Circular Façade Design for various End-of-Life scenarios

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Contents

01

Introduction

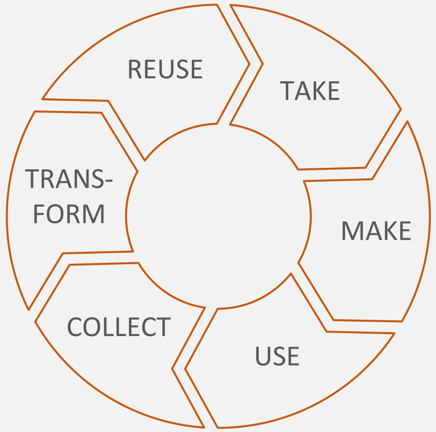
Circular Economy

LINEAR ECONOMY

Materials in a Linear Economy create waste after use.

CIRCULAR ECONOMY

Materials in a Circular Economy are collected and reused after each use



Building & Construction Industry

35%

Waste produced globally

(European Commission, 2022)

Façade System

20%

Construction Cost

(BES Consultants, 2022)

10-20%

Embodied
Carbon

(Andre et al., 2021)

Complex system

With

Multiple layers

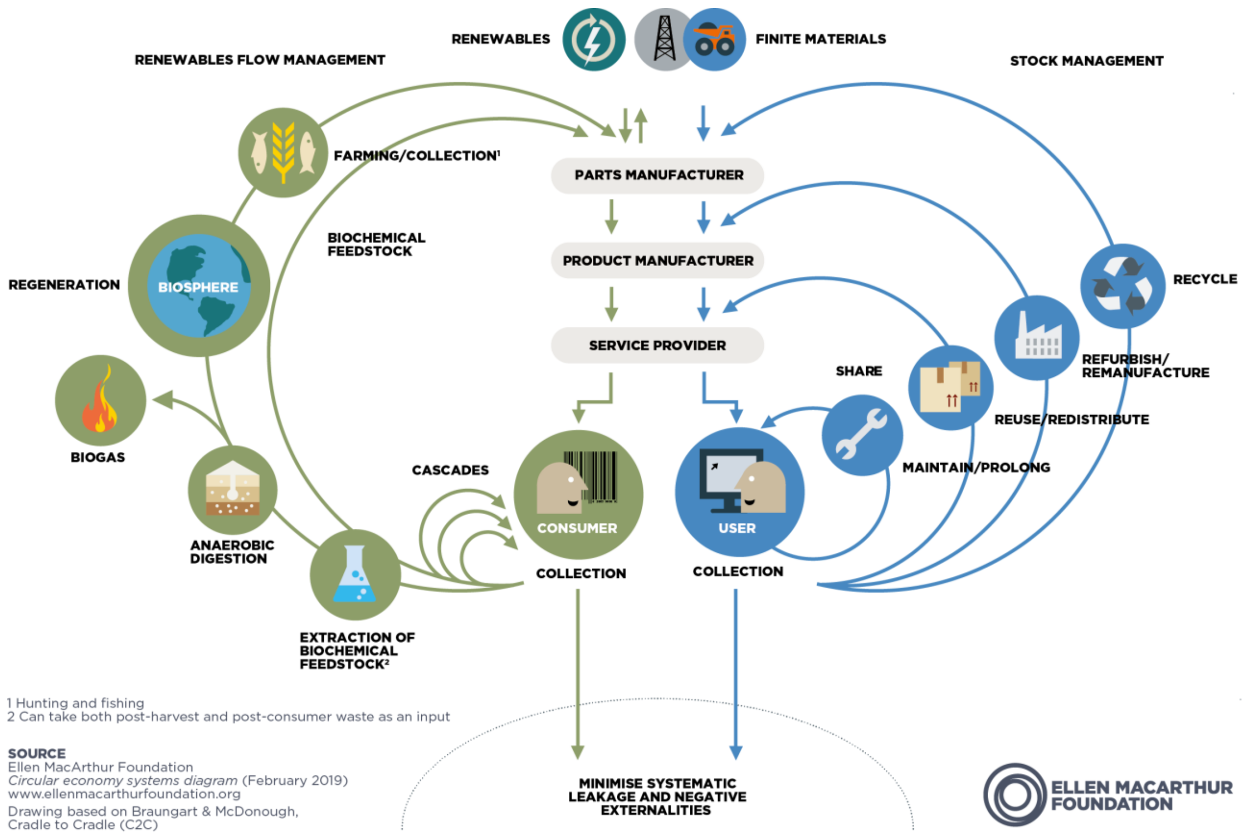
Multiple functions

Multiple materials

Multiple connections

(Hartwell et al., 2021)

Butterfly Diagram



Butterfly Diagram by Ellen MacArthur Foundation

Life Cycle Stages

Life cycle stage	Product stage			Construction process stage		Use stage							End-of-Life stage			Beyond End-of-Life stage
Processes	Raw material supply	Transport	Manufacturing	Transport	Construction - Installation Process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy	Operational Water Use	Transport	Waste processing	Disposal	Reuse, Recovery and Recycling Potential
Broader classification of stages	Design stage Stage A					Operational stage Stage B							End-of-Life stage Stage C & D			

Life cycle stages in construction works from BSEN15978

Objective

Life cycle stage	Product stage			Construction process stage		Use stage							End-of-Life stage			Beyond End-of-Life stage
Processes	Raw material supply	Transport	Manufacturing	Transport	Construction - Installation Process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy	Operational Water Use	Transport	Waste processing	Disposal	Reuse, Recovery and Recycling Potential
Broader classification of stages	Design stage Stage A					Operational stage Stage B							End-of-Life stage Stage C & D			

Life cycle stages in construction works from BSEN15978

EoL stage

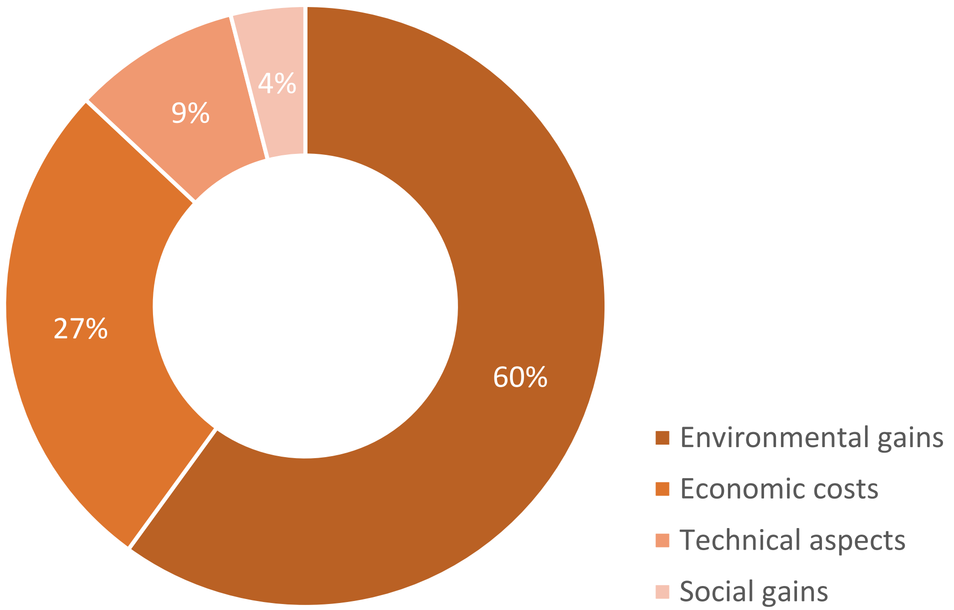
01 Extending the life leads to energy savings and less environmental impacts.

02 Constructive management at EoL enables recovery, recycling and reuse of materials and components.

03 Reduces waste sent to landfill or incineration and minimizes environmental pollution.

(European Commission, 2020), (Frosch and Gallopoulos, 1998), (Ellen MacArthur Foundation, 2013).

EoL decision making



van den Berg et al. (2023)

EoL stage

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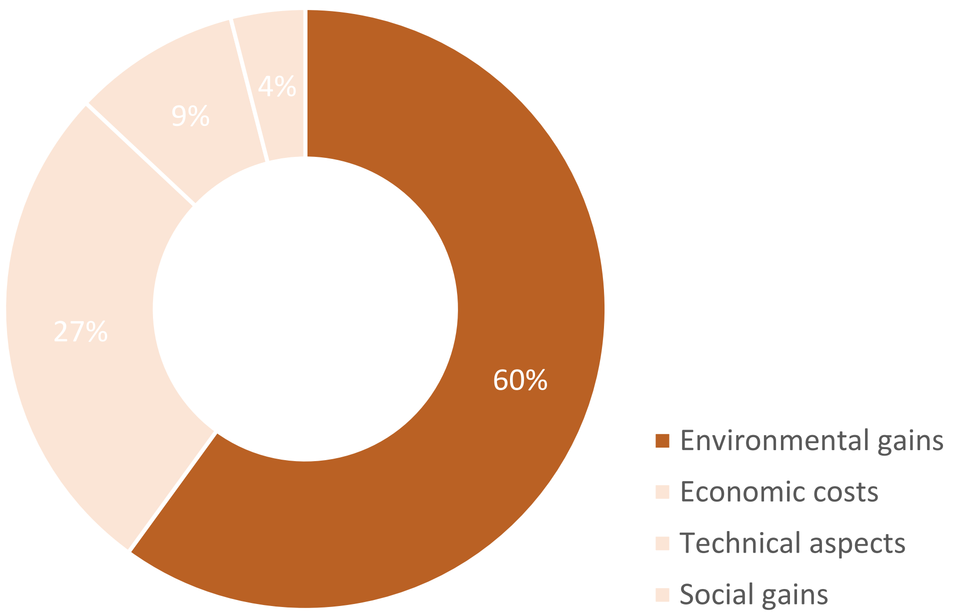
EoL decision making



van den Berg et al. (2023)

Current situation and Problems

Generative Design Aids

Thumb Rules | Checklists

Guidelines | Archetypes

Evaluative Design Aids

MFA | LCA

MCI | MCI

Generative Design aids assist in creating a circular design but do not tell which design is more circular.

Evaluative Design aids are time consuming.

Problem statement

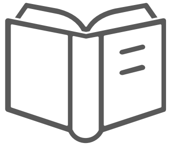
There are a very few **design guidelines** for the façade designers that take into account the various **End-of-Life scenarios** of a façade system and the **information** that needs to be considered to follow the guidelines.

Research question

What **design guidelines** can help the **façade designers** integrate the considerations for a **circular End-of-Life (EoL)** of a façade system during the design phase and what is the **information** that needs to considered while following these design guidelines?

Research Sub-questions

What are the different assessment methods for circularity?



Literature study

What are the design guidelines to integrate a circular EoL during the design stage?

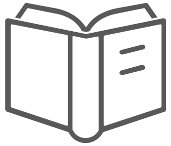
Research through Design

What information impacts the circularity of the EoL stage based on the design guidelines?

Research through Design

Research Sub-questions

What are the different assessment methods for circularity?



Literature study

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Research through Design

02

Literature Review

Circularity Assessment Methods

No.	Assessment method	Advantages	Disadvantages	Reason for not considering
1	MCI	1. Takes into account material inputs and outputs. 2. Focused on evaluating specific products and systems.	1. Does not take into account the complexity of the circularity since it does not take into account the aspects like biodiversity, toxicity and human health impacts 2. Does not take into account the CO_2 emissions thus the results showcase a high score for the materials with a high recycled content. 3. Only focused on calculating the quantity of the input and output of materials in a system.	Only calculates input and output materials in a system.
2	MFA	1. MFA is a detailed analysis of flow of all the materials within a system boundary.	1. Does not calculate the environmental impacts but calculates only the input and output flows as quantities in a system.	Does not calculate the environmental impacts.
3	BCI	1. Offers information about the building detachability along with the input and output of materials in the system.	1. Only takes into account a cradle-to-grave approach and not cradle-to-cradle approach. 2. It does not consider benefits beyond system boundaries.	Has a cradle-to-grave approach.
4	LCA	1. Takes into account the entire life cycle of the building. 2. Calculates the environmental impacts based on different indicators. 3. Includes stages regarding EoL processing impacts and benefits beyond the EoL stages.	1. Complex and time consuming. 2. Requires an extensive database to obtain accurate results.	

Research Sub-questions

What are the different assessment methods for circularity?

Literature study

What are the design guidelines to integrate a circular EoL during the design stage?

Research through Design

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Research through Design

03

Design case

AEGiR case

DigitAl and physical incremestal renovation packaGes/ systems enhancing envIronmental and energetic behaviour and use of Resources

Bigger aim

Net zero economy by 2050

Current Building Stock

85% building stock built before 2001 and will be still standing in 2050.

Renovation

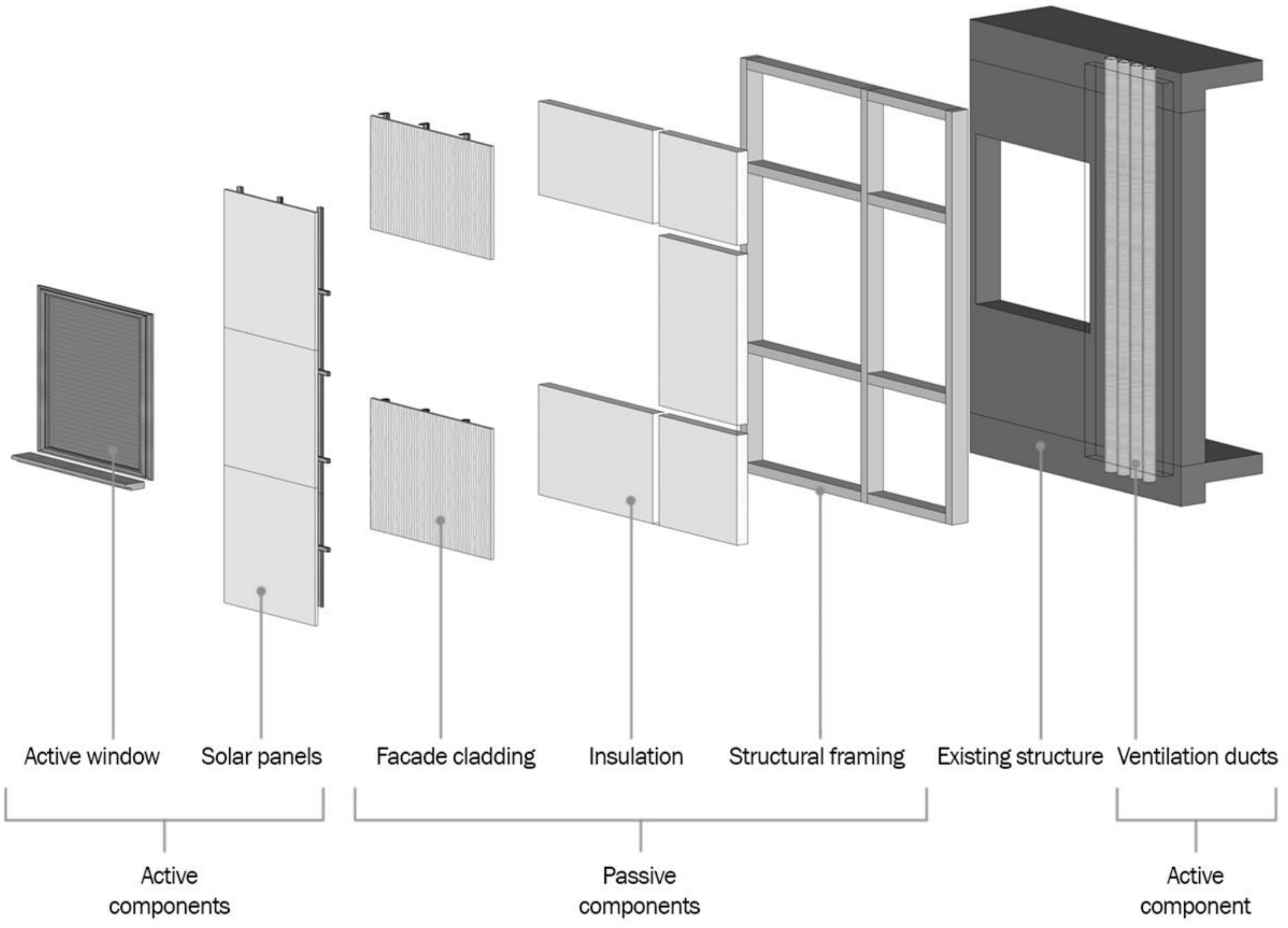
Less energy efficient buildings – more energy bills, affects indoor comfort.

New construction

Fall in the number of newly constructed buildings

European Commission,2015

AEGiR case



Wrap-it

The new envelop is wrapped around the existing building.

Circular construction

The new envelop system aims to achieve a circular construction.

Pre-fab and modular

Pre-fabricated and industrialised modular envelop system.

Components

The components of AEGiR will help to meet the energy demands.

Case Development

01

Dutch Housing

It is an important part of the Dutch building stock

02

World War II

1946 – 1969

Tackle the housing crises

03

Lifespan

The lifespan of these houses is more than 50 years

04

Energy demand

Satisfying the operational energy demand

05

Construction type

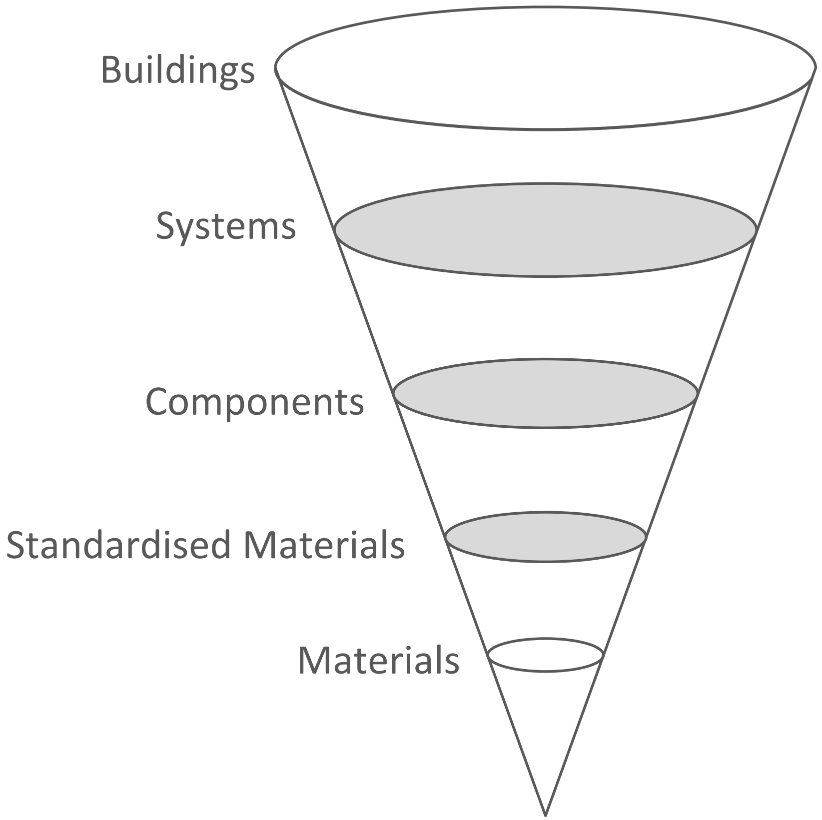
RCC framed, prefab, industrialised construction

06

Rc value

2.53 m^2 K/W

Preliminary Design Development



Constant criteria

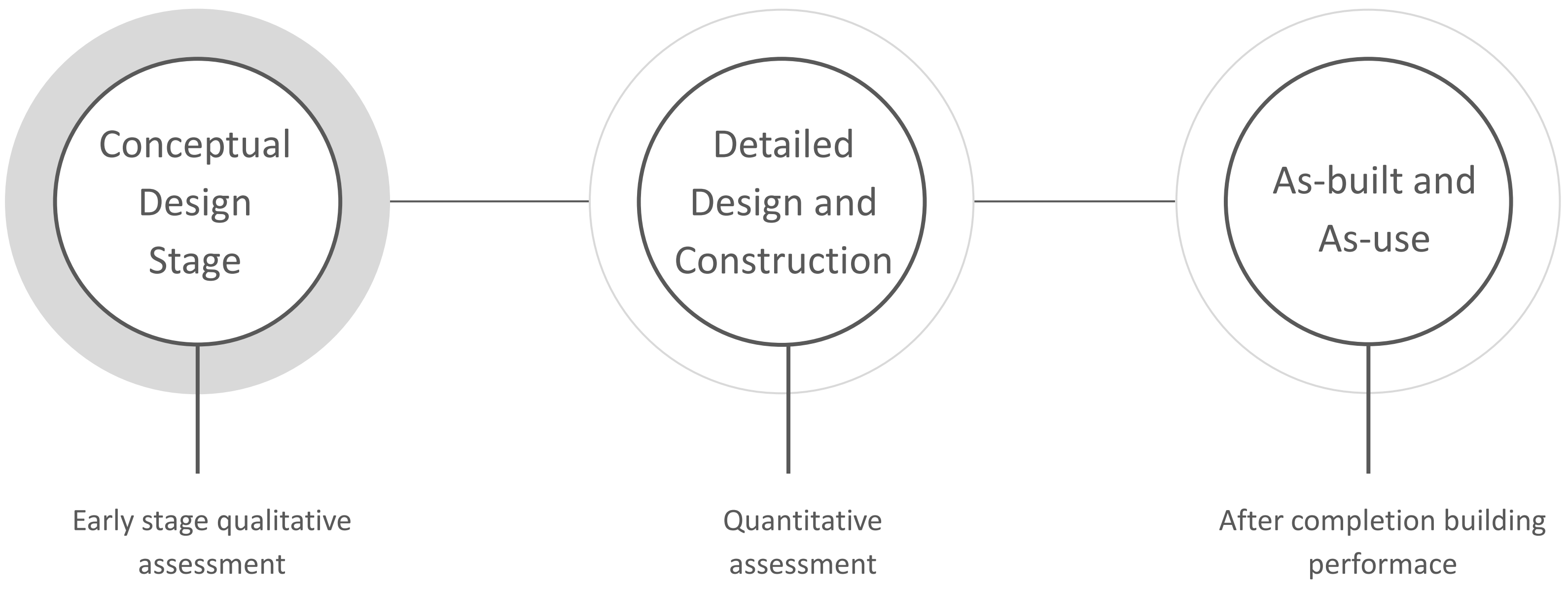
Thermal comfort
Acoustics performance
Energy performance
Daylight conditions
Rc value of the insulation

Constant Components

Solar panels
Ventilation system

Variable components

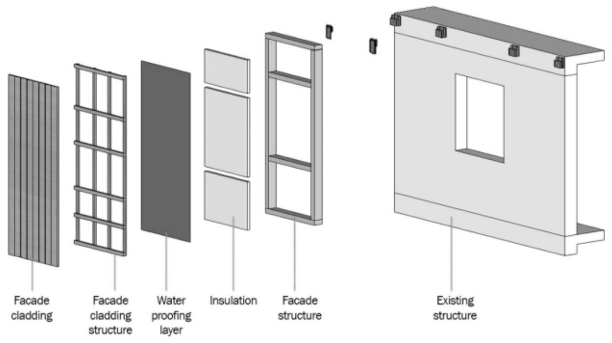
Façade cladding
Insulation
Façade cladding
Façade cladding support
Solar panel support
Window frame



Design stages as described in the level(s) indicators

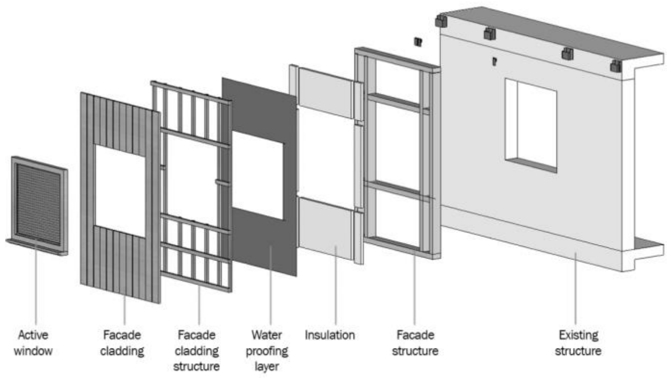
Preliminary Design

Panel A



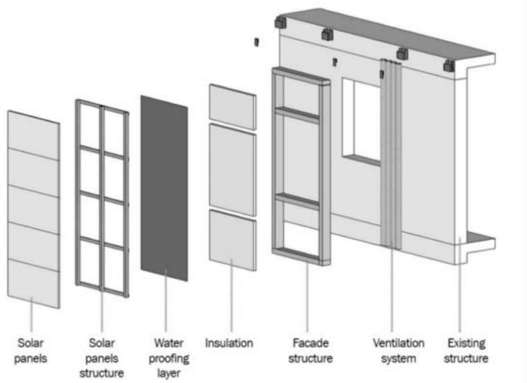
Façade Cladding
Insulation
Façade Structure

Panel B



Façade Cladding
Insulation
Façade Structure
Window

Panel C



Insulation
Façade Structure
Solar Panels
Ventilation ducts

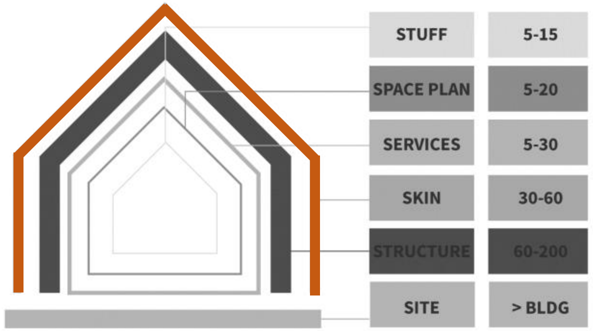
04

Design variants

End-of-Life?

End of **technical** service life

↓



Building layers by Brand (1994)

↓

30 years

End of **functional** service life

↓

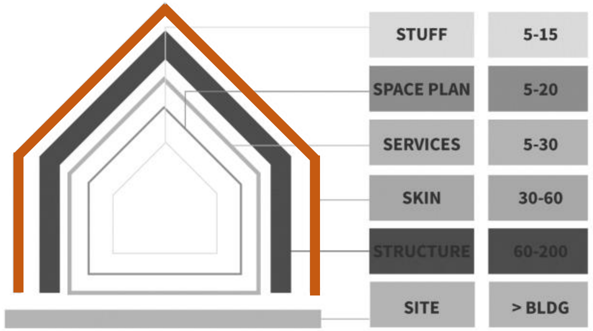
Unpredictable

↓

Change in function
Change in aesthetics of the building
Does not satisfy energy requirements

End-of-Life?

End of **technical** service life



Building layers by Brand (1994)

30 years

End of **functional** service life

Unpredictable

Change in function
Change in aesthetics of the building
Does not satisfy energy requirements

Design scenarios

Technical lifespan

Technical service life of standardised materials.

Possible EoL

All the possible EoL scenarios based on the available technology.

Circular material strategies

Material choices play a fundamental role in designing for a circular economy.

S1 **Long lifespan materials**

>60 years

Using materials and materials with a long lifespan.

S2 **Short lifespan materials**

<60 years

Components with materials that have a shorter lifespan.

S3 **Bio based materials**

Components made from bio-based materials

R-ladder

Technical lifespan

Technical service life of standardised materials

Possible & Circular EoL

All the possible EoL scenarios based on the available technology and circular EoL scenarios were identified.

Circular material strategies

Material choices play a fundamental role in designing for a circular economy

INCREASE IN CIRCULARITY

Objectives	Re-life Options	Description
• Design phase • Most sustainable • Adds value • Responsible use and manufacturing	R0 Refuse	Prevent the use of products and raw materials in the creation.
	R1 Rethink	Reconsider ownership, use, and maintenance of products.
	R2 Reduce	Decrease the use of raw materials in products and services.
• Consumption phase • Optimal Use • Preserve and Extend the life of the product	R3 Reuse	Secondary use of products by another owner for the same intended purpose.
	R4 Repair	Maintain and repair existing products for extended use.
	R5 Refurbish	Restore and improve products to a satisfactory condition for extended use.
	R6 Remanufacture	Make more products with the same purpose with discarded products or parts.
	R7 Repurpose	Make new products with a different purpose using discarded products or parts.
• End-of-Life or return phase • Capture and retain value • Use waste as a resource	R8 Recycle	Process waste into new products or materials that can be used for new products.
	R9 Recover	Process waste to recover energy.
• Loss of resources • Value lost • Environmental pollution	Landfill or Incineration	Not utilising end-of-life materials in any way

The 10R framework by Potting et al. (2017, p.5)

Design variants

Technical lifespan

Technical service life of standardised materials

Possible EoL

All the possible EoL scenarios based on the available technology.

Circular material strategies

Material choices play a fundamental role in designing for a circular economy

01 **Traditional materials**

This is important towards EoL because it is easier to repair or refurbish these materials since the raw material and the construction technique are easily available.

02 **Low-cost materials**

These materials have a reduced material cost, processing and manufacturing cost, less resource consumption.

03 **Low material production energy**

They refer to the application of materials in the system in their natural form.

Design variants

S1

Long lifespan materials

1. Traditional
2. Low cost
3. Low production energy

S2

Short lifespan materials

4. Traditional
5. Low cost
6. Low production energy

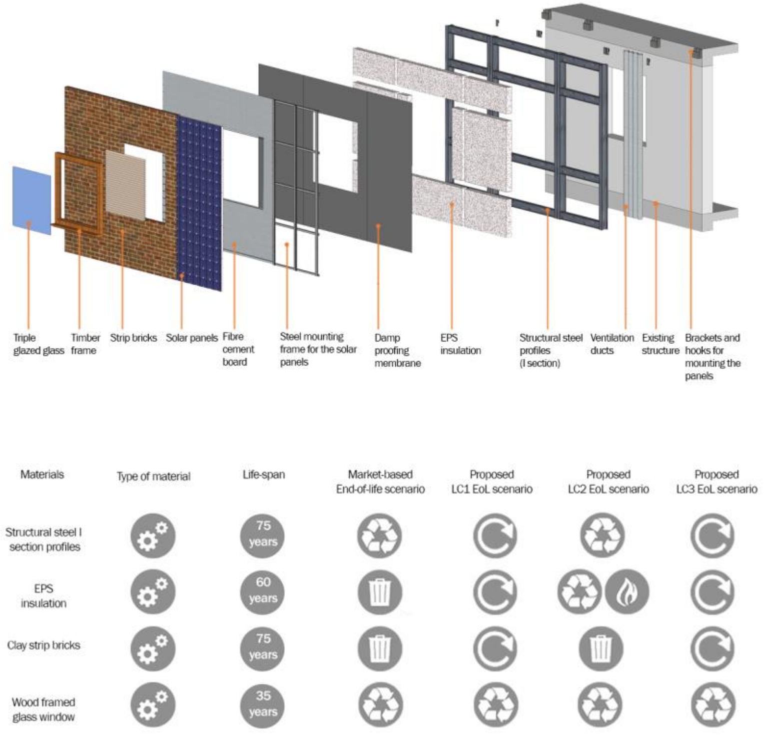
S3

Biobased materials

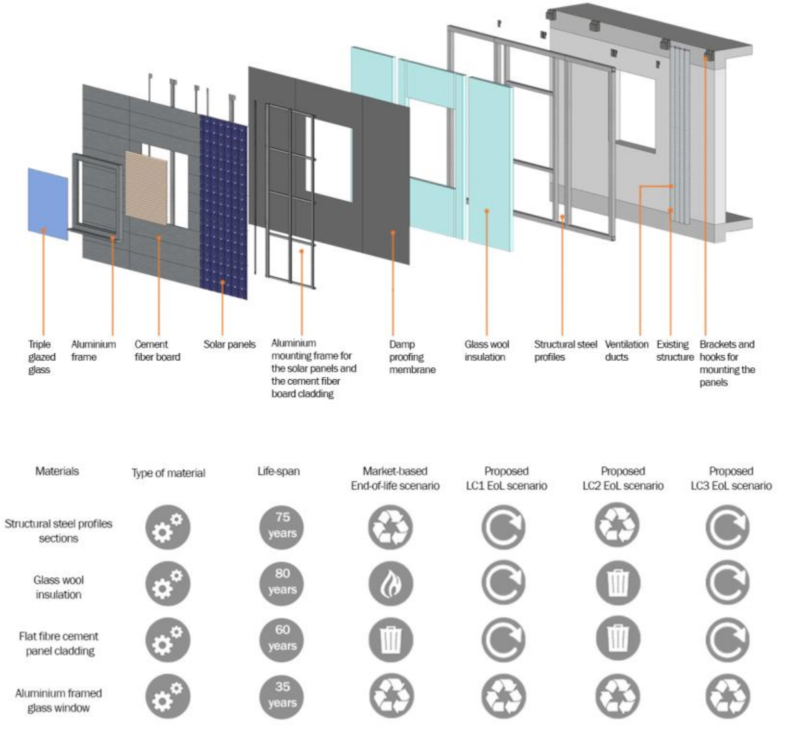
7. Traditional
8. Low cost
9. Low production energy

S1: Long lifespan materials

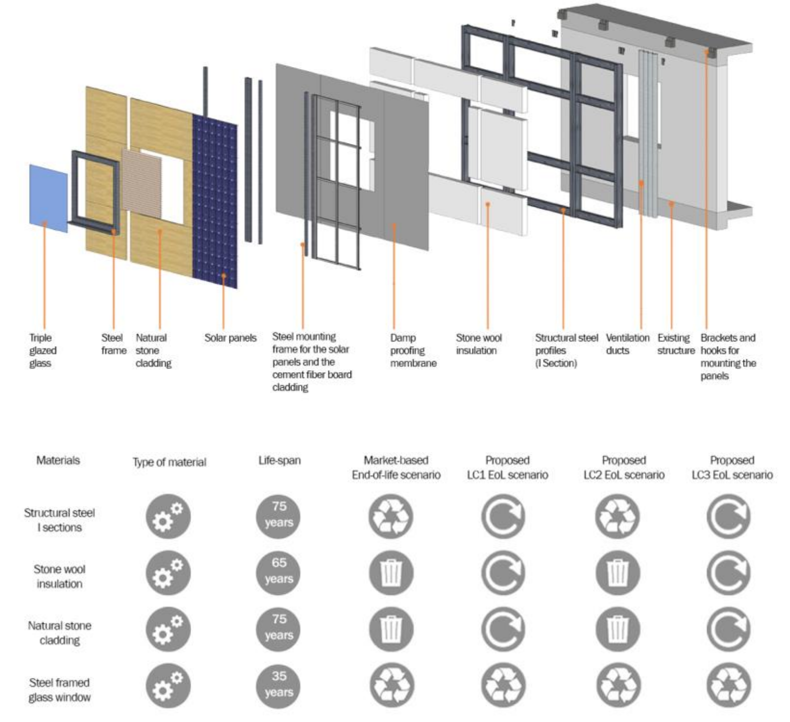
Variant 1 - Traditional materials



Variant 2 – Low-cost materials

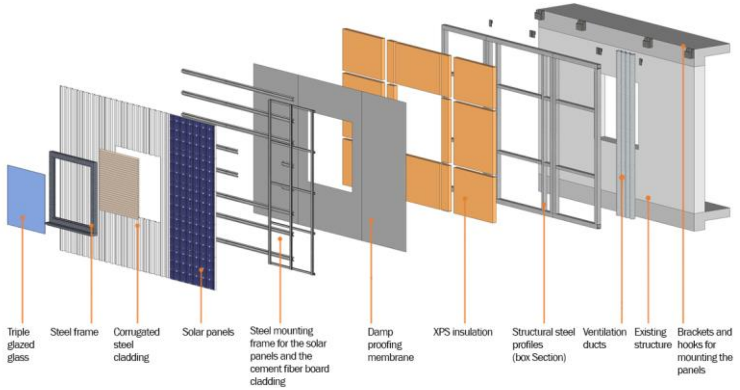


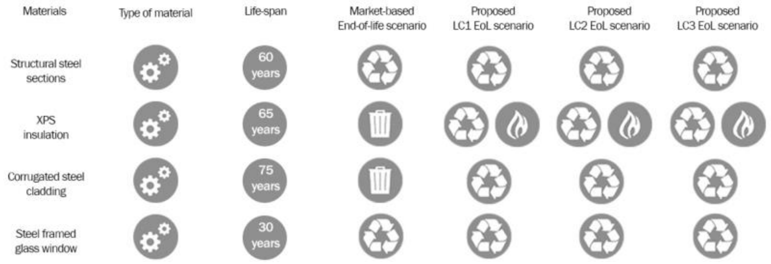
Variant 3 – Low material production energy



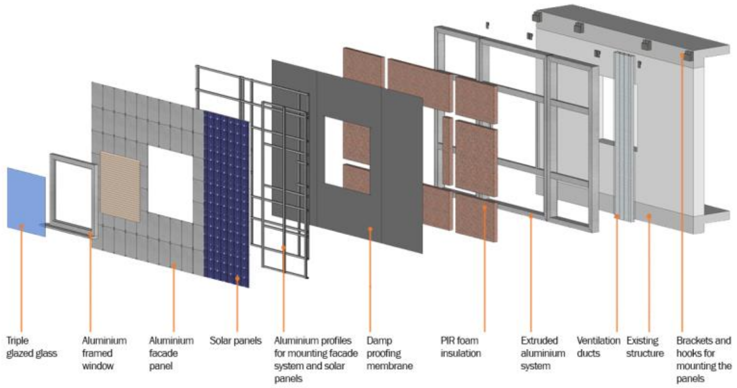
S2: Short lifespan materials

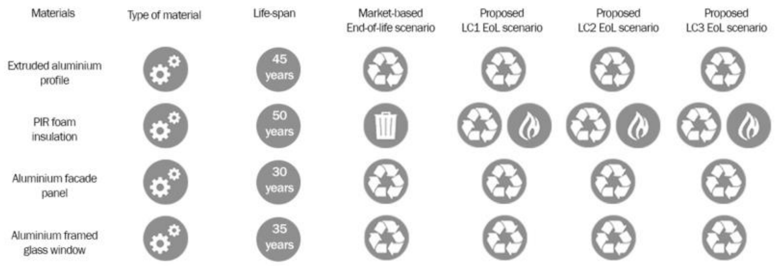
Variant 4 – Modern-Traditional materials



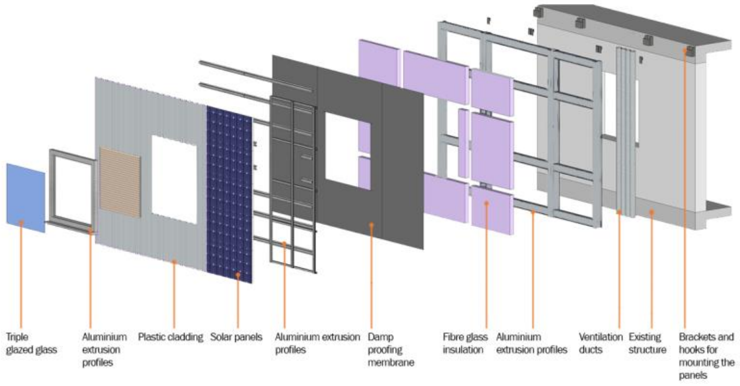


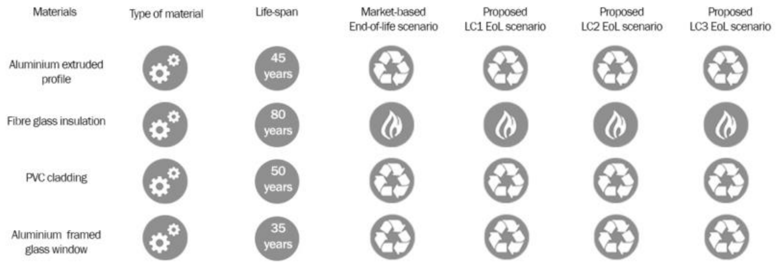
Variant 5 – Low-cost materials





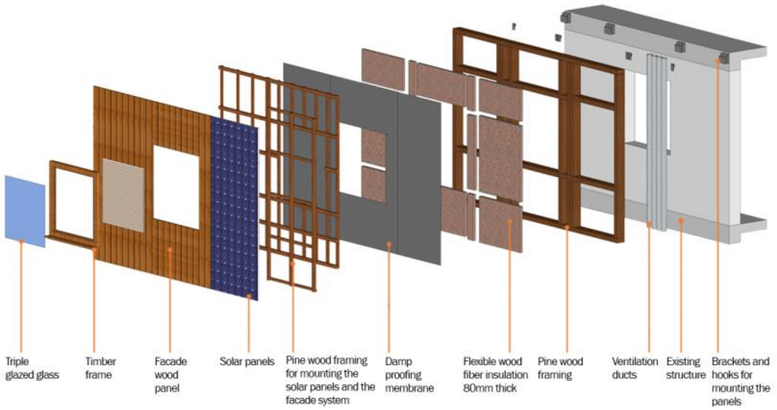
Variant 6 – Low material production energy





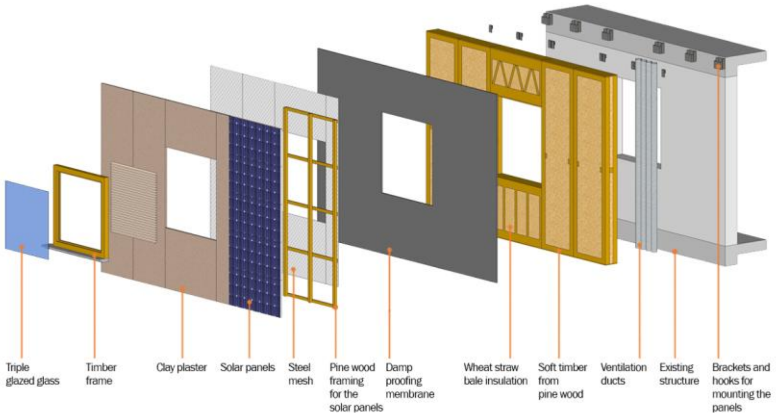
S3: Biobased materials

Variant 7 - Traditional materials



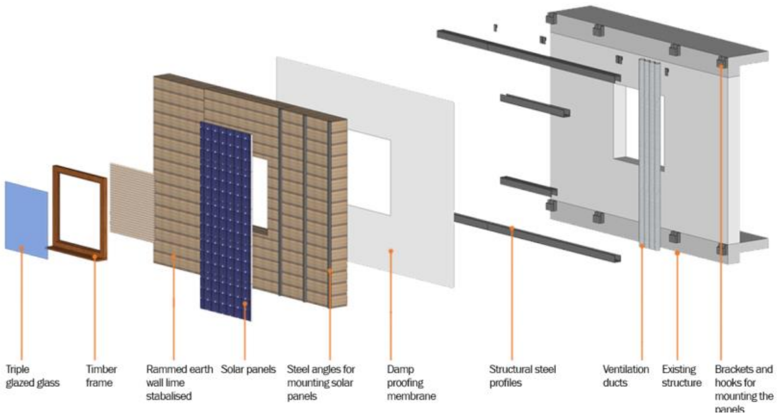
Materials	Type of material	Life-span	Market-based End-of-life scenario	Proposed LC1 EoL scenario	Proposed LC2 EoL scenario	Proposed LC3 EoL scenario
Structural pine wood		50 years				
Wood fibre insulation		50 years				
Facade wood panel		50 years				
Timber framed glass window		35 years				

Variant 8 – Low-cost materials



Materials	Type of material	Life-span	Market-based End-of-life scenario	Proposed LC1 EoL scenario	Proposed LC2 EoL scenario	Proposed LC3 EoL scenario
Structural pine wood		35 years				
Wheat straw bale insulation		100 years				
Clay plaster		60 years				
Timber framed glass window		35 years				

Variant 9 – Low material production energy



Materials	Type of material	Life-span	Market-based End-of-life scenario	Proposed LC1 EoL scenario	Proposed LC2 EoL scenario	Proposed LC3 EoL scenario
Structural steel profiles		75 years				
Rammed earth wall lime stabalised		30 years				
Timber framed glass window		35 years				

05

Evaluation & Results

Evaluation

Quantities
Calculate the quantities of all the materials in the designed variants

↓

3D model

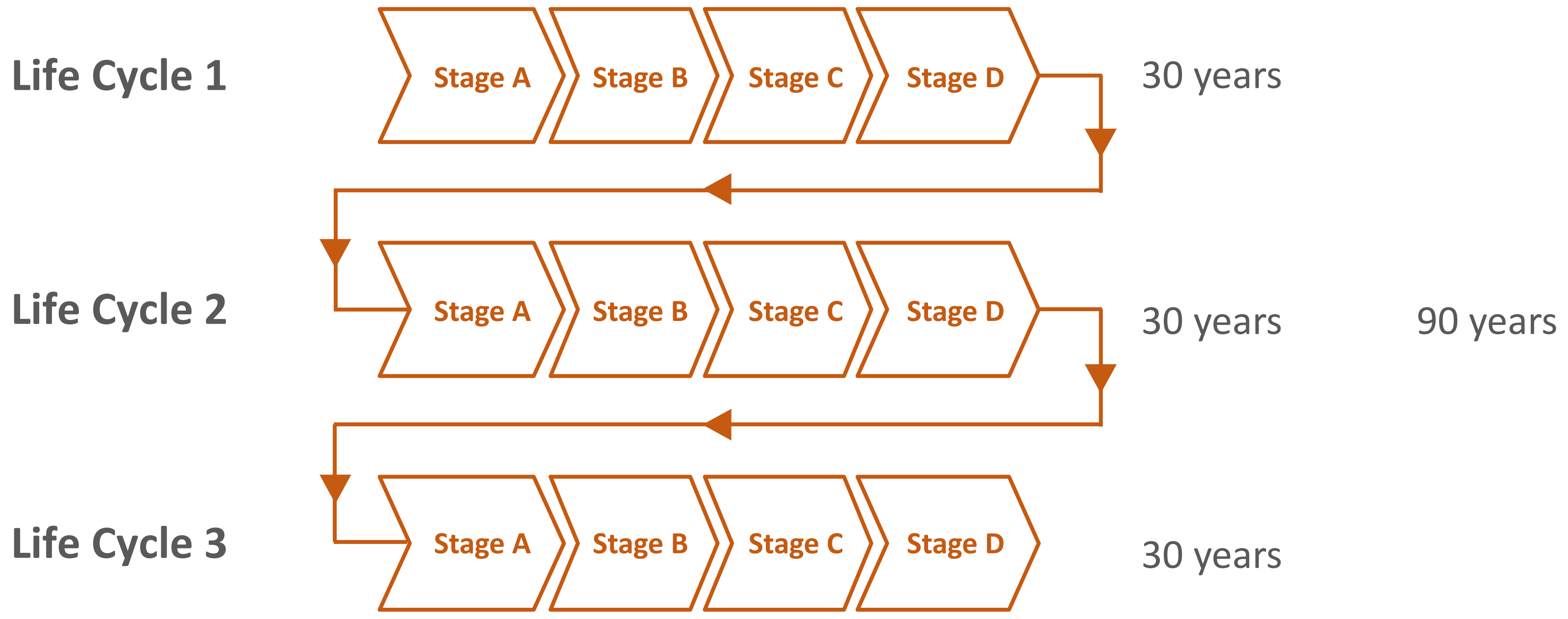
Evaluation method
Life Cycle Assessment

↓

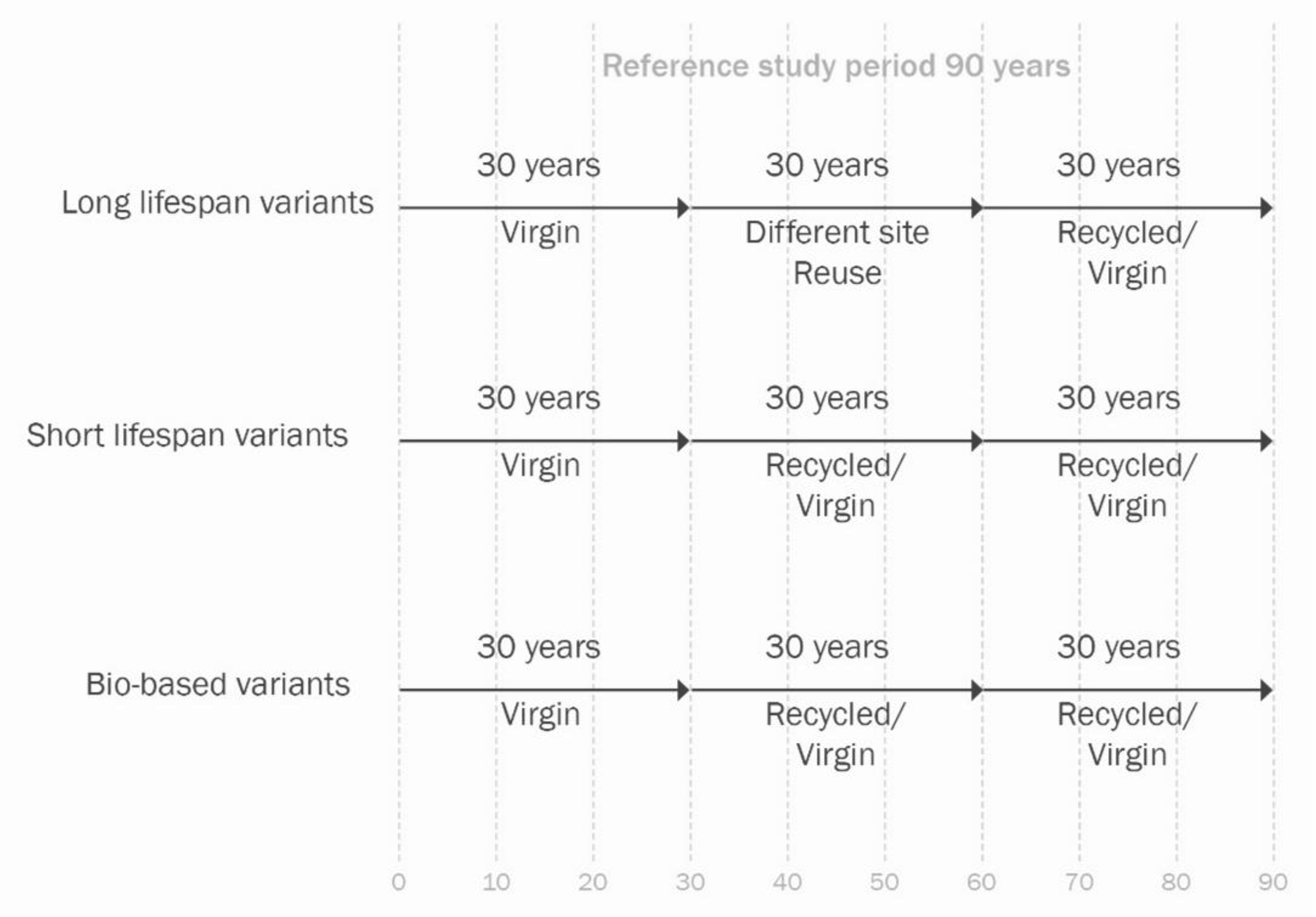
OneClick LCA

OneClick LCA
Module A,C and D

Inputs to OneClick LCA



Evaluation



Scenario 1 – Variant 1,2 & 3

Scenario 2 – Variant 4,5 & 6

Scenario 3 – Variant 7,8 & 9

KPIs

No.	KPI	Unit of measurement	Description
	Environmental impact indicators		
1	Global Warming Potential	CO_2eq	Global warming potential is a relative measure of how much heat a greenhouse gas traps in the atmosphere.
2	Biogenic Carbon Storage	CO_2eq bio	Biogenic Carbon Storage is the process of capturing and storing atmospheric carbon in living organisms and biomass.
3	Ozone Depletion Potential	kg CFC11eq	Describes the potential damage caused to the stratospheric ozone layer. Chemical refrigerants used in older air conditioning systems often have a higher ODP.
4	Acidification Potential	kg SO_2eq	Acidifying emissions that result in a lower pH-value of water and soil, decreasing the nutrient availability and intake of plants.
5	Eutrophication Potential	kg PO_4eq	Nutrient emissions (nitrogen and phosphorus) that increase the flow of nutrients to ecosystems, causing algae growth in waters.
6	Formation of Ozone of lower atmosphere	kg Ethenee	Formation of Ozone of lower atmosphere occurs when pollutants like nitrogen oxides and volatile organic compounds react with sunlight.
7	Abiotic Depletion Potential for non-fossil fuel resources	kg Sbe	Abiotic depletion refers to the global reduction of non-living, or abiotic, natural re-sources, such as mineral, metal and fossil resources.
8	Abiotic Depletion Potential for fossil fuel resources	MJ	
	Material costs		
1	Material market price	Euros	This is the regional market based cost of the standardised materials.
2	Typical labour cost for installing the material	Euros	This is the regional cost considered for installing a standardised material.

Results

Environmental impacts (kg CO_2 eq/ m2) & Building Circularity

Variants	Variant name	Environmental impact (kg CO_2 eq/ m2)	Building Circularity
Long lifespan variants	Variant 1	92	67%
	Variant 2	82	63%
	Variant 3	92	60%
Short lifespan variants	Variant 4	140	76%
	Variant 5	116	73%
	Variant 6	135	72%
Bio-based variants	Variant 7	34	75%
	Variant 8	29	53%
	Variant 9	83	12%

Environmental KPI results

Stage A and Stage C combined impacts

Most
Short lifespan materials

Least
Bio-based materials

Stage C impacts

Most
Short lifespan materials
Except GWP bio-based materials

Least
Bio-based materials
Except GWP – long lifespan materials

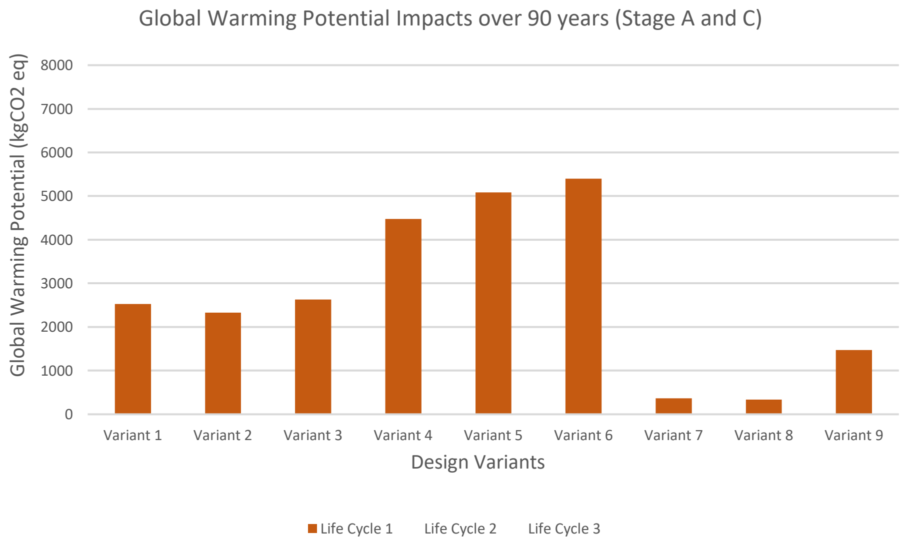
Stage D benefits

Most
Long lifespan materials

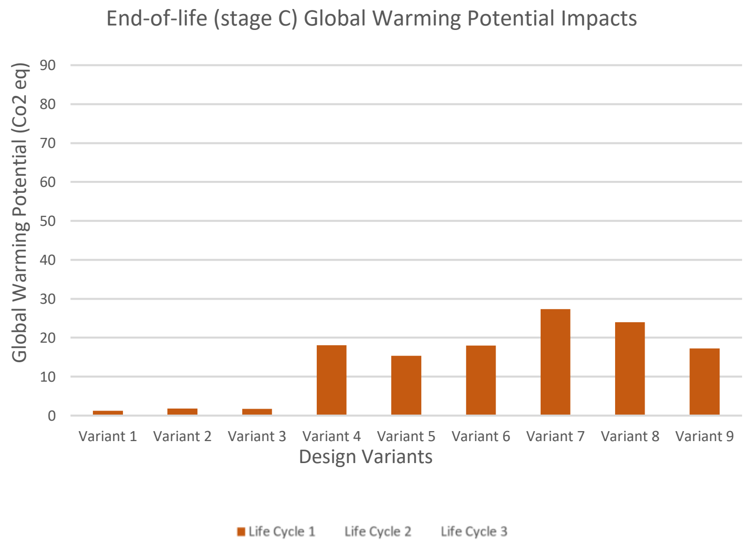
Least
Bio-based materials

Results

Stage A and Stage C combined impacts

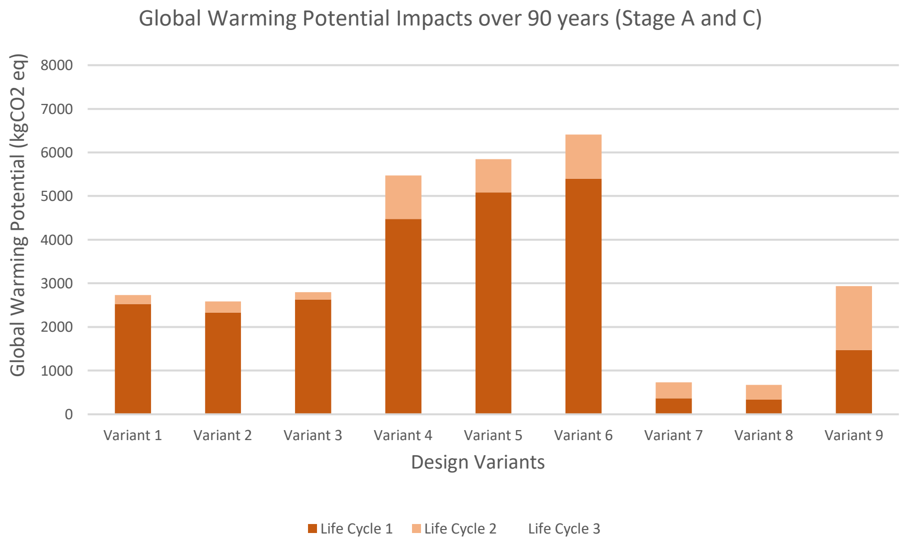


Stage C impacts

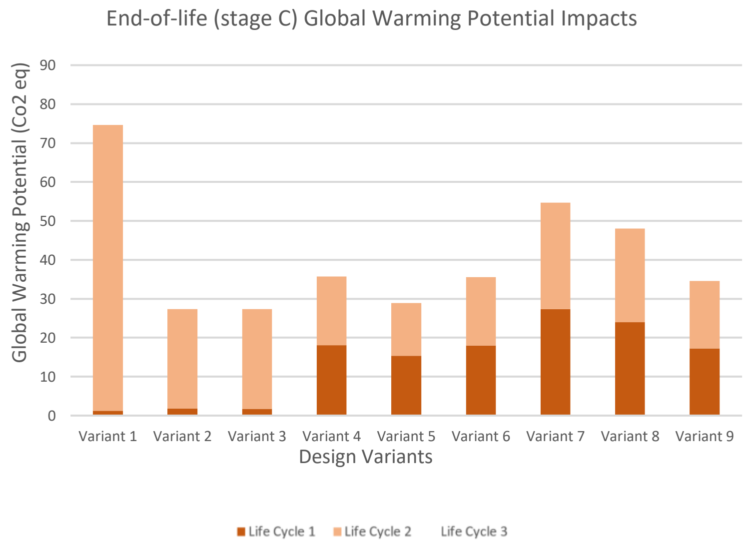


Results

Stage A and Stage C combined impacts

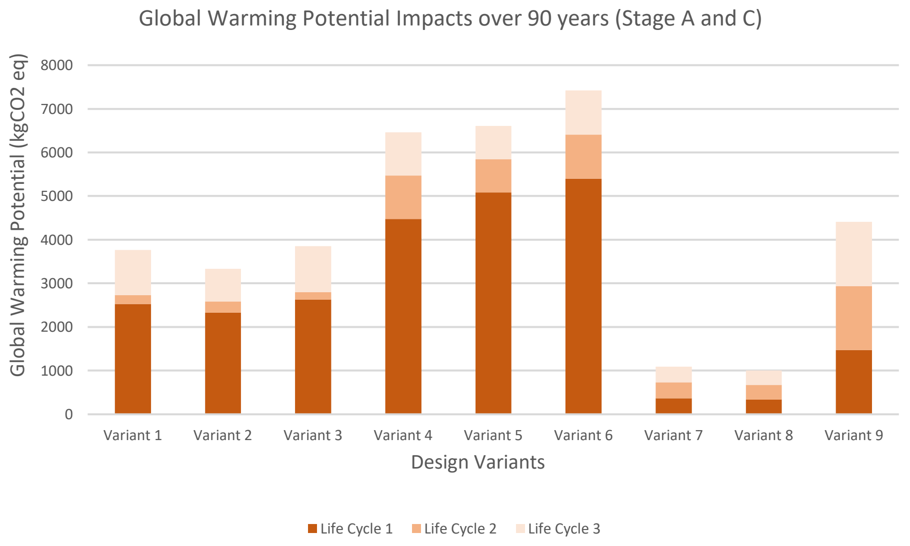


Stage C impacts

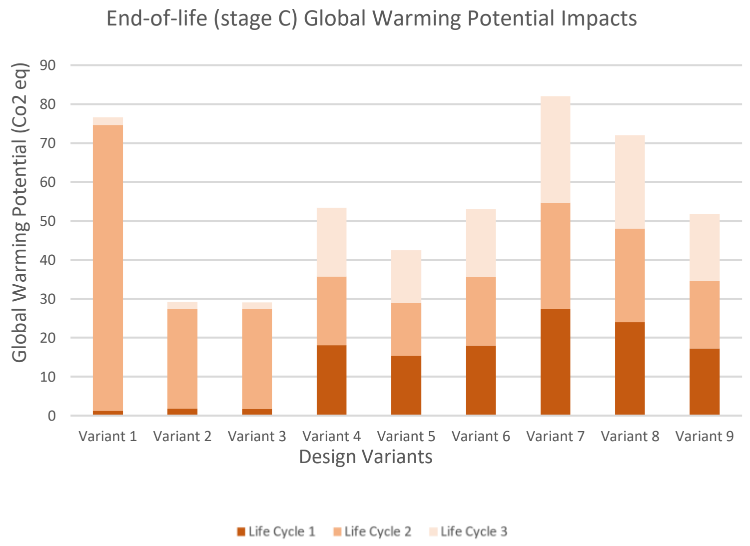


Results

Stage A and Stage C combined impacts

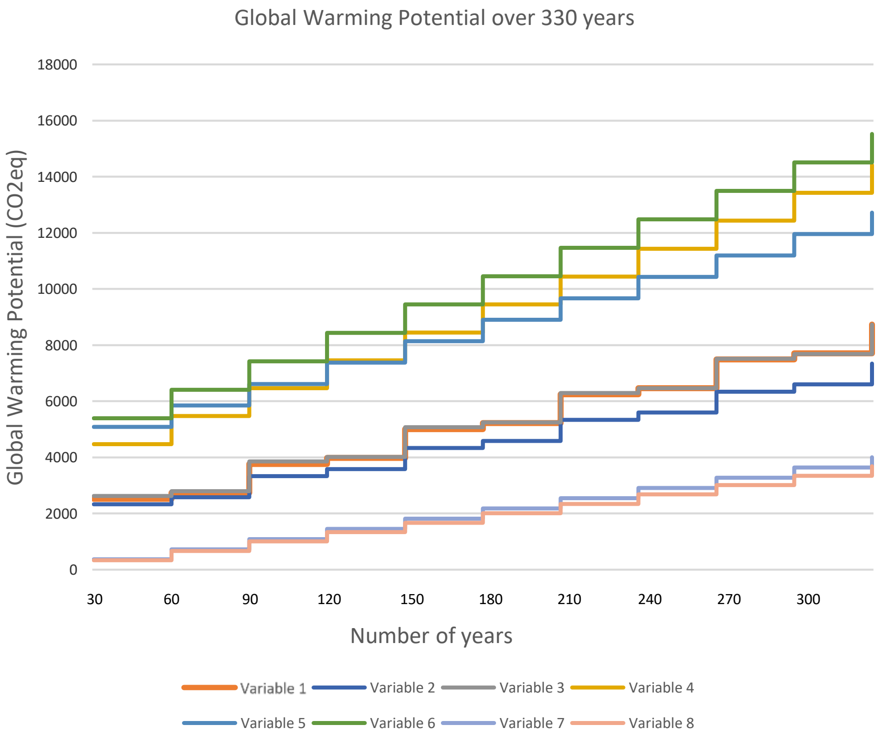


Stage C impacts

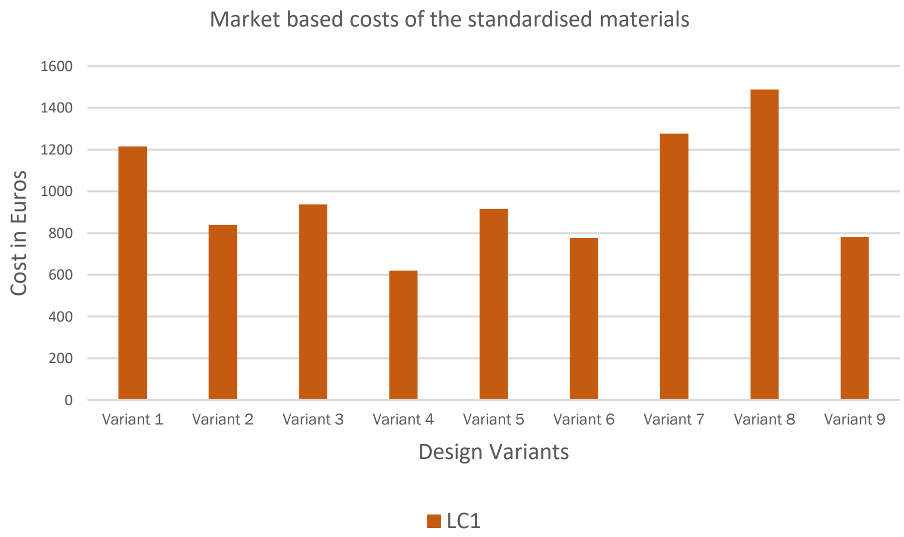


Results

GWP over a span of 300 years



Cost of the designed variables over LC1



Conclusions

- In circularity, to accurately assess the impacts, it is necessary to take into account a **multiple lifespan approach** rather than a single lifespan approach.
- Use of **more reused and recycled content** in the system created less environmental impacts.
- Thus, **lifespan and EoL** play an important role in deciding the circularity of the system. They also affect the environmental impacts that are created.
- If the **recyclability percentage and biodegradability percentage** in a system is high, the circularity is high and the GWP impacts are low.
- The materials used in the system should have a **low GWP processing energy** and a **low GWP of EoL processing.**

04

Design guidelines and information considerations

Design Guidelines & Information Considerations

Material Selection Guidelines

A **Material source**

Local materials

B **Recycled/ Reused content**

Maximise the content of reused and recycled Materials in the system

C **GWP of the EoL process**

Use materials that have possible EoL which is more circular

D **Recyclability**

Use technical materials that have a higher percentage of recyclable materials in the system.

D **Biodegradability**

Use biological materials that have a higher percentage of biodegradable materials in the system.

Life Cycle Planning

A **Select a material**

Select a material that satisfies the criteria mentioned in Material Selection Guidelines

B **Lifespan**

Select standardised materials with a long lifespan to enable their repeated reuse.

C **EoL scenarios**

All possible EoL scenarios should be known.

D **Circular EoL**

Combine the strategies for extending and closing the loop.

D **Multiple use cycles**

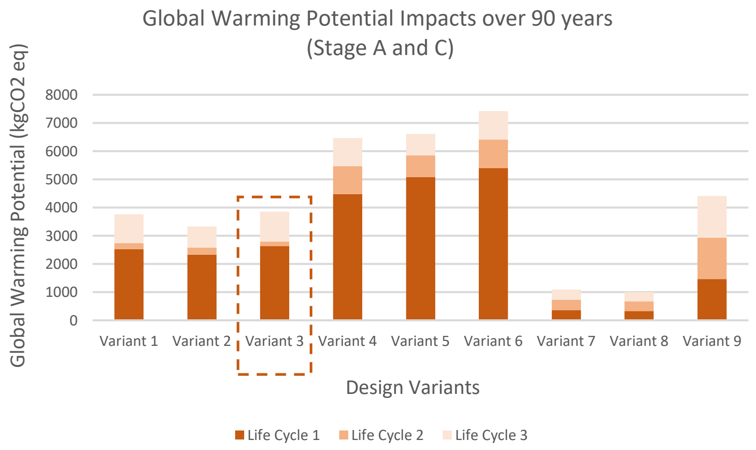
Consider multiple lifecycles and not just one lifecycle and Plan for the future cycles.

07

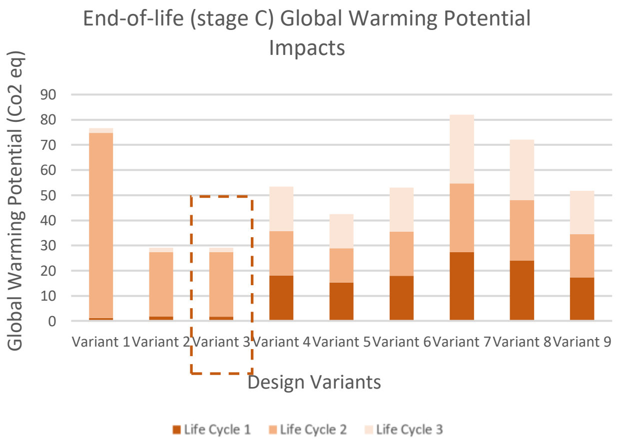
Validation & Final Design

Results

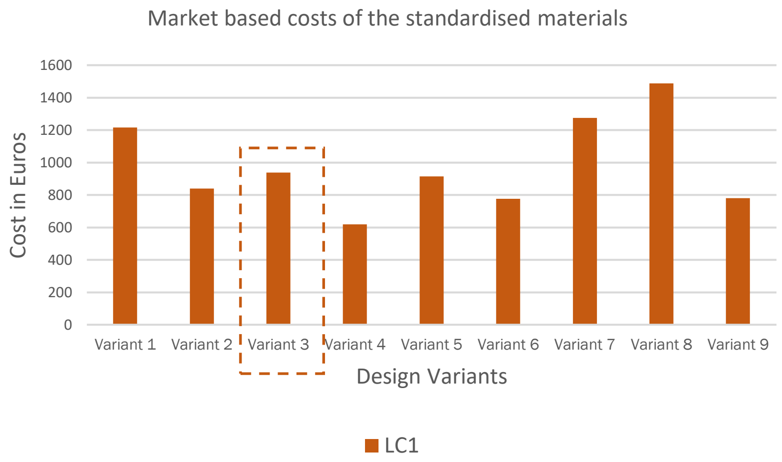
Stage A and Stage C combined impacts



Stage C impacts



Cost of the designed variables over LC1



Final Design Considerations

Material guidelines

Material sources

A B C D D

Component	Standardised material	Material source
Façade structure	Structural steel profile section	Netherlands
Insulation	Stone wool insulation	Netherlands
Façade cladding	Natural stone cladding	Netherlands
Façade cladding support	Structural steel profile section	Netherlands
Solar panel support	Structural steel profile section	Netherlands

Use local materials to facilitate easy minor and major repair as well as to reduce the emissions caused due to transportation of the materials.

Recycled/ Reused content

A B C D D

Component	Standardised material	Recycled content (LC1)	Reused content (LC1)
Façade structure	Structural steel profile section	100%	-
Insulation	Stone wool insulation	90% slag	-
Façade cladding	Natural stone cladding	0%	-
Façade cladding support	Structural steel profile section	100%	-
Solar panel support	Structural steel profile section	100%	-

Maximise the amount of reused and recycled content in the system.

Final Design Considerations

Material guidelines

GWP of EoL processing

A B C D D

Reuse and Recycle

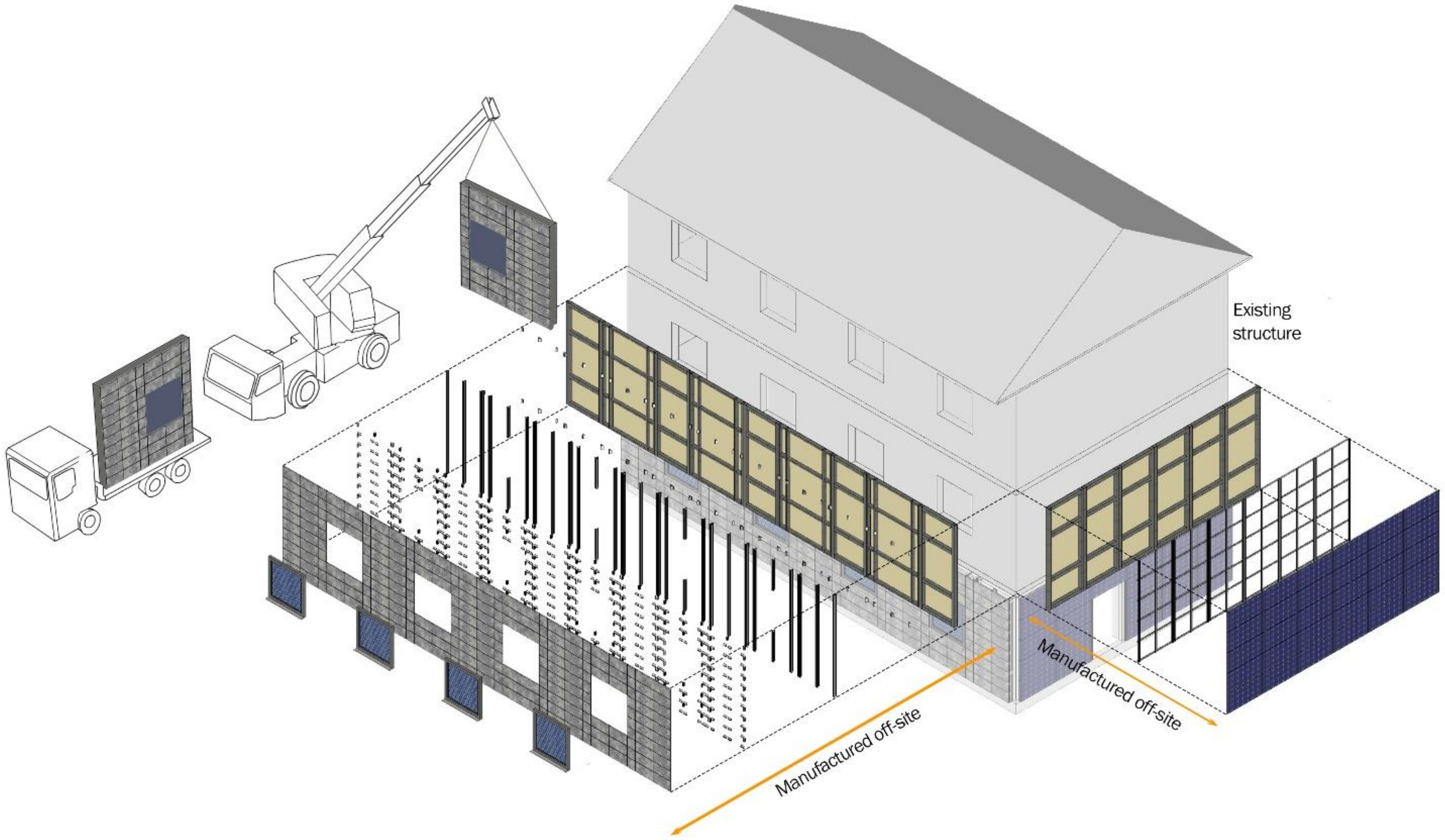
Choose materials which have a low GWP for EoL processing.

A B C D D

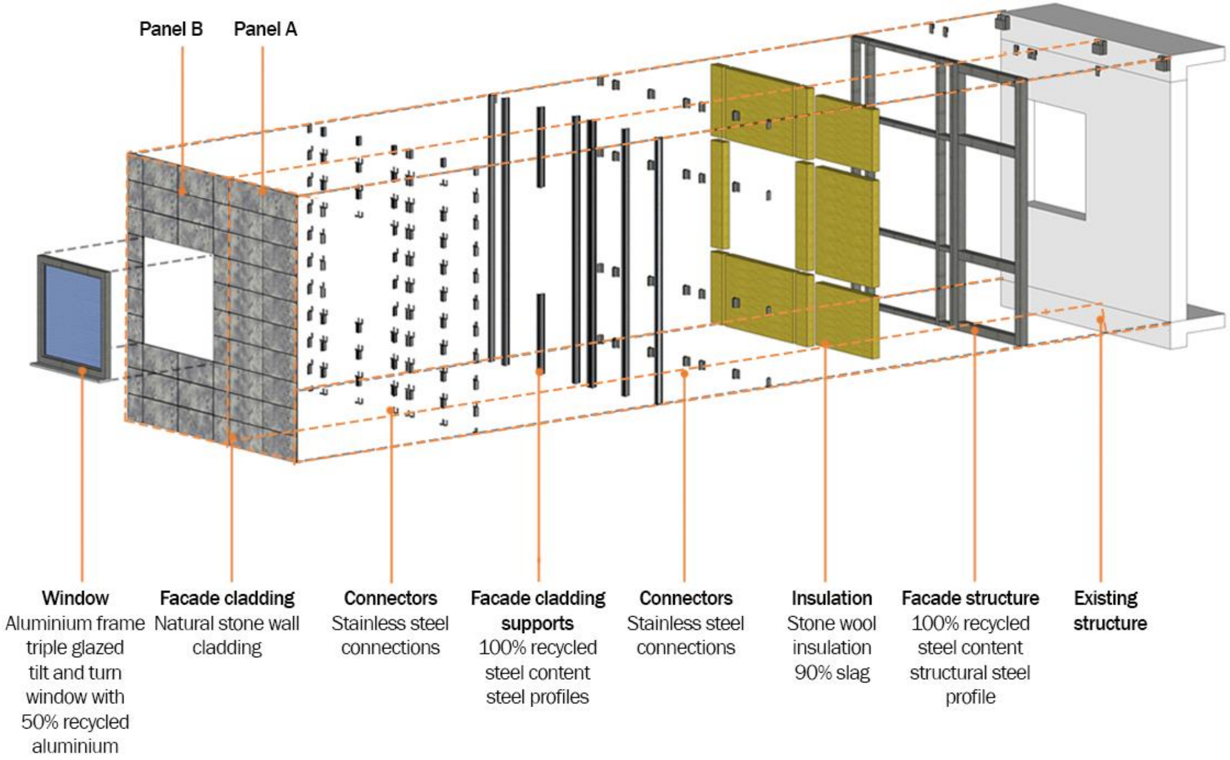
Component	Standardised material	Recyclability	Biodegradability
Façade structure	Structural steel profile section	100%	-
Insulation	Stone wool insulation	0%	-
Façade cladding	Natural stone cladding	92.6%	-
Façade cladding support	Structural steel profile section	100%	-
Solar panel support	Structural steel profile section	100%	-

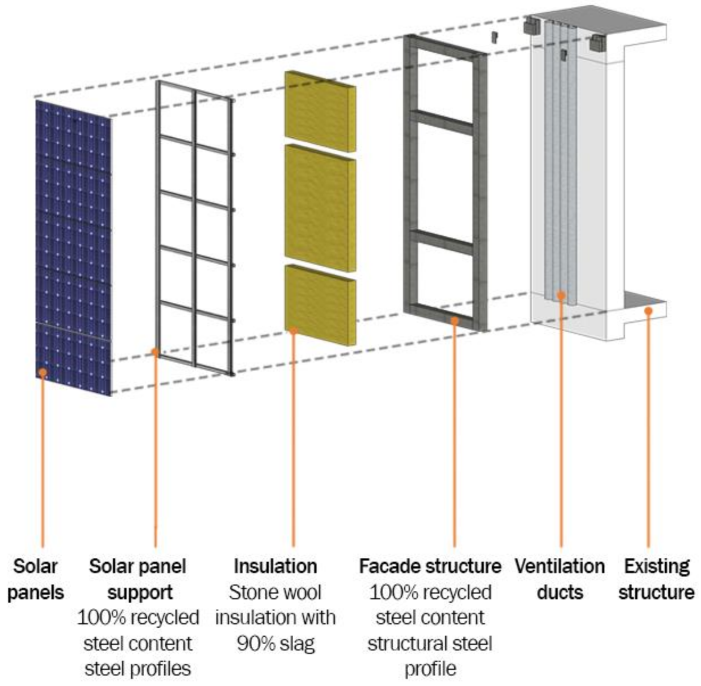
Use standardized materials with high biodegradability and recyclability

Final Design



Final Design





Final Design Considerations

Lifecycle Planning

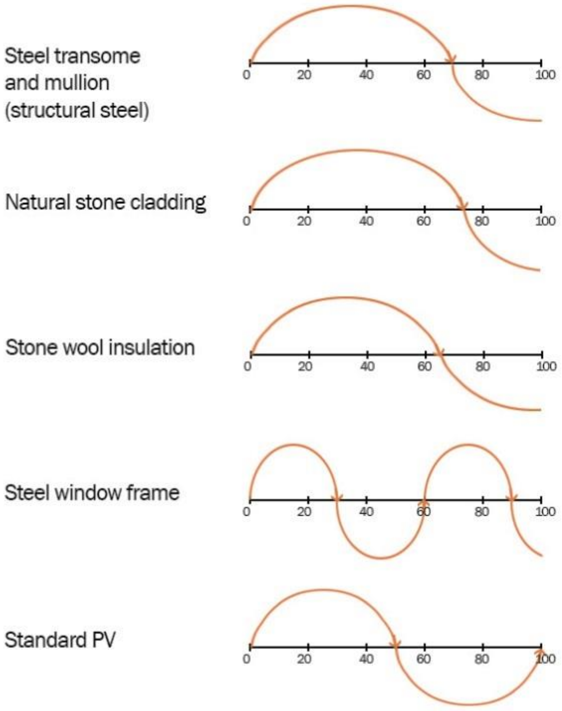
Select a material

A B C D E

Select a material that satisfies the criteria mentioned in material selection guidelines.

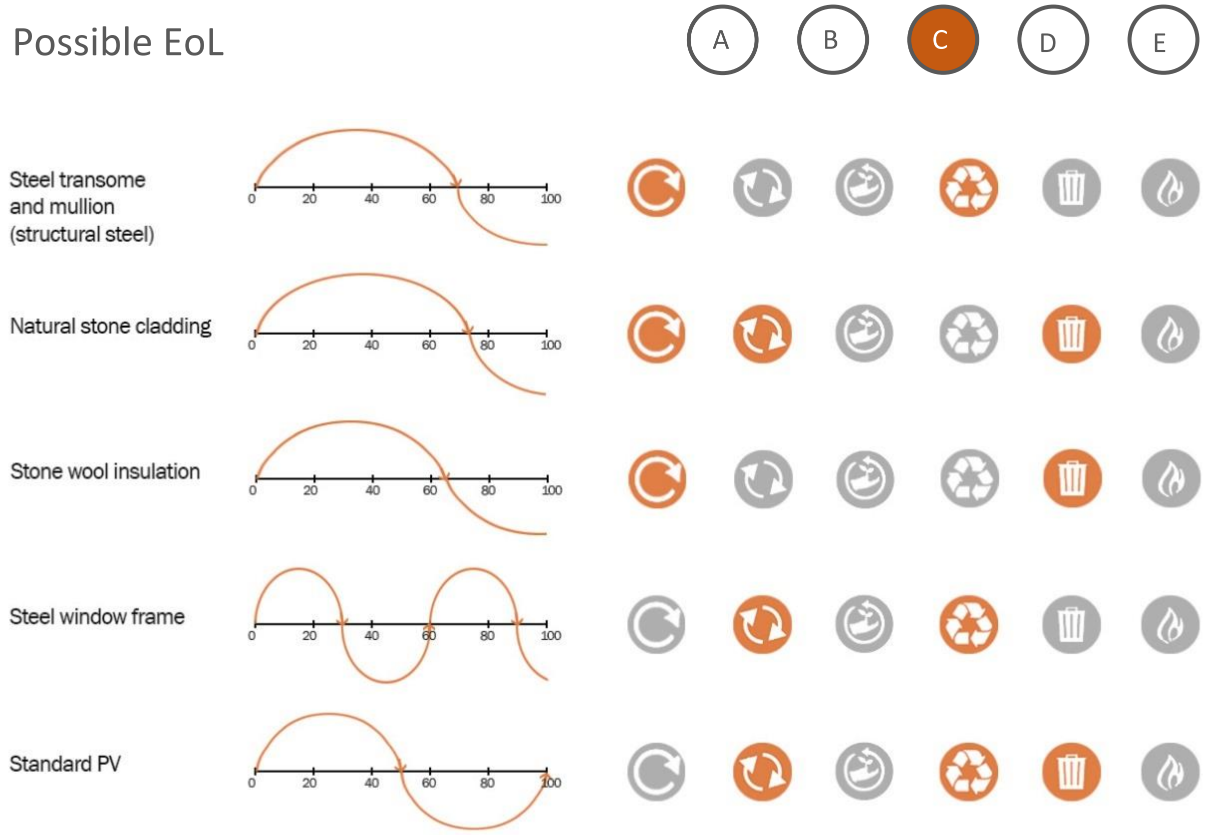
Lifespans

A B C D E



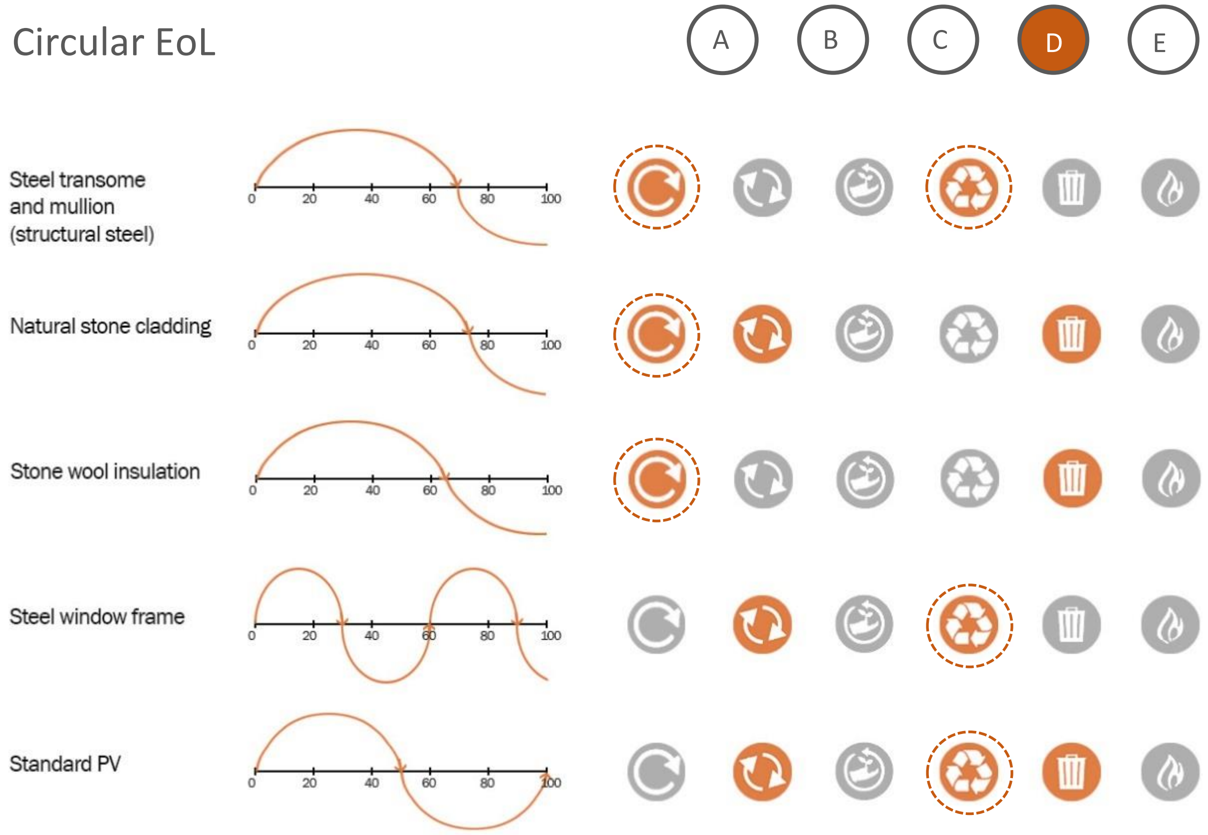
Select standardised materials/ components with longer lifespans to facilitate their repeated reuse.

Possible EoL



Lifecycle Planning

Circular EoL

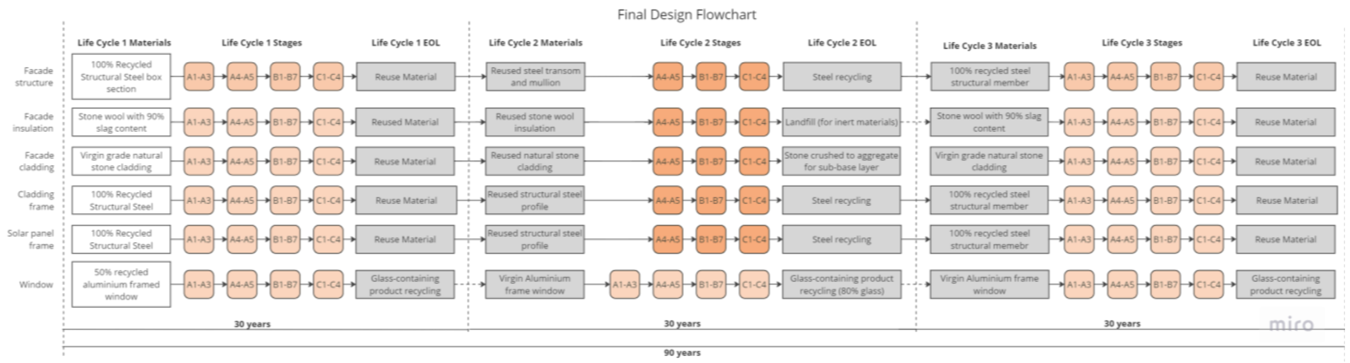


For technical materials, combine the strategies for reuse (extending the loop) and recycle (closing the loop).
For bio-based materials use the strategy for closing the loop if reuse is not possible.

Lifecycle Planning

Multiple life cycles

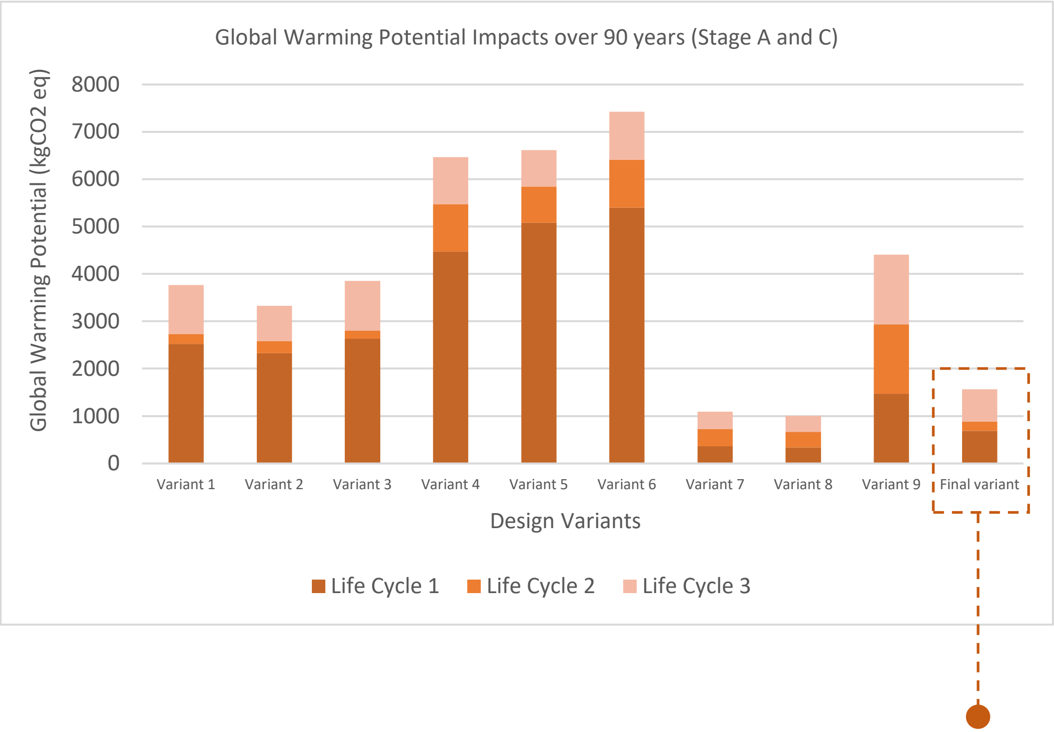
A B C D E



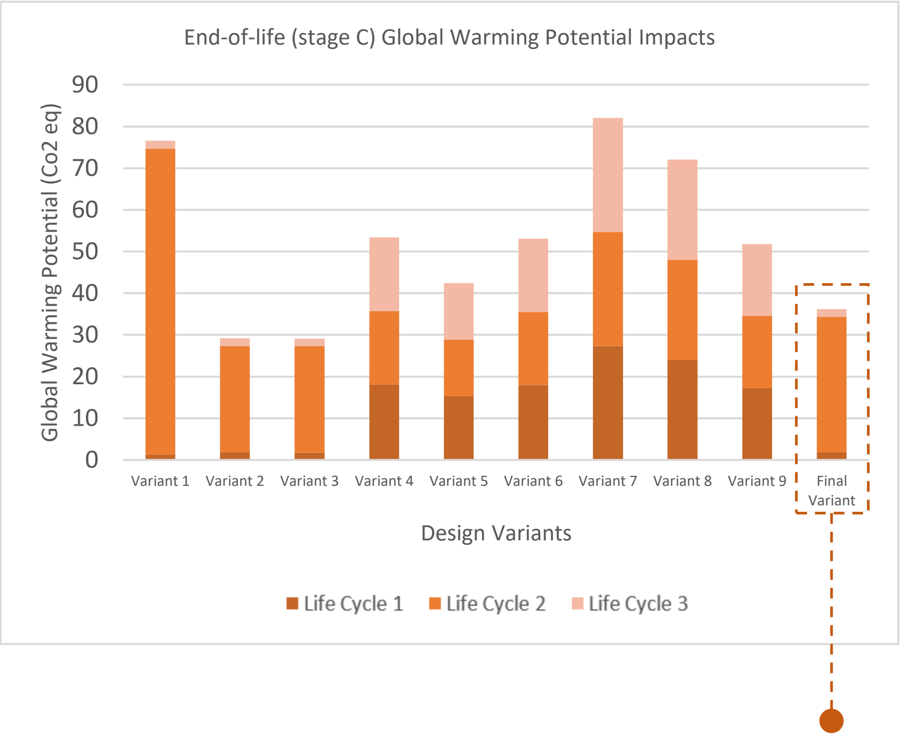
Consider multiple lifecycles and not just the first technical cycle for the evaluation process. Always plan for future life cycles.

Results

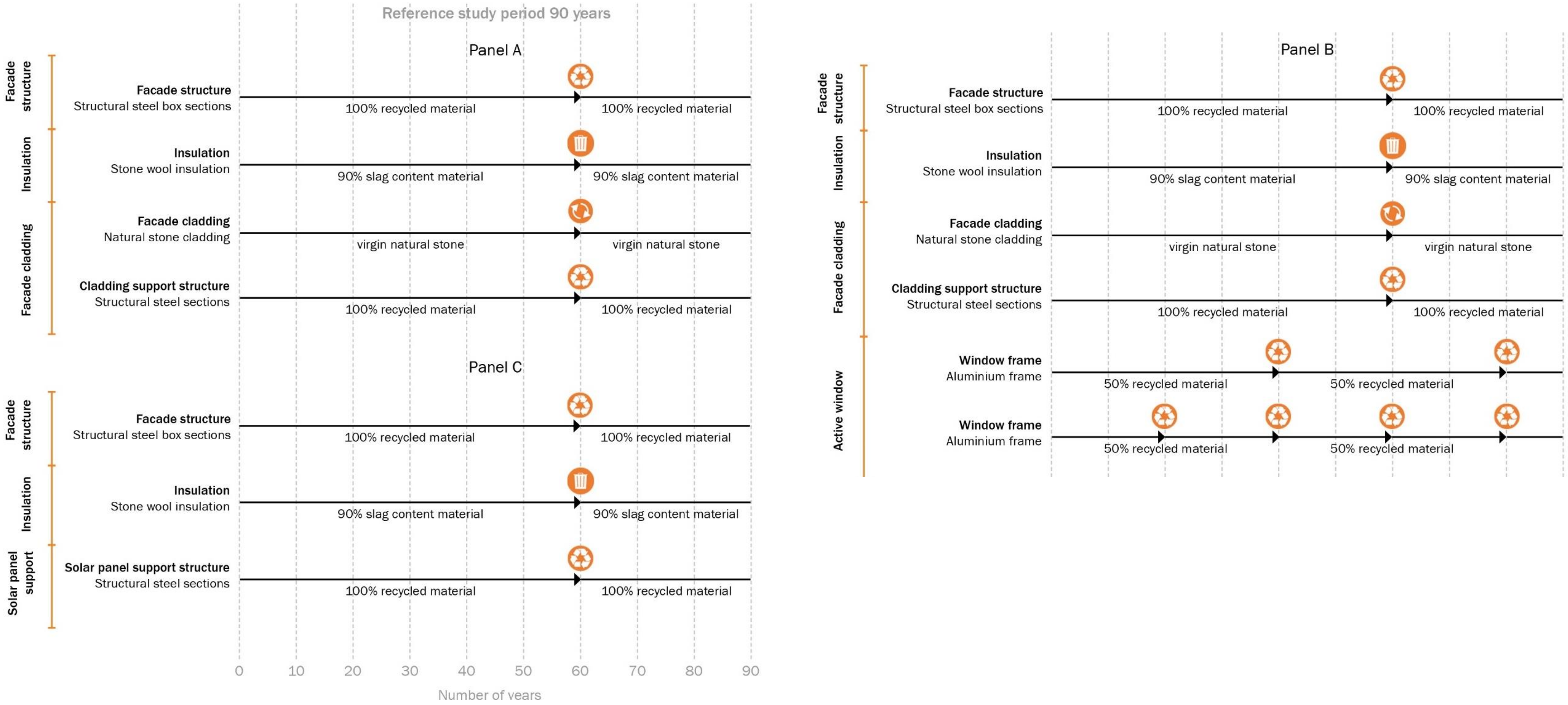
Stage A and Stage C combined impacts



Stage C impacts



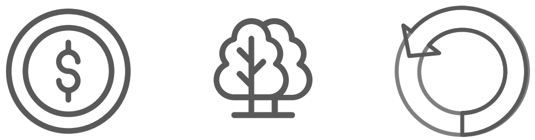
Recommended circular EoL scenarios



01

Discussions

Discussions



Trade-offs between cost
and environmental impacts
and circularity

Walter Stahel's inertia principle states that, "*Do not repair what is not broken, do not remanufacture something that can be repaired, do not recycle a product that can be remanufactured".*

In other words
Do not repair what is not broken, do not manufacture something that is in the market, do not recycle a product that can still be reused.

Thankyou

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