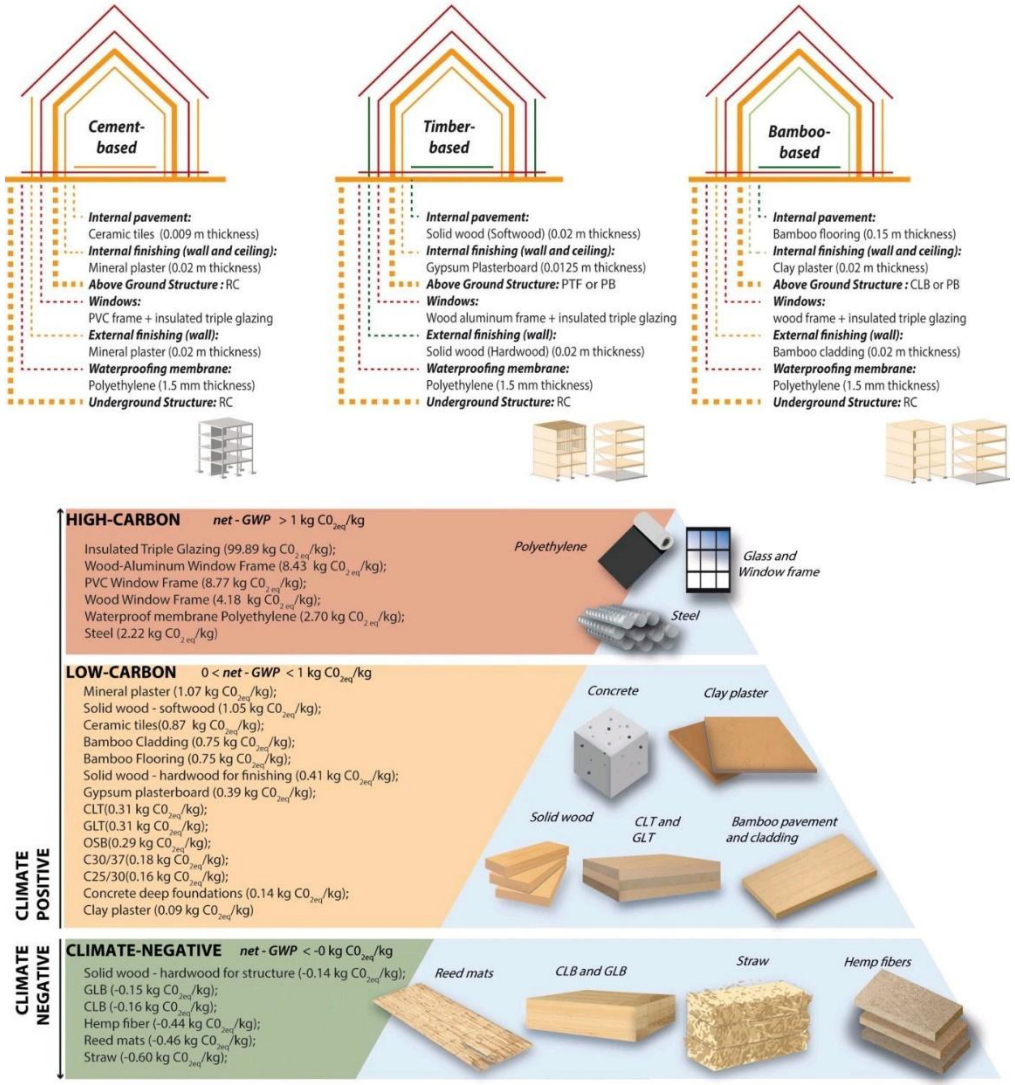


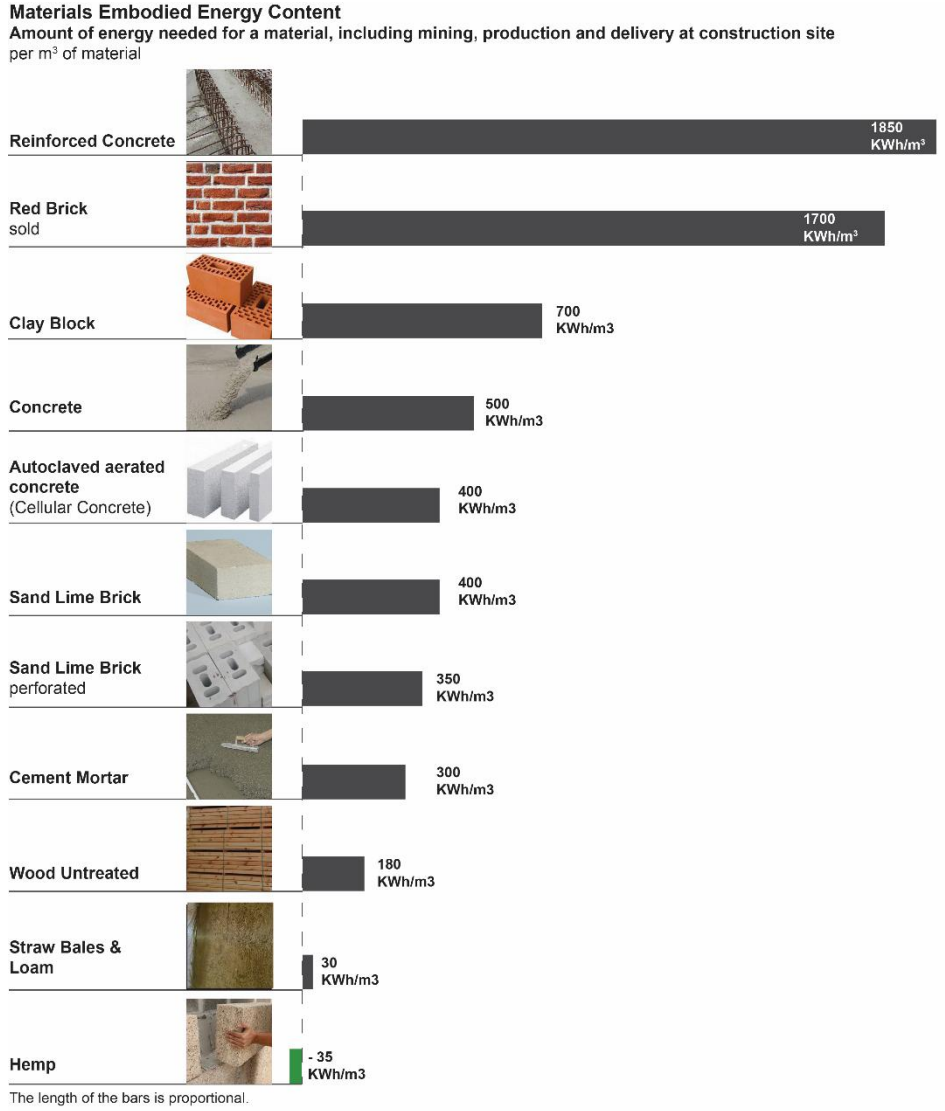


LIÈGE université SBD Lab

1. GHG Emissions

Low carbon and bio-based buildings



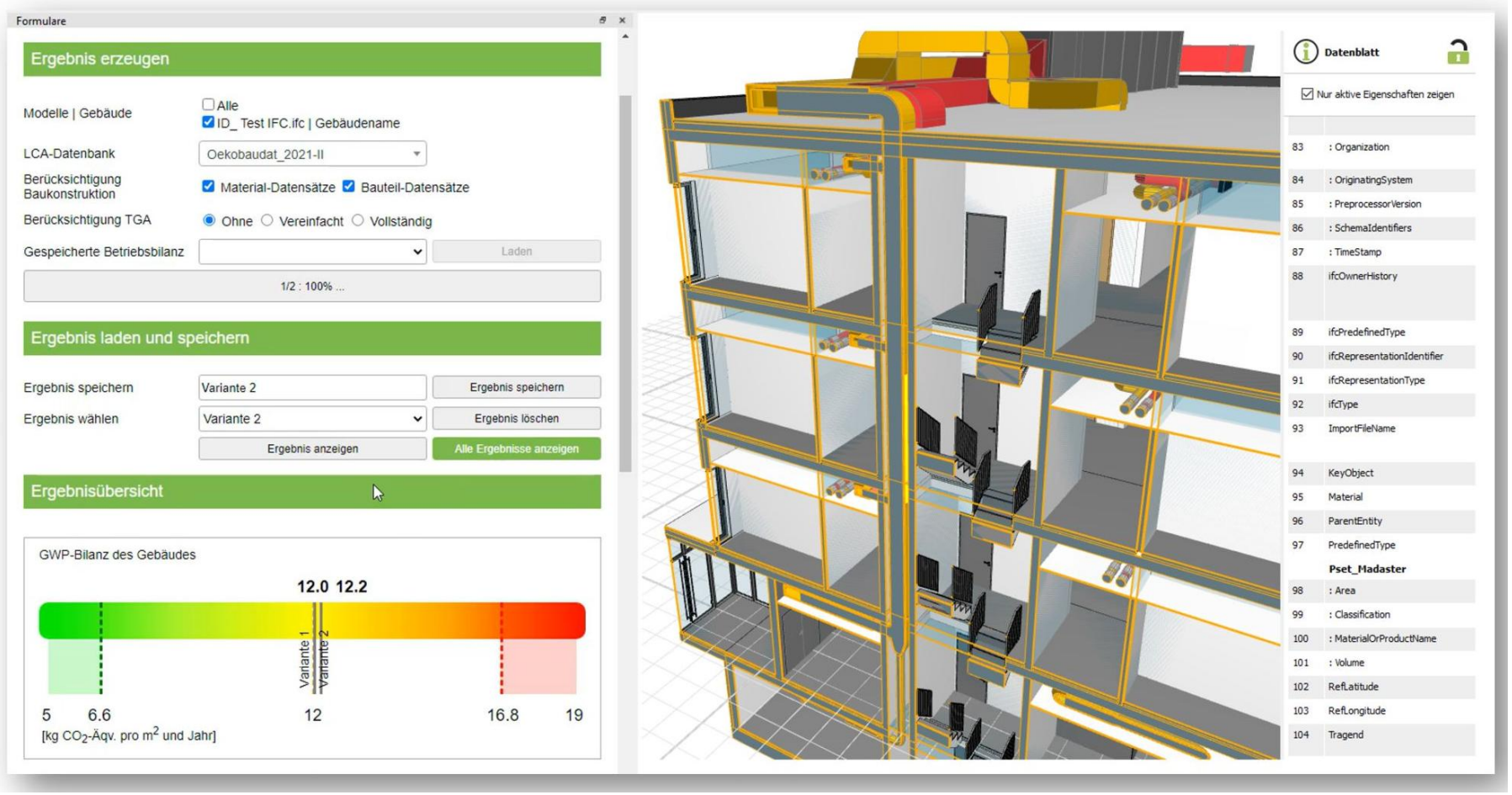


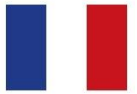
Source: Jan Slagman

LIÈGE université SBD Lab

1. GHG Emissions

Embodied and Operational Emissions





- 2023, Operational emissions: 4 kgCO2.equiv. per m2 for new residential buildings
- 2023, Embodied emissions (Office) 1000 kgCO2.equiv per m2

- 2023, Operational emissions: 12 kgCO2.equiv. per m2 for new residential buildings
- 2026, Embodied emissions (dwelling) 750 kgCO2.equiv per m2

Source: DGNB, Sebastian Theißen, BIM-based emissions modeling

LIÈGE université SBD Lab

Embodied GHG Emissions

Categories of carbon negative materials & potential of negative emissions

Timber

Straw

Cork

Hemp

Bamboo

Biochar

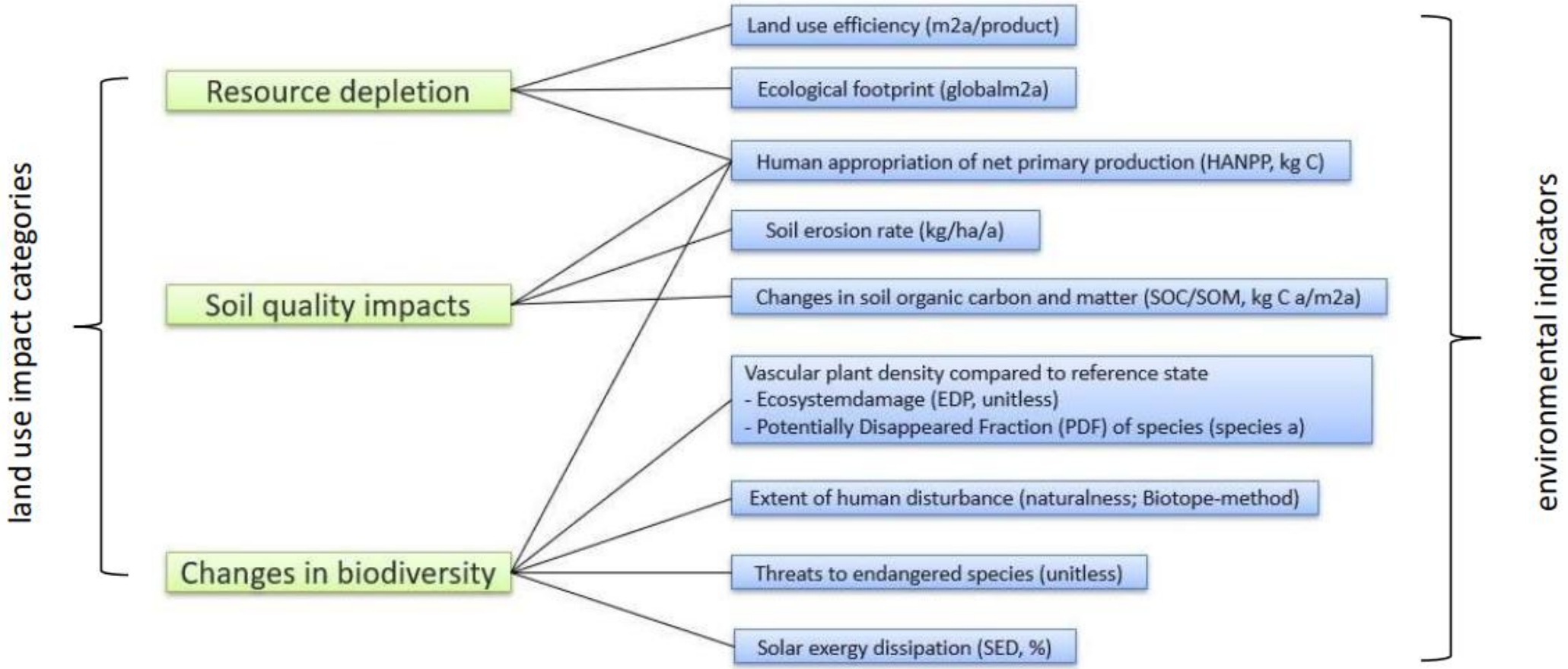
Captured carbon

Biomineralization (Low carbon aggregates)

Potential of negative emissions	
Biobased Materials	10-50%
Charcoal Concrete	2-10%
Carbonized Concrete	2-3%

2. Land Use Impact

LCA based calculation ISO 14040

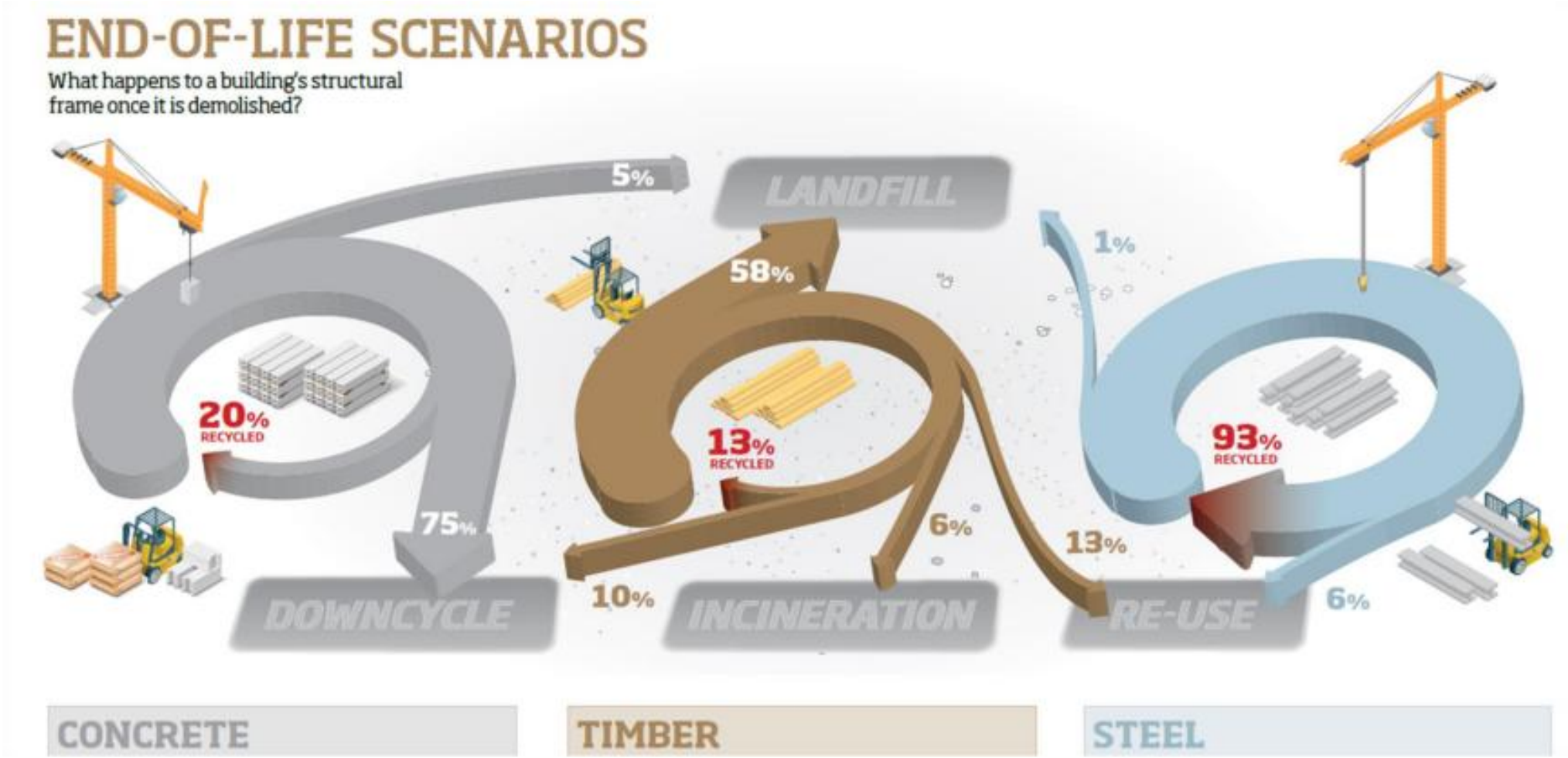


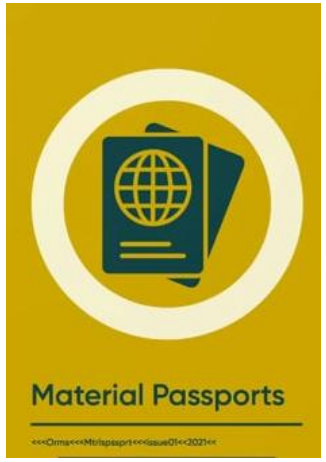
Set of environmental indicators for land use impact categories [5].

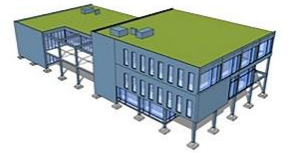
LIÈGE université SBD Lab

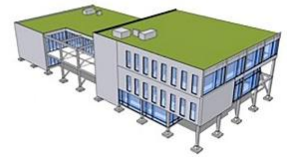
3. Reused Content

LCA based calculation ISO 14040





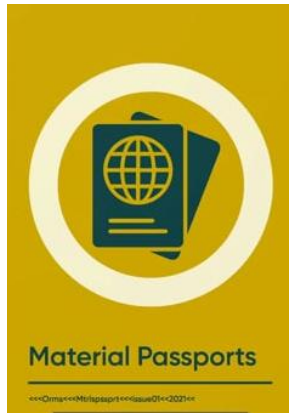




LIÈGE université SBD Lab

3. Reused Content

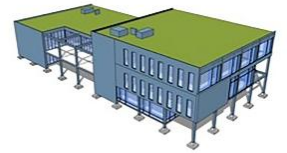
LCA based calculation ISO 14040

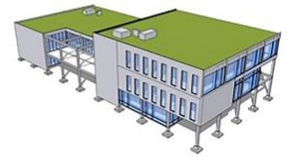


+ Circularity
- CO2

Reused material	•Reusing the same material or element repeatedly more than once
Reclaimed materials	•Reclaiming and reusing material in its existing form either for its original purpose or an alternative purpose
Recycled materials	•Using materials to make new products
Reusable material	•Virgin materials that could be reused for their original purpose, not recycled as new products or materials

- Circularity
+ CO2

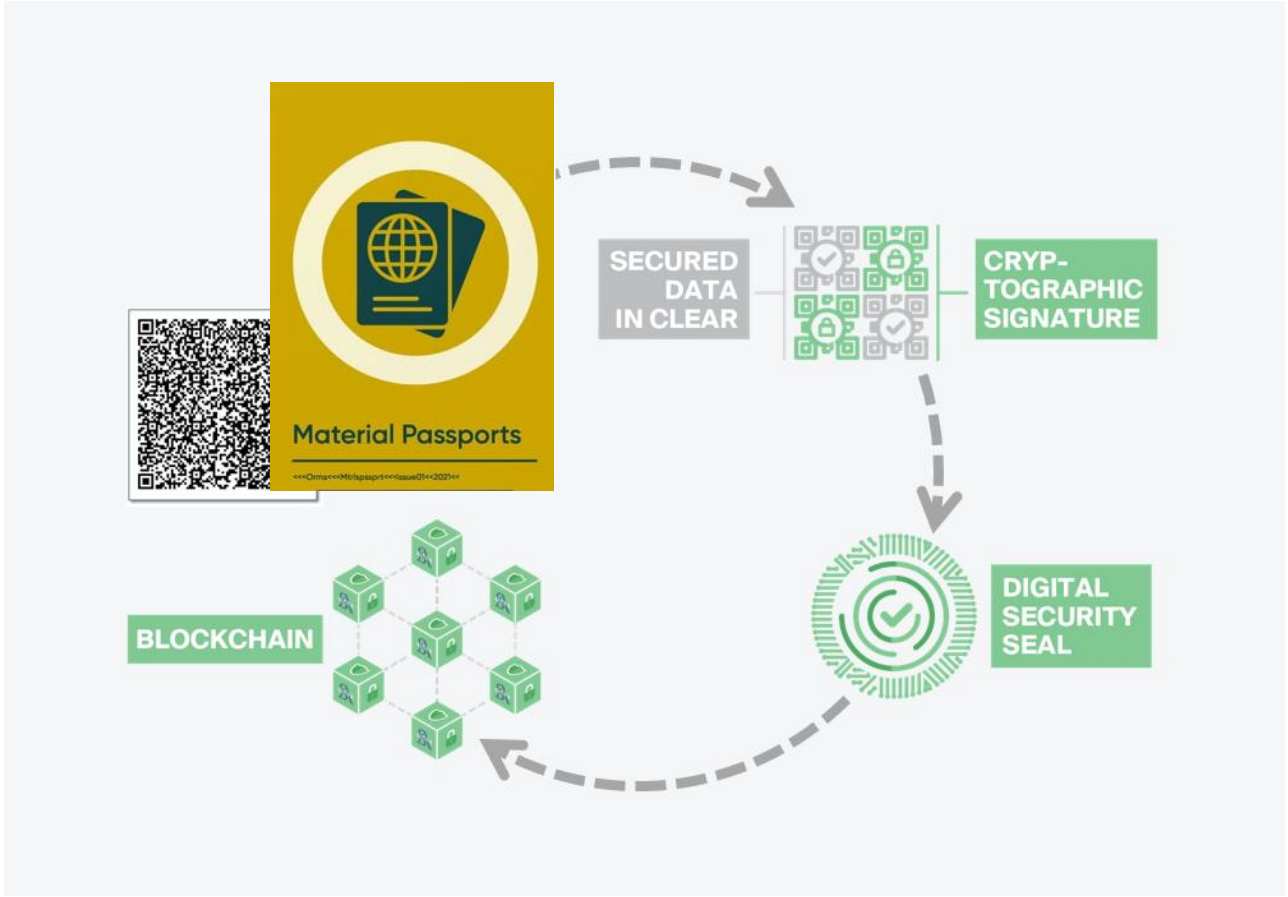


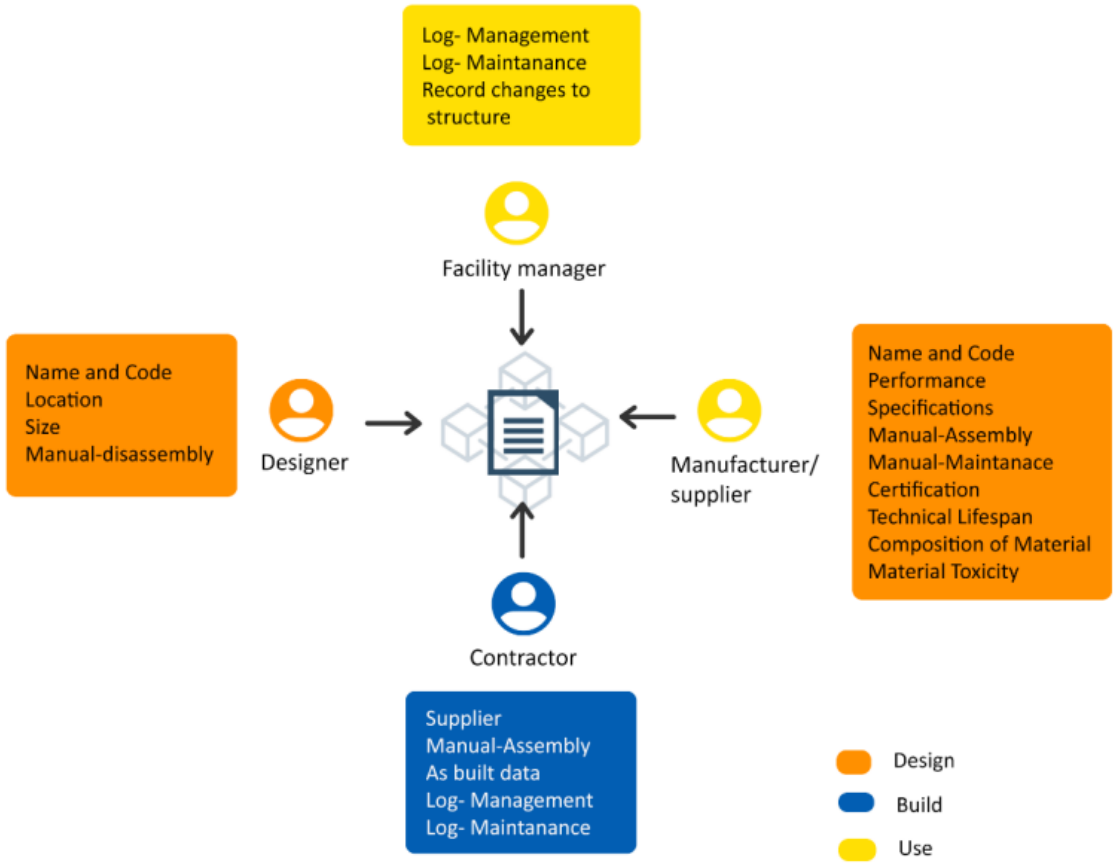


LIÈGE université
SBD Lab

3. Reused Content

Tag and Trace + Material Passport + Blockchain





Source: Namuru 2021

LIÈGE université SBD Lab

4. Design for Adaptability (DfA)

Flexible Buildings

Adaptable Buildings

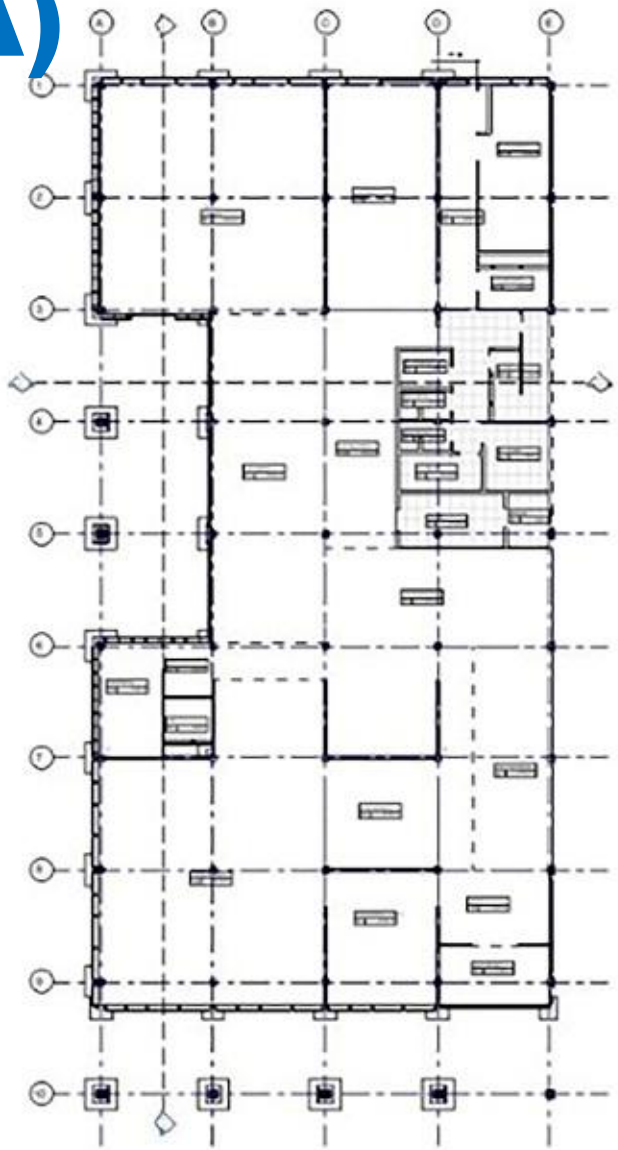


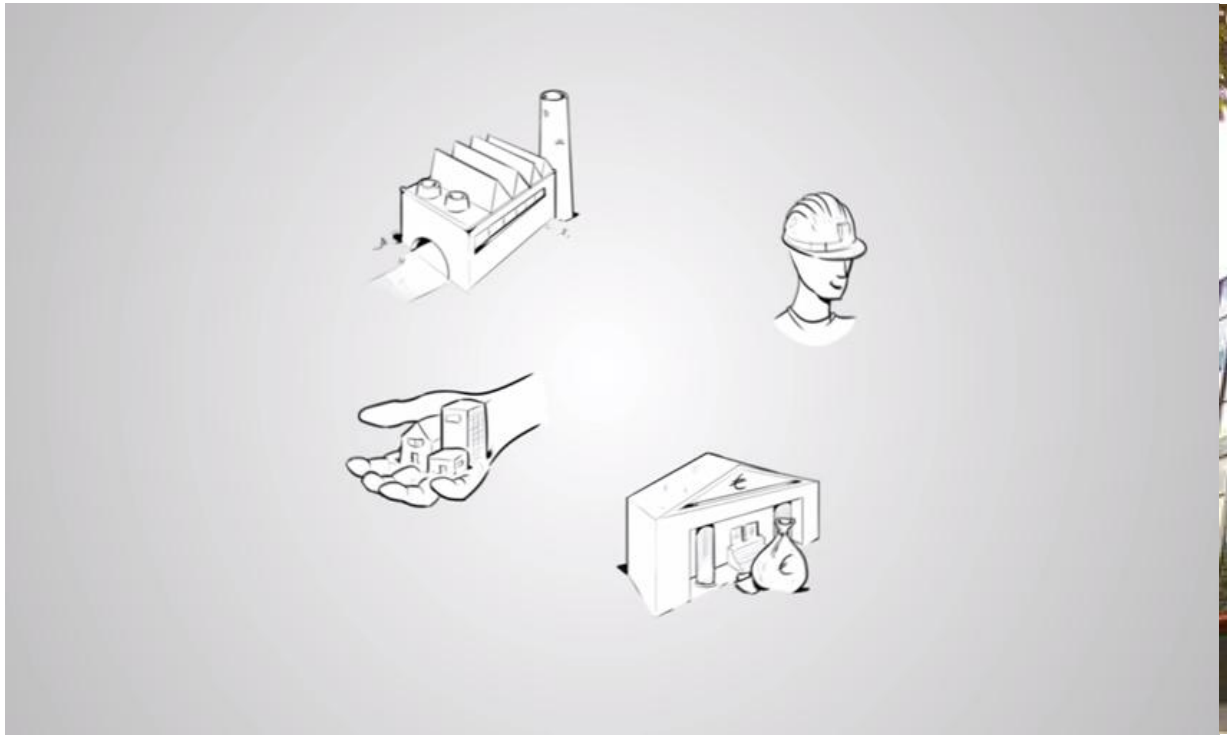
Figure 2 Six Levels of Adaptability by Schmidt and Austin 2016

LIÈGE université SBD Lab

5. PSS Product-service systems

Circular Economy Services Companies + Leasing Elements

A CE service company is a company that provides a broad range of circularity solutions, including designs and implementation of materials savings projects, retrofitting, materials reuse, materials infrastructure outsourcing, materials replacement and risk management.

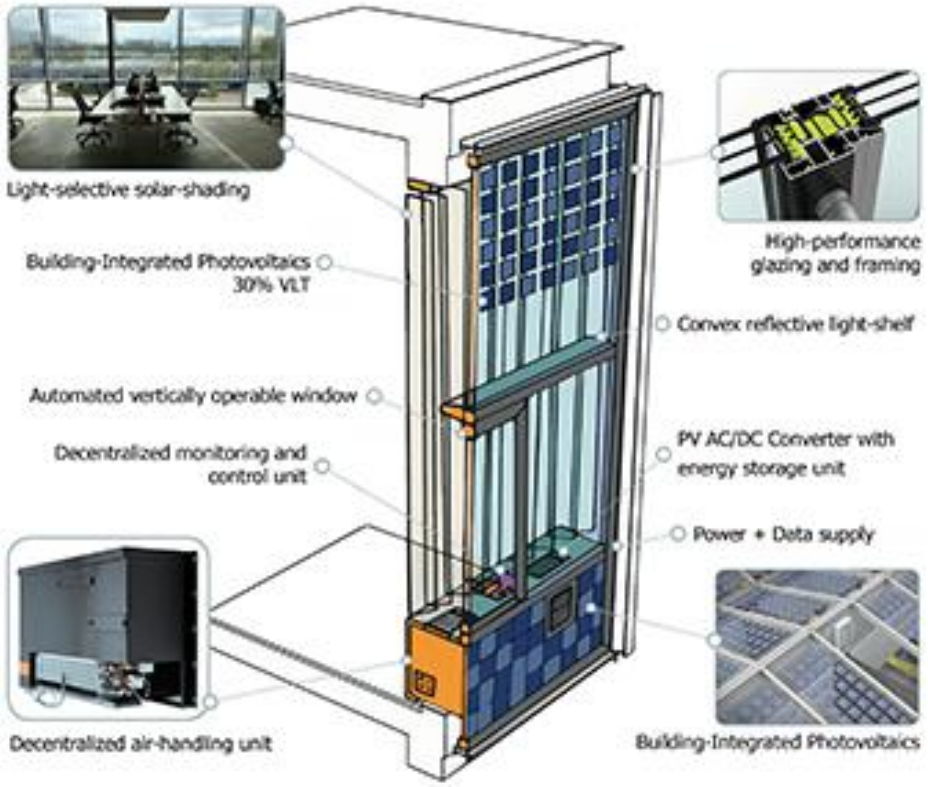


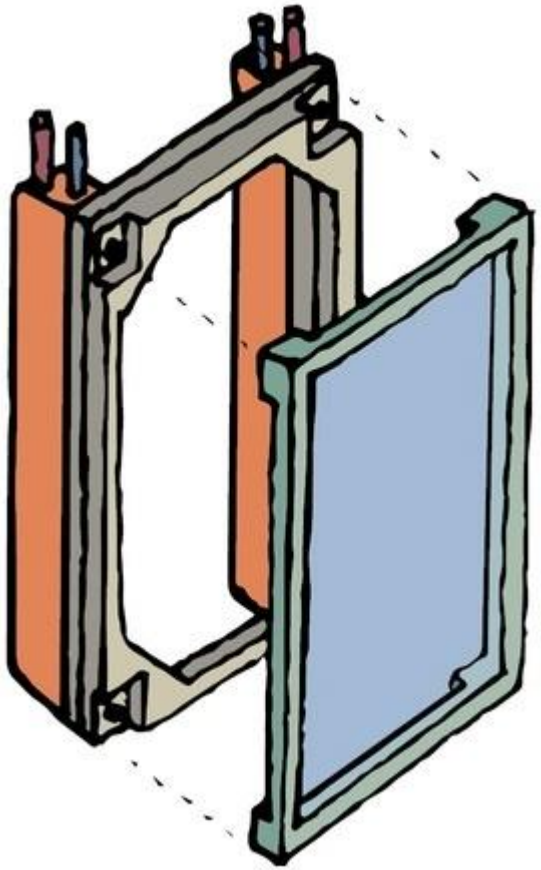
Source: TU Delft's Leasing Facades - a circular approach to real estate management

5. PSS Product-service systems

Circular Economy Services Companies + Leasing Elements

A CE service company is a company that provides a broad range of circularity solutions, including designs and implementation of materials savings projects, retrofitting, materials reuse, materials infrastructure outsourcing, materials replacement and risk management.





Source: TU Delft's Leasing Facades - a circular approach to real estate management

LIÈGE université SBD Lab

5. PSS Product-service systems

Circular Economy Services Companies + Leasing Elements

Source: Park 2020, Business park in Hoofddorp, Netherlands

6. Design for Disassembly (DfD)

Building life stages CEN 15978:2018+A2

Description of the stages during the buildings' life, according to EN

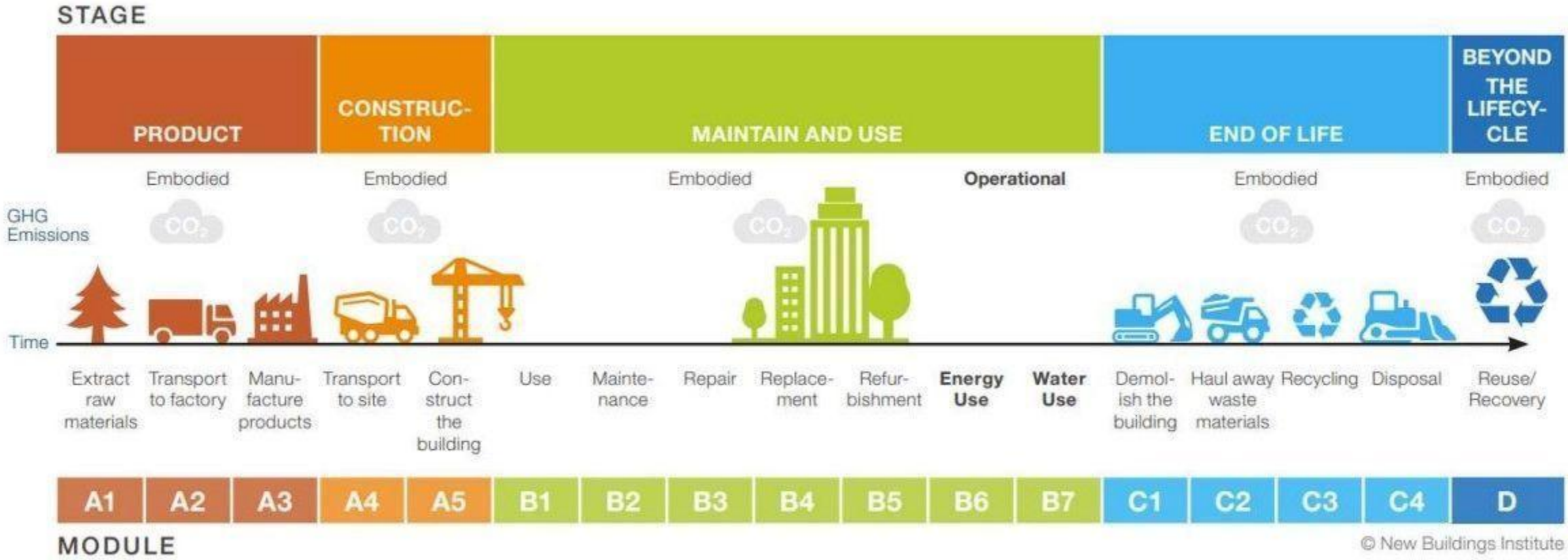


Figure 1: Lifecycle stages of building carbon. Data source: BS EN 15978:2011
Source: Bowles, Cheslak, and Edelson 2022

Source: Description of the stages during the buildings' life, according to EN 15978.:2012, p.21

LIÈGE université SBD Lab

6. Design for Disassembly (DfD)

ISO 20887 – 2020: Design for disassembly and adaptability

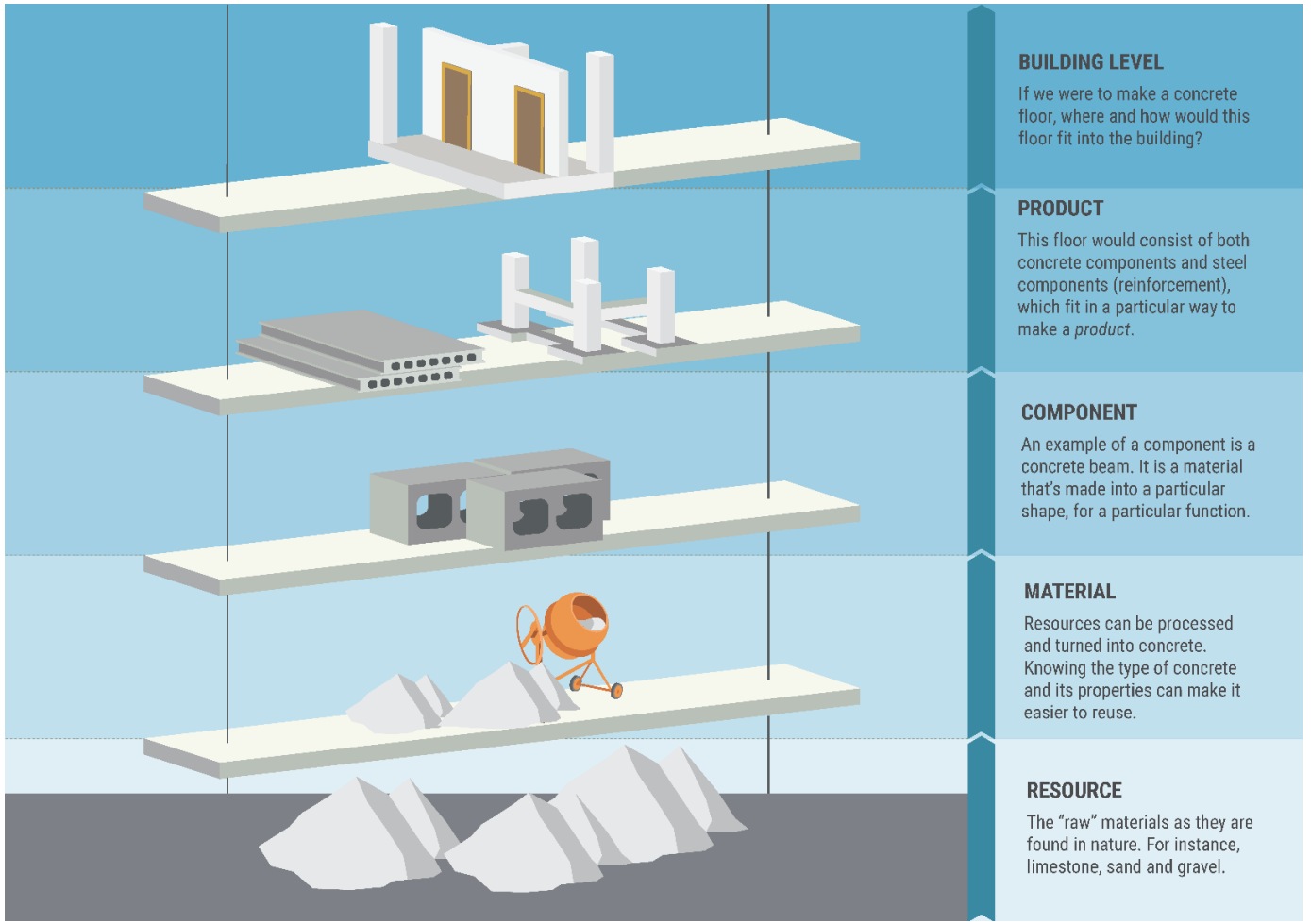
INTERNATIONAL STANDARD

ISO 20887

First edition
2020-01

Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance

Développement durable dans les bâtiments et ouvrages de génie civil — Conception pour la démontabilité et l'adaptabilité — Principes, exigences et recommandations



Source: https://www.metabolic.nl/news/circular-economy-materials-passports/

LIÈGE université SBD Lab

6. Design for Disassembly (DfD)

t' Centrum, Westerloo, BE (Benees Architects)



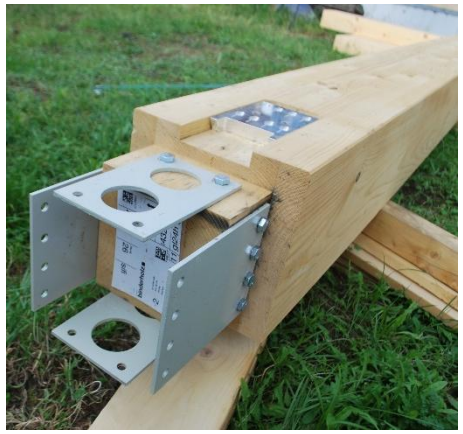


Table 1: Possibilities of reusing timber by connection type (Hradil 2024)

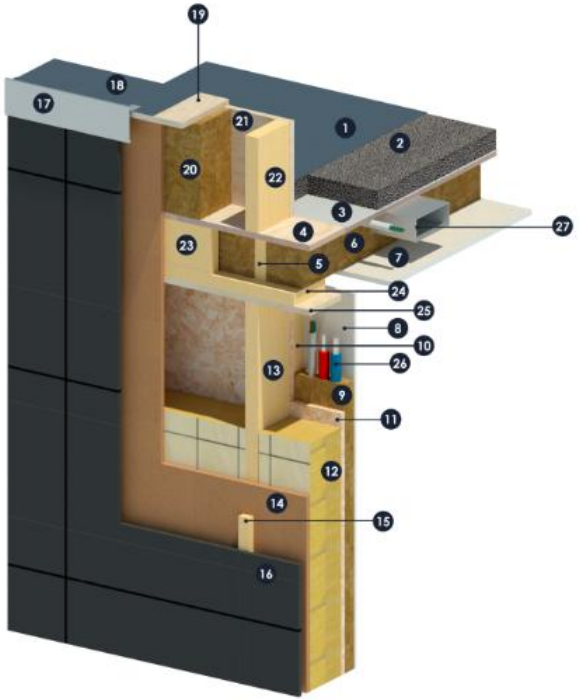
Connections	Suitability	Note
Glued connections	not suitable	Cannot be separated without damaging the elements.
Carpentry joints	sometimes suitable	Notches can cause stress concentration if the elements are used in different configuration.
Nails, staples	sometimes suitable	Fail in bending, and therefore are difficult to remove without damaging the element.
Screws	mostly suitable	The same connector is not so effective in the same hole.
Bolts, dowels	suitable	The hole and the cracks should be checked.

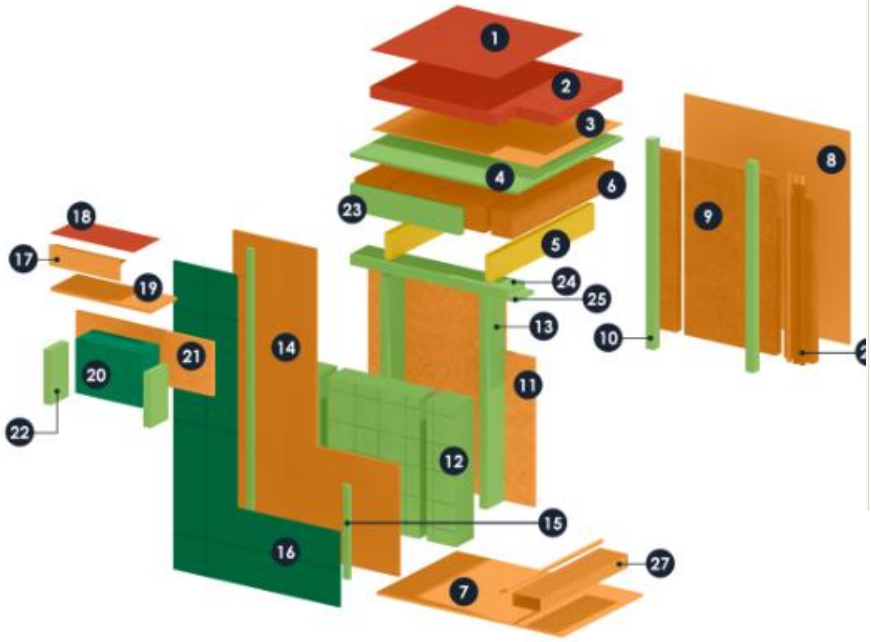
Table 2: advantage & disadvantages regarding different characteristics, grouped by building system

	Assembly recovery	*Component recovery*	*Heavy timber*
Number of deconstruction steps	+	-	+
Dealing with damage	-	+	+
Complexity	±	±	+
Unknown/short service life	-	+	+
Verification	± Irrespective of building system	±	± Irrespective of building system
Value of recovered elements	+	-	+

6. Design for Disassembly (DfD)

ISSO Standaard Referentiedetails: Meetmethodiek losmaakbaarheid





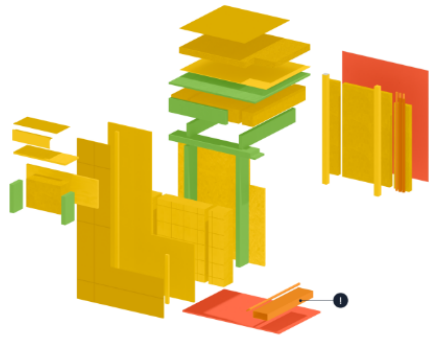
LEVENSDUURKENMERKEN VAN DE SAMENSTELLING

De levensduur heeft een indicatie omtrent de levensduur per type materiaallaag. Op de afbeelding wordt de levensduur per materiaal aangeduid in een kleur volgens deze legende:

Site	Structure	Skin	Services	Space plan
oneindig	> 60 jaar	30 – 60 jaar	7 - 25 jaar	5 – 20 jaar

Constructieve producten (producten onder de laag 'Structure') blijven meestal de gehele levensduur van een gebouw behouden, terwijl de afwerking meerdere malen wordt vervangen. Producten met kortere levensduur dan die van het gebouw waarin ze toegepast worden, zijn extra interessant om losmaakbaar uit te voeren.

Het is dan ook zinvol dat verbindingen tussen lagen met een verschillende levensduur maximaal toegankelijk zijn en dat de type verbindingen eenvoudig en snel te demonteren zijn. Voornamelijk in functie van renovatie- en/of herstelwerken moet worden vermeden dat lagen met een verschillende levensduur met elkaar worden vermengd (doorkruisingen, zoals technische leidingen in een gespoten isolatie) en dat de zijden van de materiaallaag (randen zoals een tand- en groefverbinding) maximaal ongebonden zijn met aanliggende materiaallagen.



5| DRAAGBALKEN DAK

6| ROTSWOLISOLATIE

7| GIPSKARTON PLAFOND

16	Gevelbekleding vezelcement	0,01
	U-waarde [W/m²K]	0,185

Source: Circular buildings: disassembly potential measurement method
Source: UGent, To bio or not to bio, https://milieubewustisoleren.be/

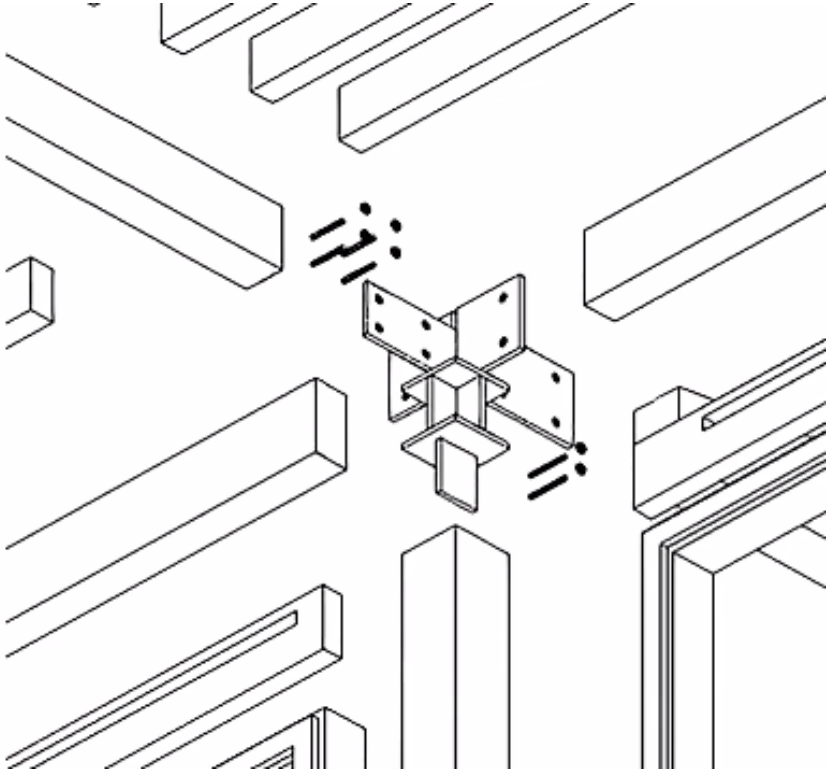
LIÈGE université SBD Lab

Conclusions

LIÈGE université

Designers

Material Choice



Key questions to answer

1. Does the material fit the purpose?
2. To what extend is the material available?
3. Can the raw material be mined locally?
4. How much energy is needed to produce the material?
5. Is the production process happening locally?
6. How much waste is produced during the production process?
7. Is there environmental contamination or hindrances during the production process?
8. What maintenance does the material require?
9. Is the product ready for disassembly?
10. Can the product be recycled?

Designers

Material Choice

Lessons Learned

Regenerative and Positive Impact Architecture

1. 
Design for Reversibility and Modularity
enable easy assembly and disassembly for long building lifespans

2. 
Design for Circularity
select components that can be properly reused and expanded their lifespan

9. 
Enable Collaborative Consumption and Leasing Services
extend the suppliers and producers responsibility

Certification and Liability

Green Building Rating Systems as Design Rules

Use Level(s) at 3 different levels

Level 1

Concept stage/qualitative

Level 2

Design and construction/ quantitative

Level 3

Reality/monitoring, including the handover to the client

LIÈGE université SBD Lab

Circular Buildings

Circularity Challenges

Definition and Terminology

•Persistent issue of contradicting or inconsistent language across standards and working groups.

Reference Service Life

•Timing and temporality remain a tension point: assessment now vs. postponing impacts into the future.

Building Taxonomy and Functional Unit

•Functional unit definition remains a key challenge in comparing resource flows, retained value, and environmental impacts.

Retained Value

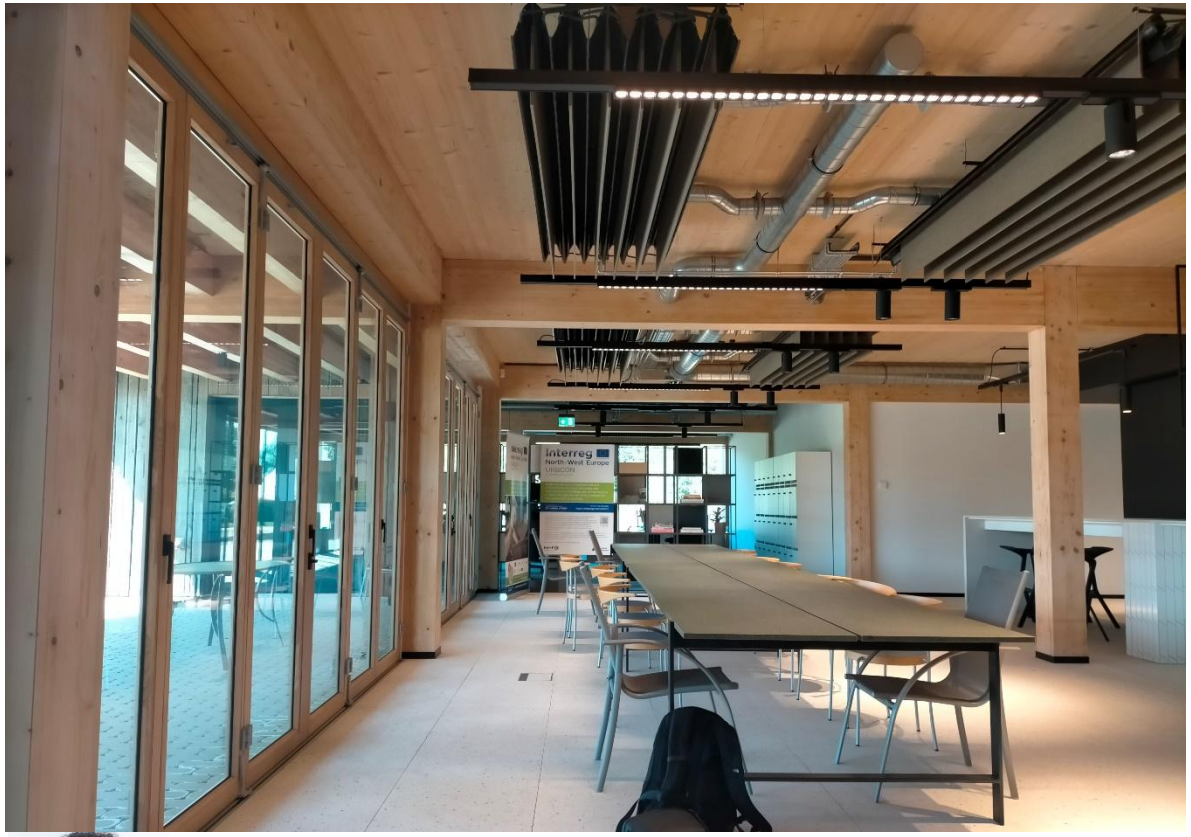
•The retained value is the engine of the circular economy. The value must be retained from day one and not pushed to a second life.

Circularity Assessment

•To assess circularity, we first need measurements, then data collection, and finally calculations.

•Unfortunately, no one is currently doing measurements and data collection because there are no defined KPIs and metrics.

Decision Support for Circularity in Office Building Design



Prof. Dr. Shady Attia
Sustainable Building Design Lab, UEE,
Applied Sciences, University of Liège, Belgium
shady.attia@uliege.be

/in/shady-attia-14352a7
/www.shadyattia.org

LIÈGE université
SBD Lab