Circular housing envelope elements from residual materials

Jesse Emmelot, 4386744

P5 || 28-01-2021

Introduction

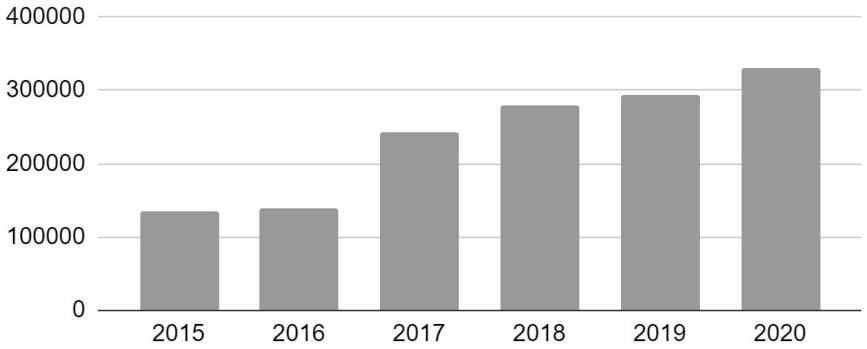
Housing numbers in the Netherlands

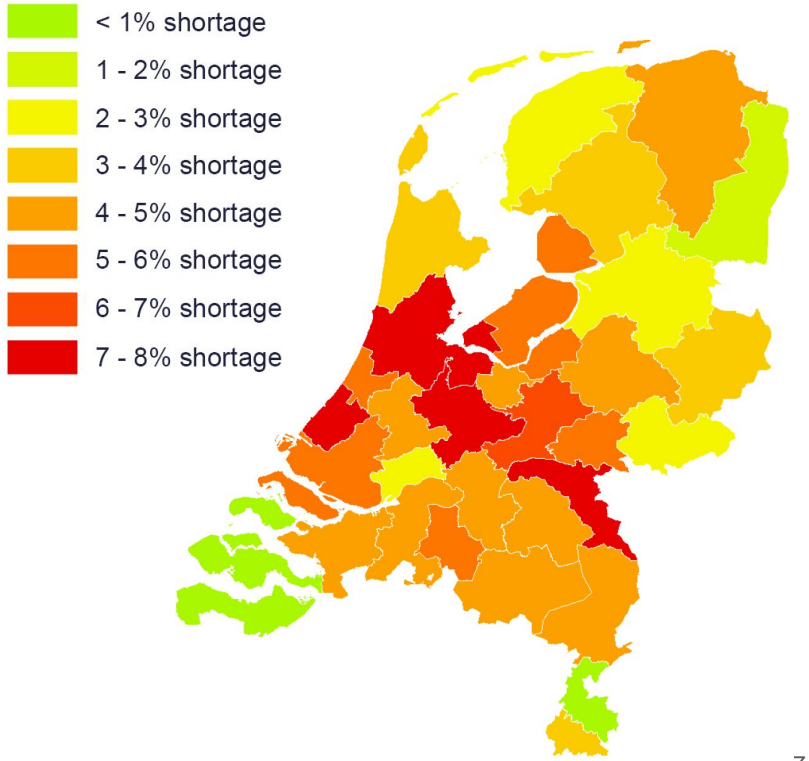
300,000

Housing shortage

80,000

Annual demand of new houses

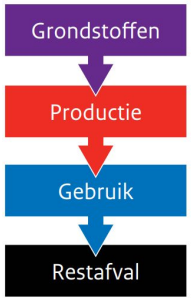


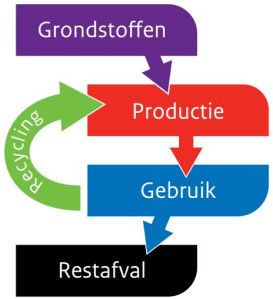


Circular economy ambitions for 2050

Strategic government goals

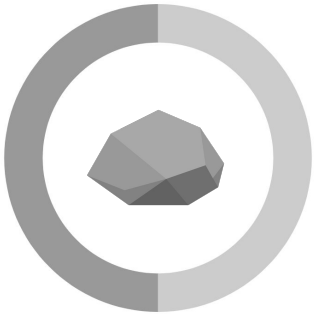
1. High grade use of resources in existing chains
2. Use of renewable, widely available resources
3. Developing new production methods and products





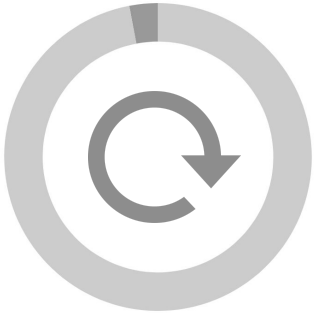
Resources in the Built Environment

50%



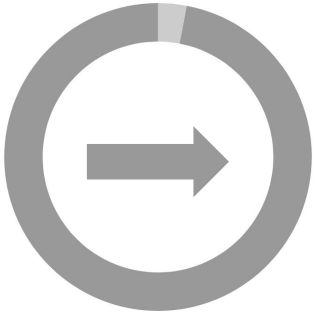
Share of resource use
in the Netherlands

3%



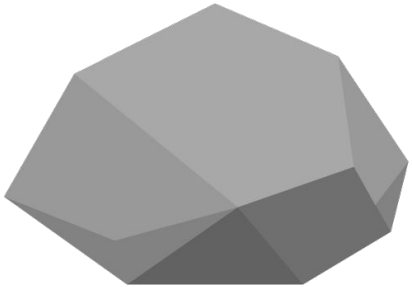
Reuse of resources
for original purpose

97%

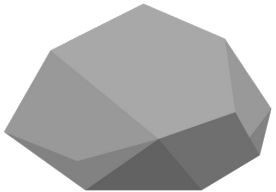


Reuse for different
purposes or downcycling

Resources in the Built Environment



x 2.5



Demand for building resources

Supply of secondary resources

Other material streams

Plastic recycling

Other material streams

Plastic recycling

Virgin plastic (€ 0.85 / kg)

Recycled plastic (€ 0.95 / kg)

- Not as strong
- May leak faster
- Bad odors
- Inaccurate color

Other material streams

Combined / mixed materials

Other material streams

Polluted / contaminated materials

Varying definitions, interests and ambitions

Vereniging Afvalbedrijven
Partner in de circulaire economie

drift for transition

milieu centraal

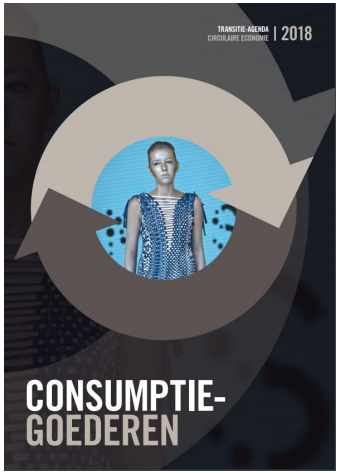
Rijksoverheid

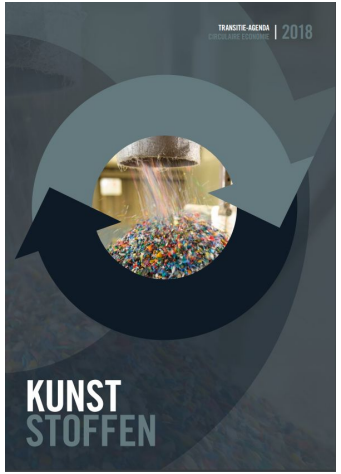
renewi

Research approach

Objectives

1. Connect ambitions and material streams from different resource sectors.
2. Increase the circularity of conventional housing elements
3. Apply resources from linear material streams in a circular way

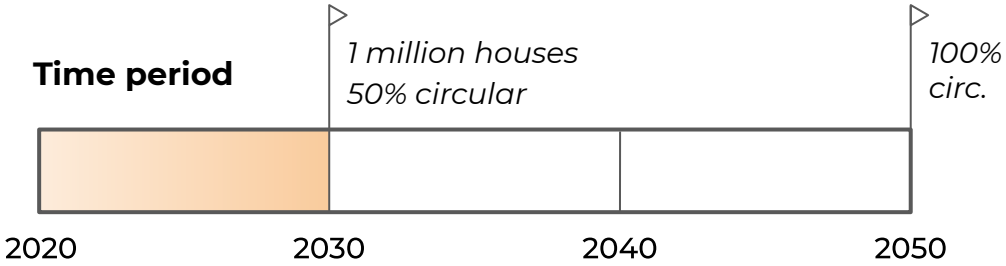




Scope

Objective boundaries

1. Focus on housing envelope elements
2. Focus on reuse from linear (i.e. non-circular) streams
3. No preselection of materials
4. Only look for materials used within the Netherlands

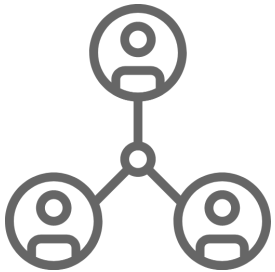


Main research question

How can the circularity of conventional Dutch housing envelope elements be increased, through the application of residual resources from linear material streams?

Sub-questions

1. *How can circularity be defined and measured?*



Perspectives from different parties

Uniform language & calculation methods

Indicators

Regulations & limitations

Sub-questions

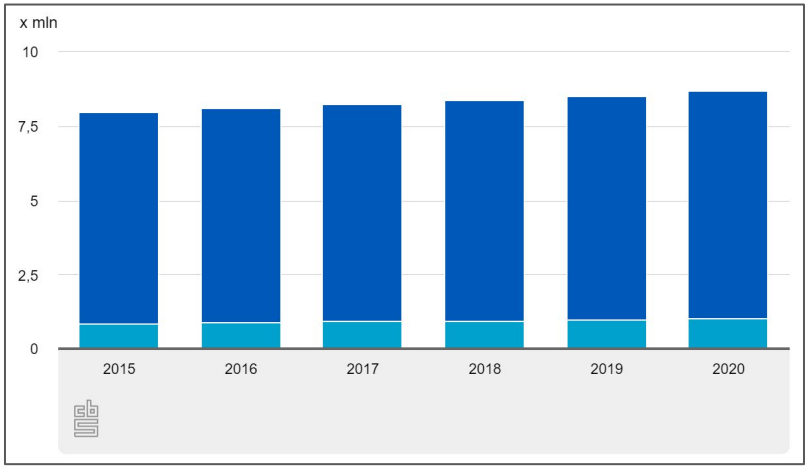
2. *What materials are conventional in contemporary Dutch housing envelope elements and which elements have high potential for circular improvement?*

Sub-questions

3. *What linear residual materials can be found, which may be applicable to the chosen housing envelope elements in a circular way?*

Sub-questions

4. *How might the market around residual materials change in the near future?*



Design goals & Final product

Design goals

1. Testing the feasibility and implications of increasing the circularity of conventional housing envelope elements.
2. Designing or referencing alternative elements

Final product

1. Catalogue of ideas
2. Advisory framework

Design criteria

1. They should be **circular** as defined by the research.
2. They should be a **standardizable** application in Dutch housing construction
3. They should be **competitive** with existing building elements, in terms of functionality and aesthetics.
4. Their materials should be available in **significant volumes**, i.e. no scarce materials like critical metals.
5. Their production should have **minimal negative side effects** on people and the planet.

Defining & measuring circularity

Defining circularity

Chosen definition

“Reducing the consumption of raw materials, designing products in such a manner that they can easily be taken apart and reused after use (eco-design), prolonging the lifespan of products through maintenance and repair, and the use of recyclables in products and recovering raw materials from waste flows. A circular economy aims for the creation of economic value (the economic value of materials or products increases), the creation of social value (minimization of social value destruction throughout the entire system, such as the prevention of unhealthy working conditions in the extraction of raw materials and reuse) as well as value creation in terms of the environment (resilience of natural resources).”

- Van Buren et al. (2017)

Defining circularity

Chosen definition

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R-strategies

Defining circularity

Chosen definition

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Value creation

Defining circularity

Main principles

1. Use of the R-ladder for circular strategies
2. Creating values

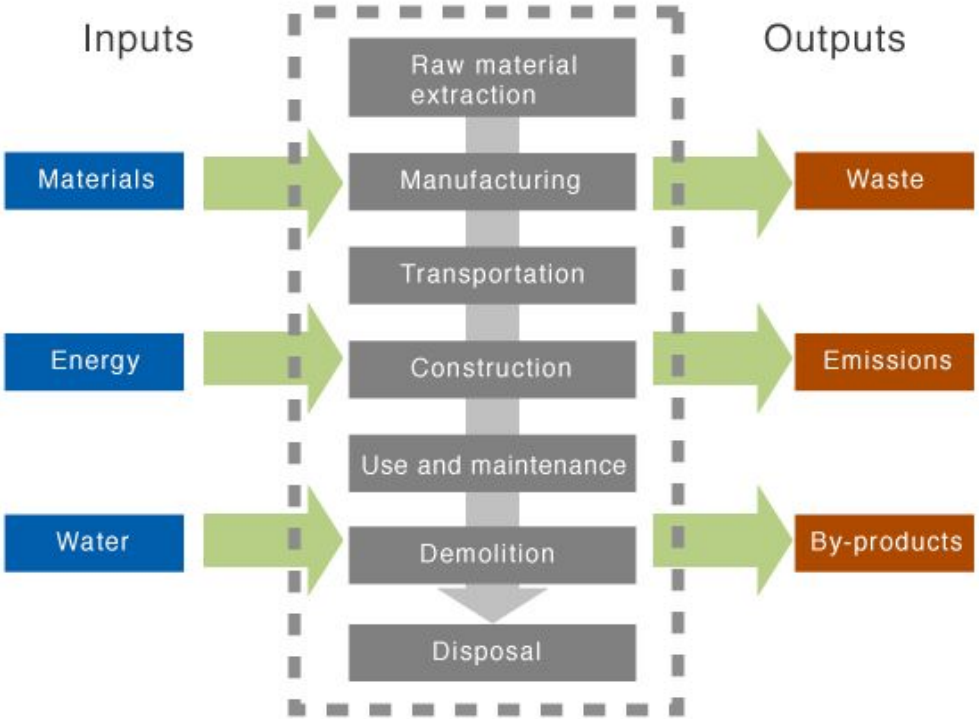
‘Linear’ materials / products by definition fail these principles

Baseline circularity criteria

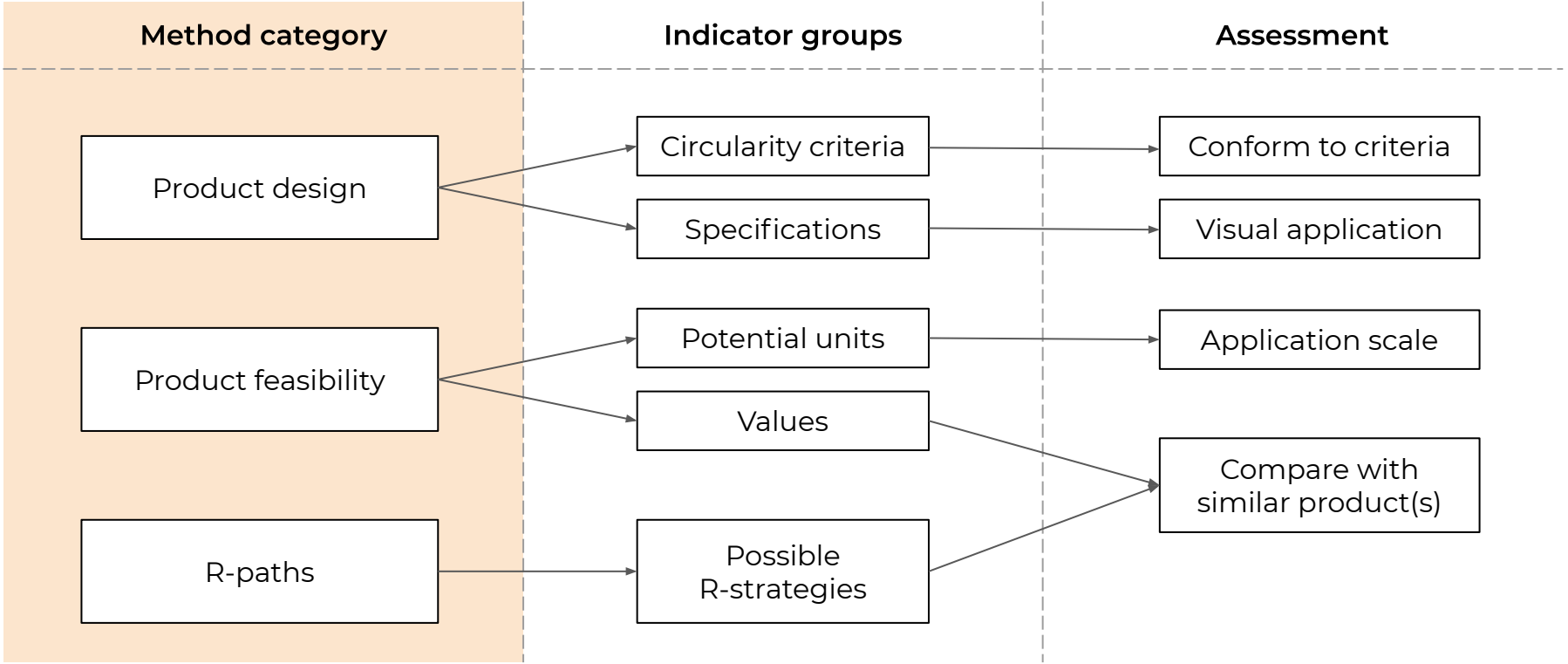
1. Minimal amount of material use
2. Installable & demountable as separate unit
3. Pure materials, unless reused
4. No toxic substances

R0	Refuse
R1	Rethink
R2	Reduce
R3	Reuse
R4	Repair
R5	Refurbish
R6	Remanufacture
R7	Repurpose
R8	Recycle
R9	Recover

Measuring circularity



Measuring circular potential



Conventional housing envelopes

Conventional elements & significance

High significance	Medium significance	Low significance
Door (frame)	Curtains	Balcony platform
Facade cladding	Dormer cladding	Chimney
Facade insulation	Dormer insulation	Door awning
Facade structure	Dormer insulation	Louvers
Roofing	Facade interior finish	Railing
Roof insulation	Gutter (drain)	Rolling shutter
Roof structure	Rolling shade	Vapor / water barrier
Window (glass)	Roof interior finish	Ventilation grilles
Window (frame)	Sunshade	Window sill

Significance criteria

1. Frequency of inclusion
2. Amount of material used
3. Type of material used

Conventional elements - groups

High significance	Medium significance	Low significance
Door (frame)	Curtains	Balcony platform
Facade cladding	Dormer cladding	Chimney
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Conventional elements - groups

High significance	Medium significance
Door (frame)	Curtains
Facade cladding	Dormer cladding
Facade insulation	Dormer insulation
Facade structure	Dormer insulation
Roofing	Facade interior finish
Roof insulation	Gutter (drain)
Roof structure	Rolling shade
Window (glass)	Roof interior finish
Window (frame)	Sunshade

Doors, windows and dormers

- Wood
- Polymer (optional w/ steel)
- Aluminium (optional w/ steel)

Conventional elements - groups

High significance	Medium significance
Door (frame)	Curtains
Facade cladding	Dormer cladding
Facade insulation	Dormer insulation
Facade structure	Dormer insulation
Roofing	Facade interior finish
Roof insulation	Gutter (drain)
Roof structure	Rolling shade
Window (glass)	Roof interior finish
Window (frame)	Sunshade

Insulation

- Polymer (EPS, XPS, PUR, PIR)
- Mineral (glass wool, rockwool)
- Natural (wood fibre, cellulose)

Conventional elements - groups

High significance	Medium significance
Door (frame)	Curtains
Facade cladding	Dormer cladding
Facade insulation	Dormer insulation
Facade structure	Dormer insulation
Roofing	Facade interior finish
Roof insulation	Gutter (drain)
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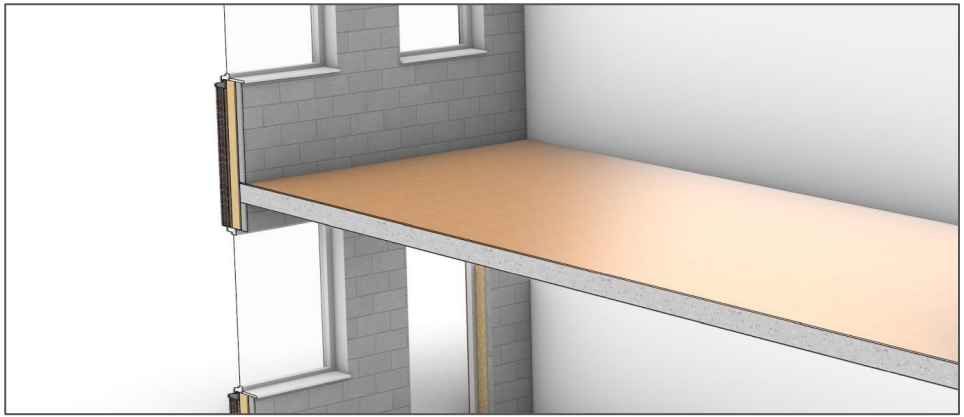
Window (glass)	Roof interior finish
Window (frame)	Sunshade

Structural components

- Concrete (reinforced)
- Steel
- Wood
- Brick
- Limestone



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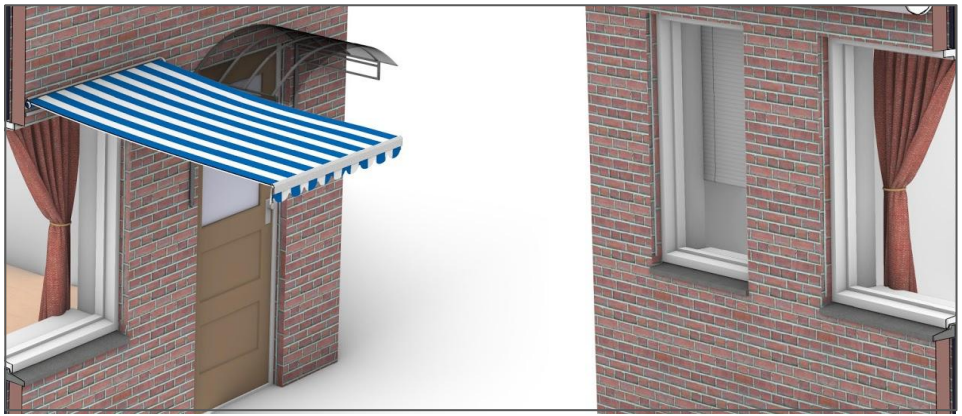
Window (glass)	Roof interior finish
Window (frame)	Sunshade

Cladding and roofing

- Aluminium
- Bitumen
- Ceramics
- Composite
- Copper
- Natural stone
- Polymer
- Reed
- Steel
- Wood-based
- Zinc



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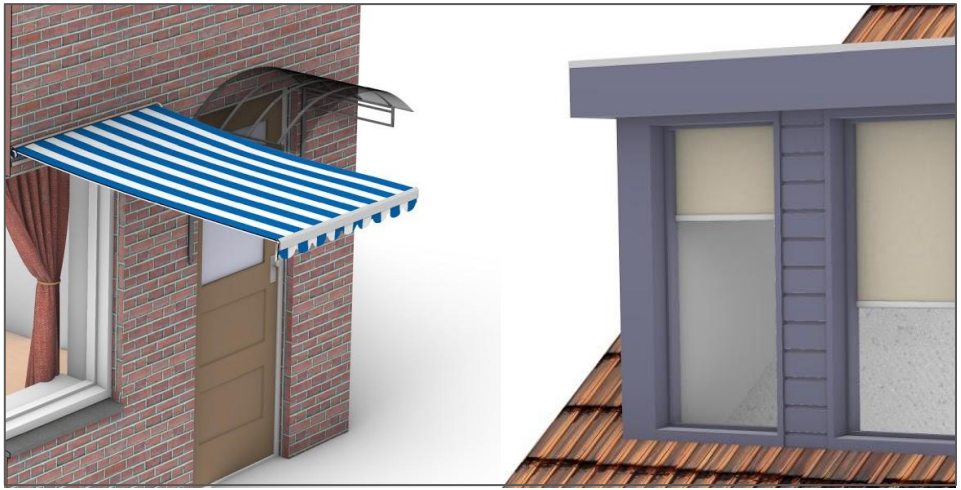
Roof structure	Rolling shade
Window (glass)	Roof interior finish
Window (frame)	Sunshade

Curtains and sun shading

- Acrylic
- Polyester



Gauging circular improvement potential

Element group	Material type	Material	Lifespan	Highest common end-of-use
Insulation	Polymer	EPS	35 - 50	Reuse, recycling (mechanical)
		XPS	50	
		PUR	50	Reuse (sheets), repair, recycling
		PIR	50	Reuse, recovery
	Mineral	Glass wool	50	Reuse, repurpose, recycling
		Rockwool	75	
	Natural	Wood fibre	50	
		Cellulose	20 - 30	Repurpose, recycling

Most problematic elements & materials

Element group	Material type	Material	Reason for (not) selecting
Insulation	Polymer	EPS	Potential for high grade use of secondary PS
		XPS	
		PUR	Potential for reuse from former applications
		PIR	Potential for upcycling into other applications
	Mineral	Glass wool	
		Rockwool	Above average lifespan, high grade recycling
	Natural	Wood fibre	Potential for reuse from former applications
		Cellulose	

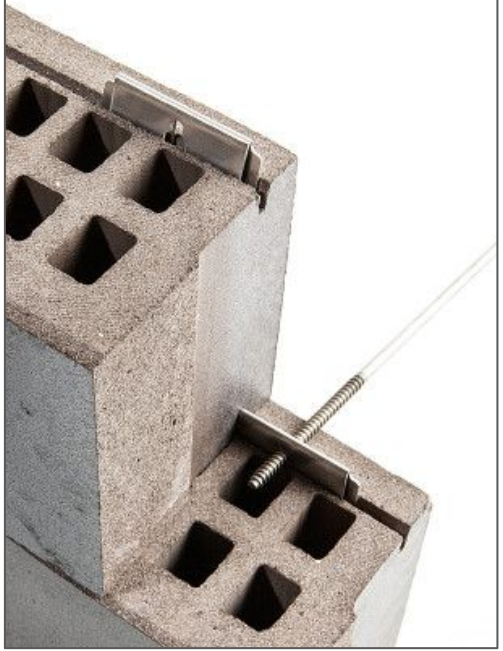
Selection of conventional elements & materials

Element group	Included	Not included
Doors, window & dormers	-	Wood, polymer, aluminium
Insulation	EPS, XPS, PUR, PIR, glass wool, wood fibre, cellulose	Rockwool
Structural components	-	Concrete, steel, wood
Cladding & roofing	Brick, bitumen, clay tiles, stone, polymer, reed, steel, wood	Aluminium, composites, copper, MDF/HDF, zinc
Curtains & sun shading	Acrylic, polyester	-

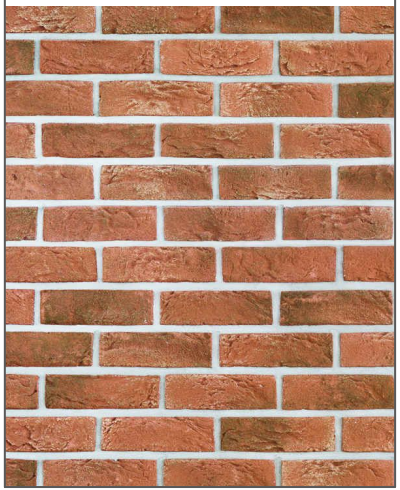
Circular improvements

Circular improvements of conventional selection

Improve circularity of the conventional material



Original material



Look for a more circular alternative material

Applying R-strategies

Improvements to original material

For each material

- R-strategy
- Improvement
- Benefits

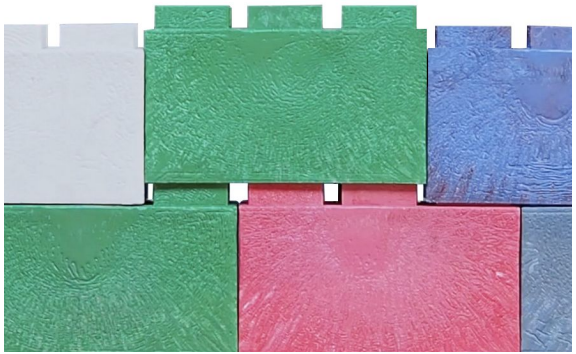
ORIGINAL IMPROVEMENT				
Element (group)	**Materials**	**R-strategy**	**Improvement**	**Benefits from improvement**
Insulation	EPS / XPS	Reuse	Extending the lifespan	The sheets could be removed and reused somewhere else without any damage to the material
		Reuse	Reuse from former applications	Possibilities for sourcing secondary polystyrene from many different industries
		Recycle	Higher grade recycling (Upcycling)	Increasing the technical-functional- and economic value
	PUR	Rethink	Using more ecological compounds	Spray-on PUR uses blowing compounds containing HFCs. Alternatives to this may be possible
		Rethink / Reuse	Using sheets instead of spray	Sheets are easier to remove and do not require blowing compounds (which contain HFCs)
		Reuse	Reuse from former applications	Possibilities for sourcing secondary PUR from multiple different industries
		Recycle	Higher grade recycling	Increasing the technical-functional- and economic value
	PIR	Reuse	Extending the lifespan	The sheets could be removed and reused somewhere else without any damage to the material
		Recycle	Higher grade recycling	Increasing the technical-functional- and economic value
	Glass wool	Reuse / Recycle	Prevent mixing and contamination	While glass wool is already highly recyclable, it is easier to recycle when highly pure
	Wood fibre	Reuse	Use wood from former applications	Possibilities for sourcing secondary wood from many different industries within the country
	Cellulose	Reuse	Reuse from former applications	Possibilities for creating cellulose out of materials from many different industries
		Refurbish	Adding cellulose to wornout sections	More prone to degradation in certain spots, new cellulose can be applied only where needed
Cladding & roofing	Bitumen	Repair	Adding bitumen or sealant for repair	Adding or fixing damaged bitumen only where needed
		Recycle	Making new bitumen from residuals	Separating bitumen during building demolition allows it to be recycled to a fairly high grade
	Brick	Reuse	More adaptive connections	Solving the issue of bricks being difficult to remove from a wall without breaking them
		Reuse / Recycle	Using / making bricks from rubble	Making use of the large amounts of demolition waste
	Ceramics / stone	Reuse	Reuse from former applications	Possibilities for sourcing secondary ceramics or stones from many different industries
		Reuse	More adaptive connections	Solving the issue of some ceramics being difficult to remove from a wall without breaking them
		Repair	Gluing broken tiles (like a vase)	Possibility for reusing broken ceramics in an aesthetic way, akin to gluing together broken vases
		Recycle	Making new bricks from rubble	Making use of the large amounts of demolition waste
	Polymer	Reuse / Repurpose	Reuse from former applications	Possibilities for sourcing secondary polymer from multiple different industries
		Recycle	Use of lower grade recycled polymer	Secondary polymer not usable in its original way may be used in a redesigned application
		Recycle	Higher grade recycling (Upcycling)	Increasing the technical-functional- and economic value
	Reed	Repair / Refurbish	Repairing damaged sections	While reed is prone to wear and damage, it can be easily repaired or refurbished where needed
	Steel	Reuse / Repurpose	Reuse from former applications	Possibilities for sourcing secondary steel from many different industries
	Wood	Reuse	Reuse from former applications	Possibilities for sourcing secondary wood from many different industries
		Repair / Refurbish	Remove individual planks/boards	Possibilities for a high degree of adaptivity with wooden members, through smart connections
Curtains & shading	Acrylic / Polyester	Reuse / Repurpose	Reuse from former applications	Possibilities for sourcing secondary textile from many different industries
		Repair / Refurbish	Fixing tears or raffling / adding new	Damages to the textile may be fixed with relatively little effort, possibly by adding new textile
		Recycle	Higher grade recycling (Upcycling)	Increasing the technical-functional- and economic value

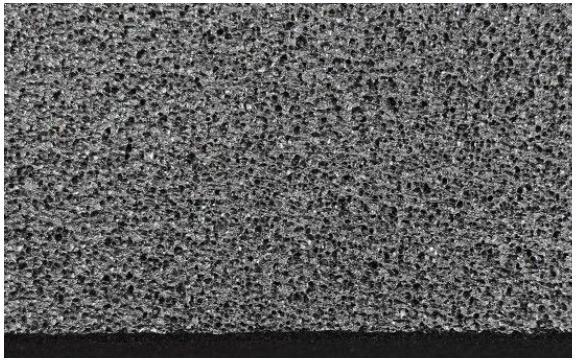
Improvements to original material

Material	R-strategy	Improvement	Benefits from improvement
Brick	Reuse	More adaptive connections	Bricks are easier to remove from a facade, without breaking them.
	Reuse / Recycle	Using / making bricks from rubble	Making use of the large national amounts of demolition waste

Improvements with alternative material

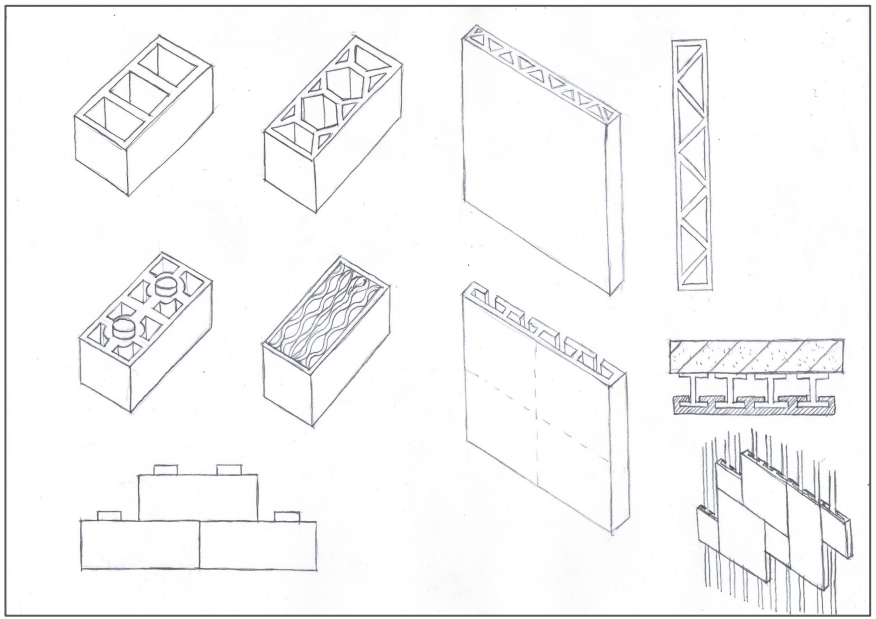
Material	R-strategy	Alternative material	Benefits from improvement
Brick	Recycle	Polymer (PE, PET, PVC)	Potential for upcycling of secondary polymer
	Recycle	Glass(wool)	Potential for upcycling of secondary glass(wool)
	Recycle	Paper / cardboard (press)	Potential for upcycling of secondary paper / cardboard

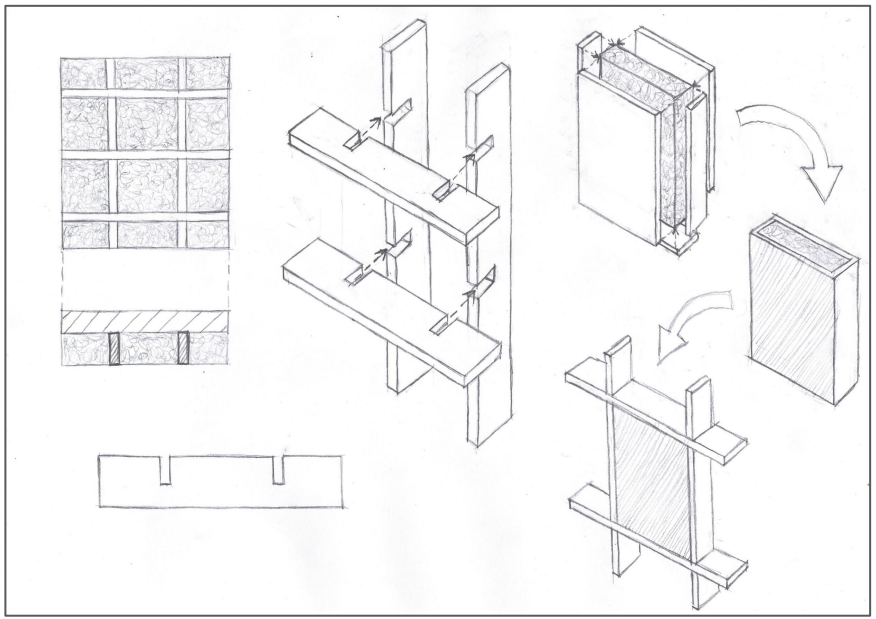




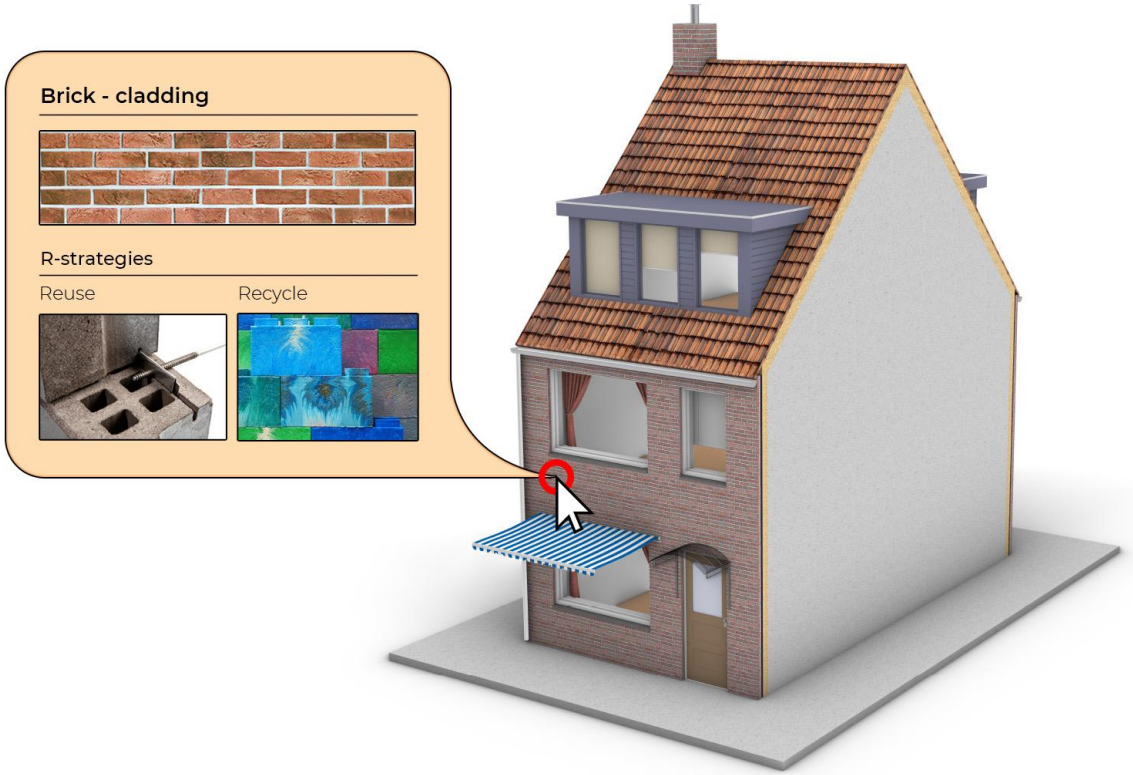
Alternative applications

Sketch ideas





Catalogue presentation



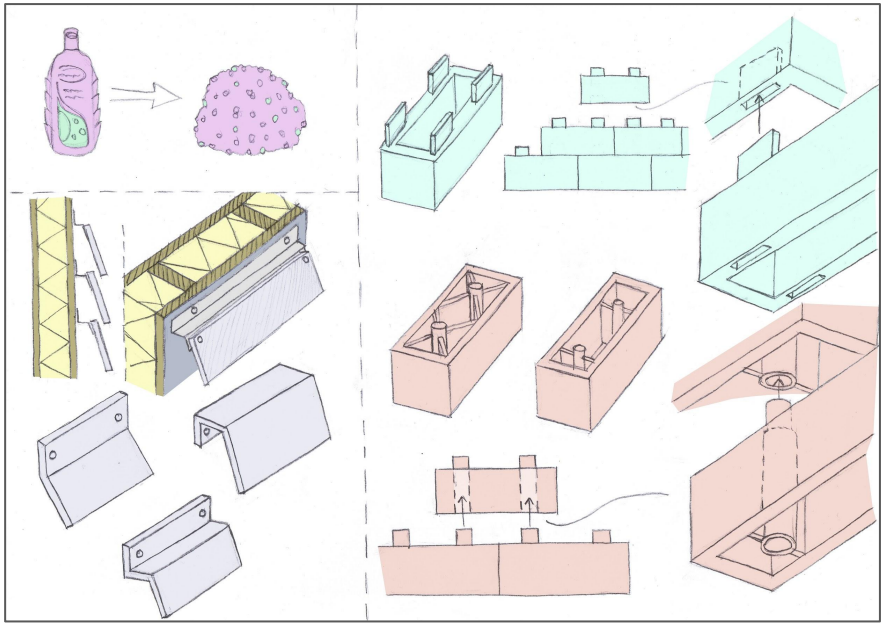
Final selection for calculations

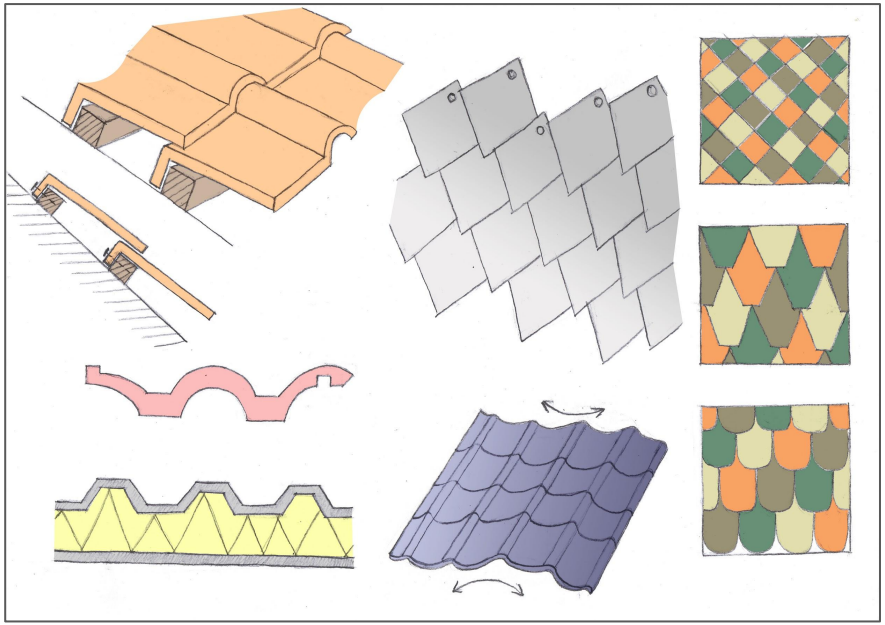
Material	R-strategy	Reasoning
Polymer	Reuse / Recycle	Versatile material, with market issues in some its current applications
Rubber	Reuse / Repurpose	Hard to reuse when worn, inherently hard to recycle, often downcycled
Brick	Reuse / Recycle	Large part of total waste, conventionally not meant for circular use
Ceramic tile	Reuse / Recycle	
Wood	Reuse / Repurpose	Many former applications in which the lifespan is not fully utilised

Final selection and their former applications

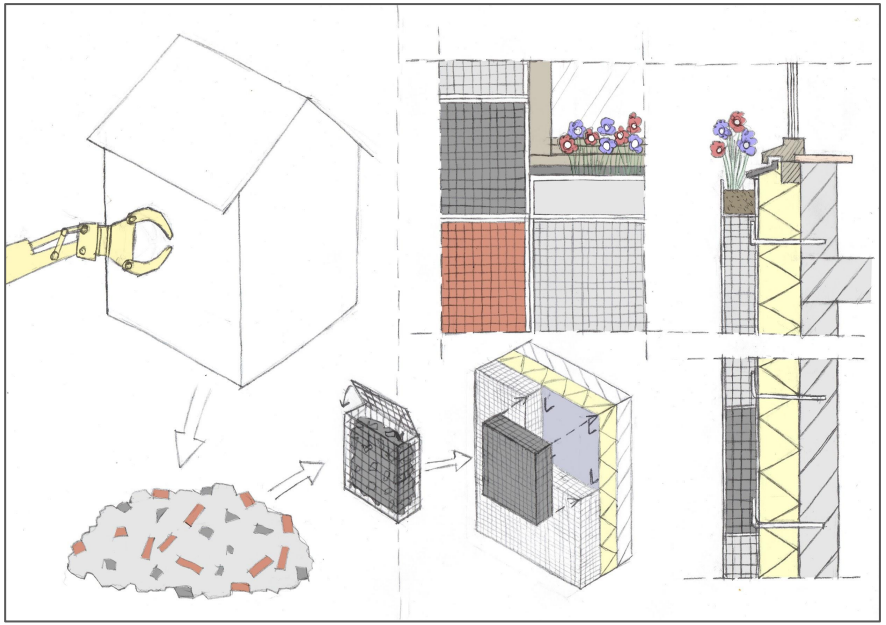
Material	**PET**	**HDPE**	**Rubber**	**Brick**	**A/B wood**
Application	Bottles	Fluid containers	Tires	Masonry	Various
					

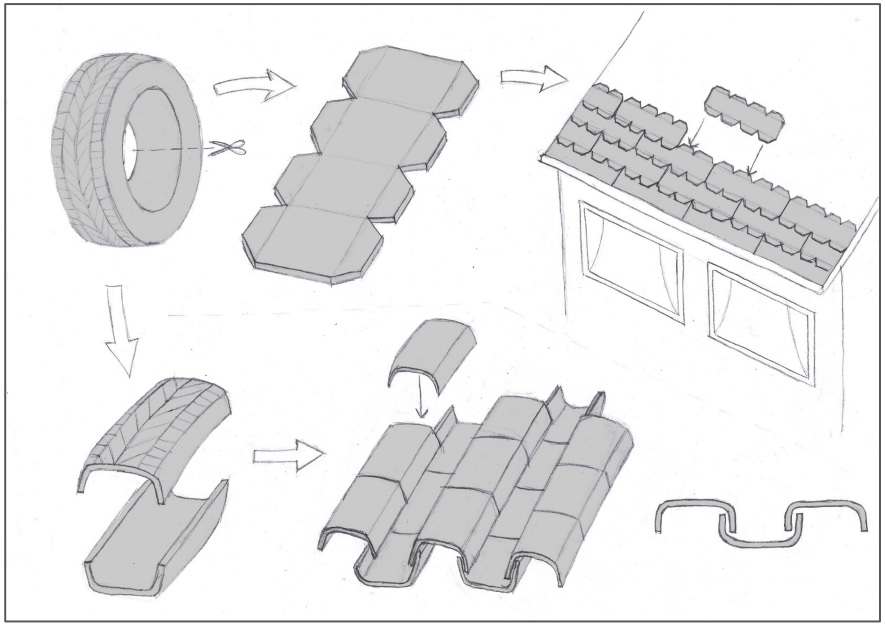
Case studies





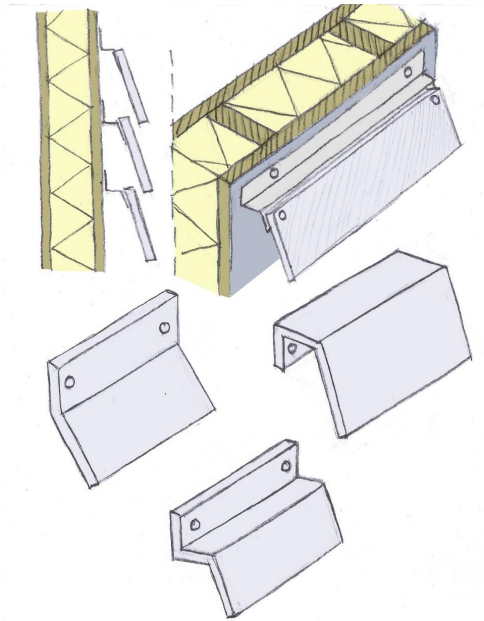
Case studies



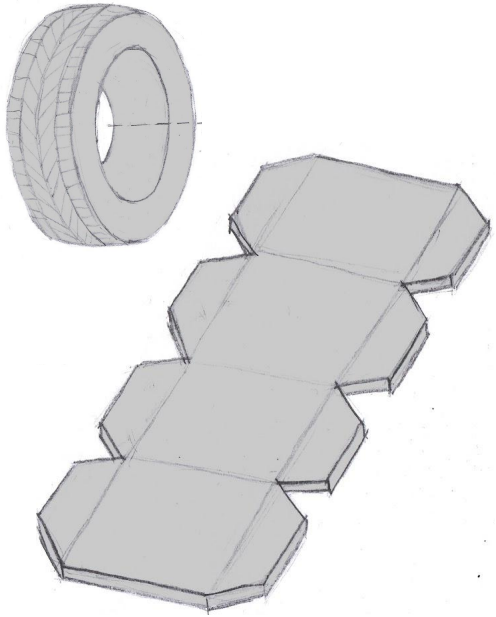


Case studies - favourite concepts

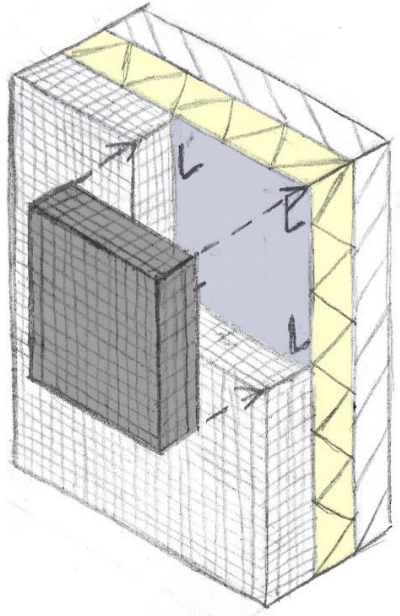
Polymer cladding elements



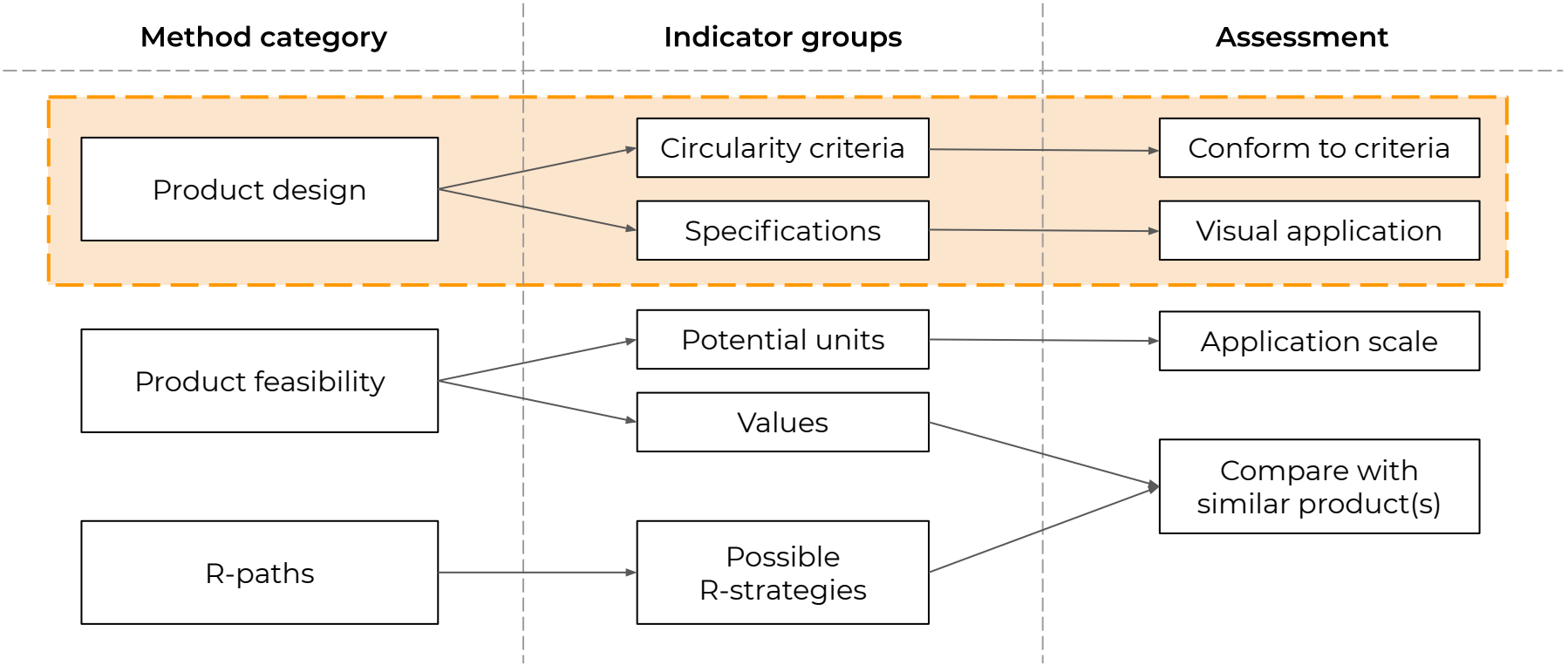
Rubber (tire) shingles



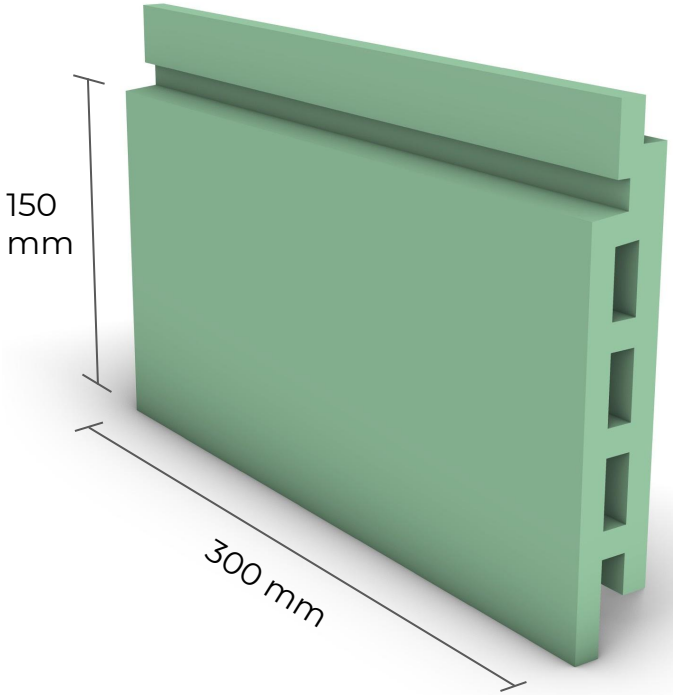
Stone rubble compartments

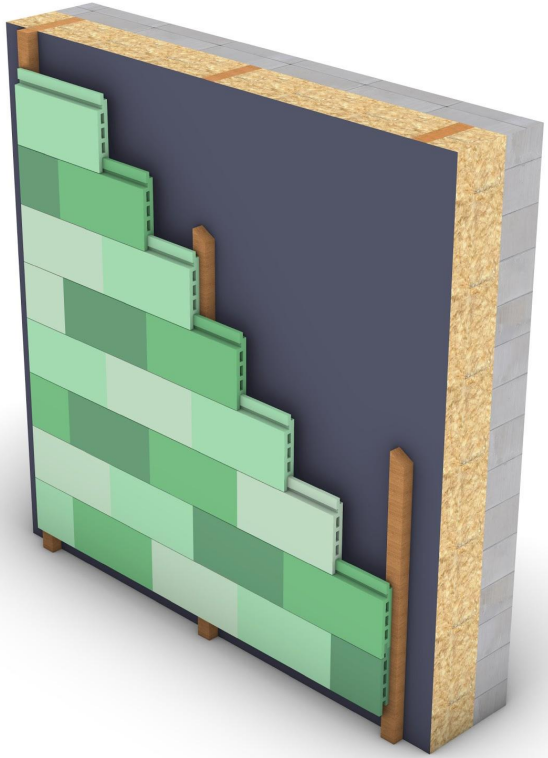


Measuring circular potential

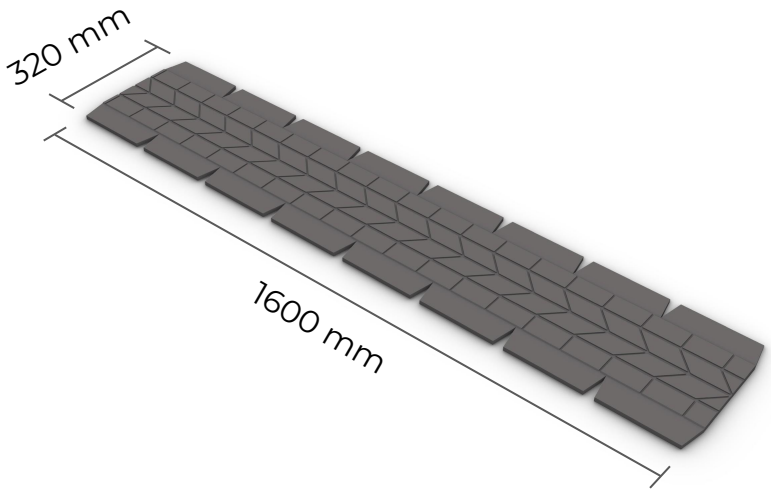


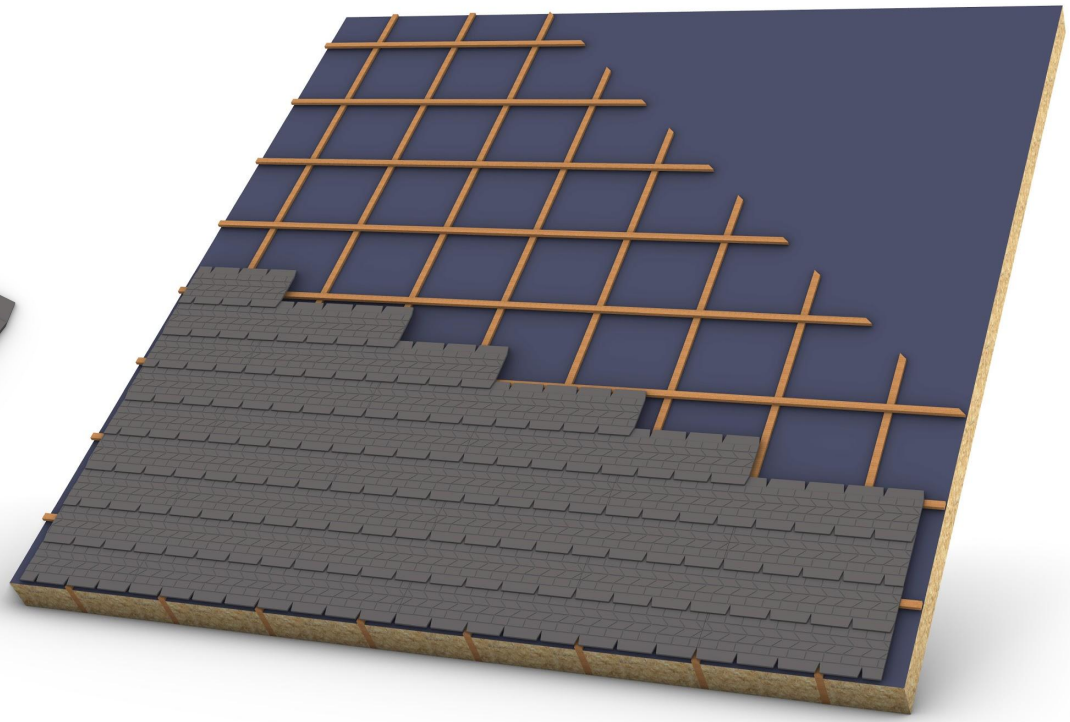
Case study 1 - HDPE cladding panels



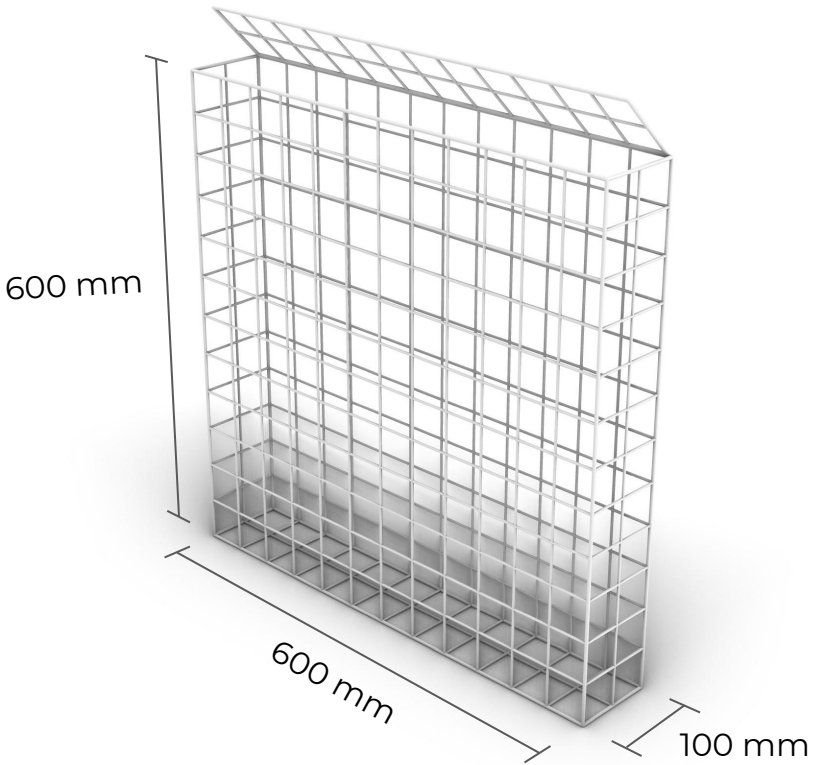


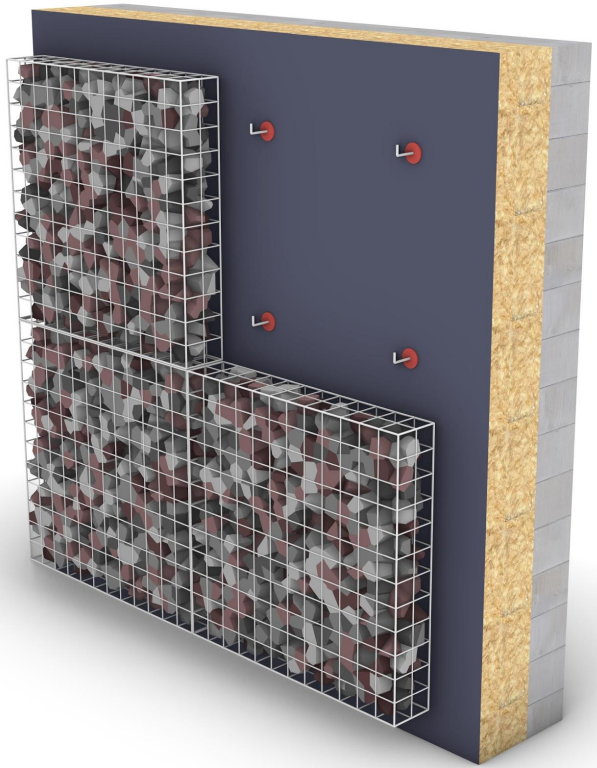
Case study 2 - Rubber tire shingles



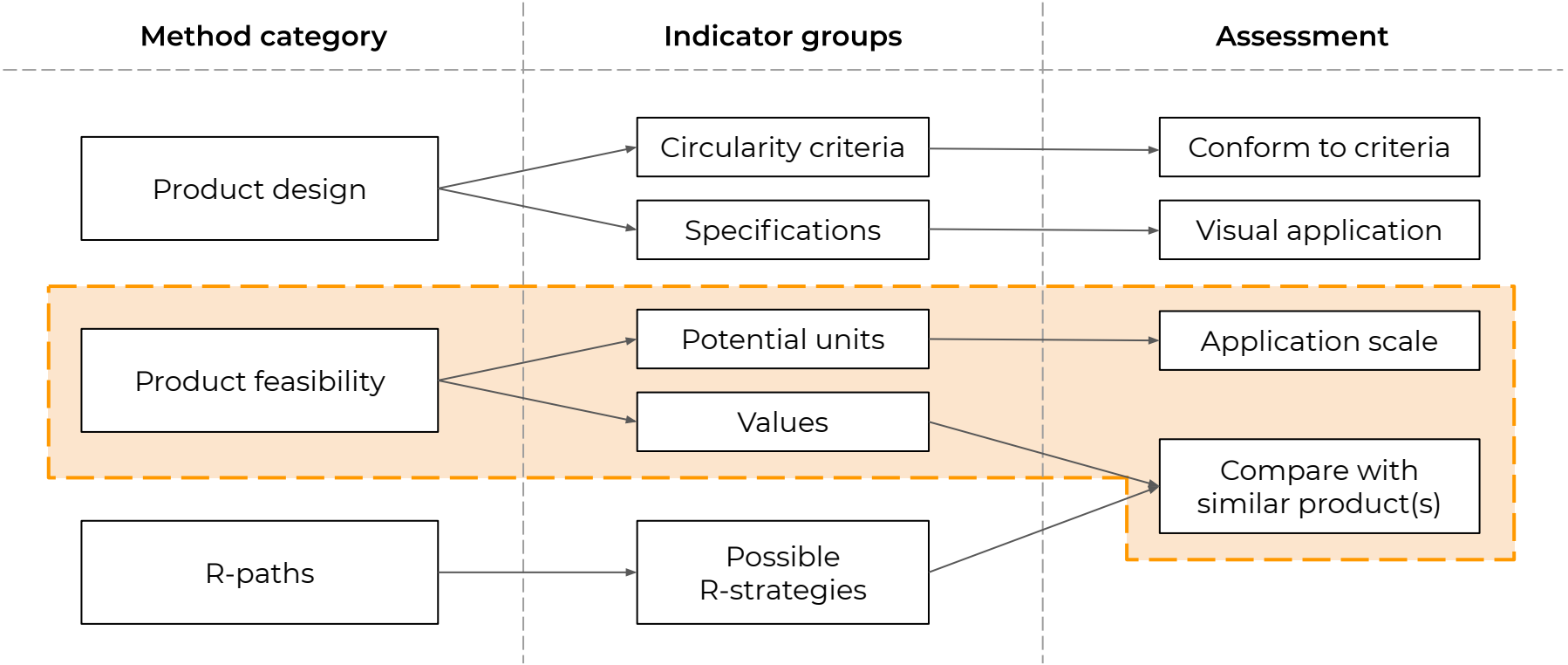


Case study 3 - Demolition rubble compartments





Measuring circular potential



Product feasibility - values

Expected lifespan

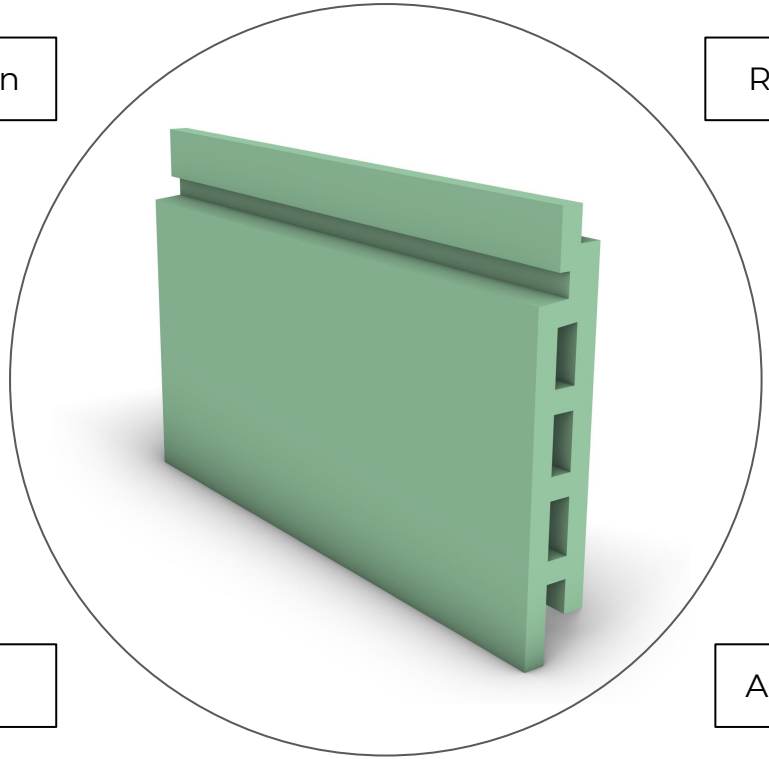
Density

Stiffness

Thermal resistance

Flammability

Tolerances



Resistance to UV

Resistance to water

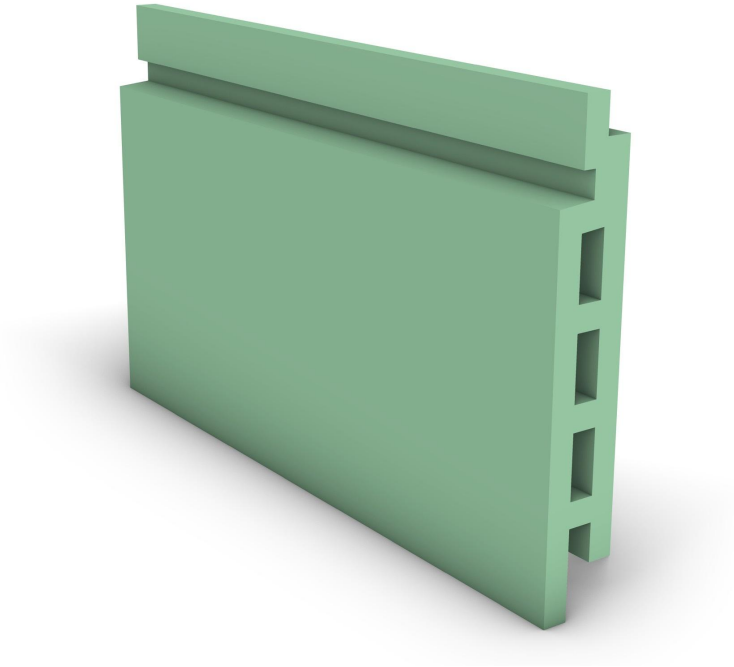
Resistance to oxidation

Product system circumstances

Aesthetic qualities

Product feasibility

R-HDPE

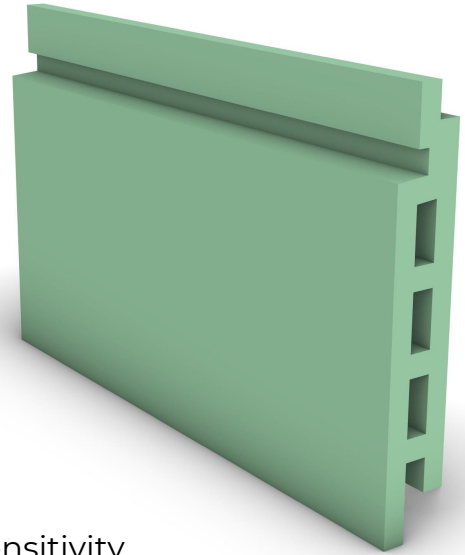


Keralit ®

Vinyplus ®

Product feasibility

R-HDPE



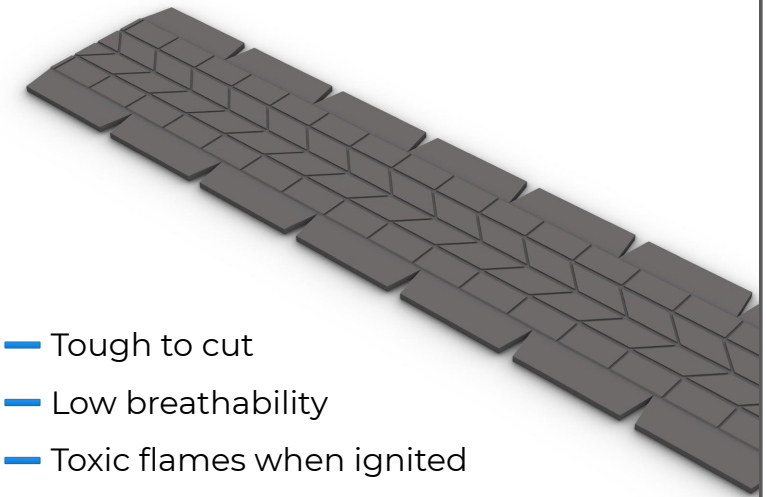
- High UV sensitivity
- Low stiffness
- Potential colour inconsistency

Keralit ®

Vinyplus ®

Product feasibility

Rubber (tire) shingle



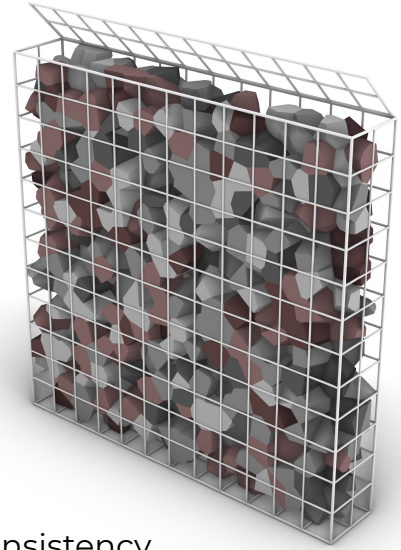
- Tough to cut
- Low breathability
- Toxic flames when ignited
- Relatively low UV resistance
- May start to leach over time

Bitumen shingle (PRECIT)

Ceramic tile (Koramic Madura)

Product feasibility

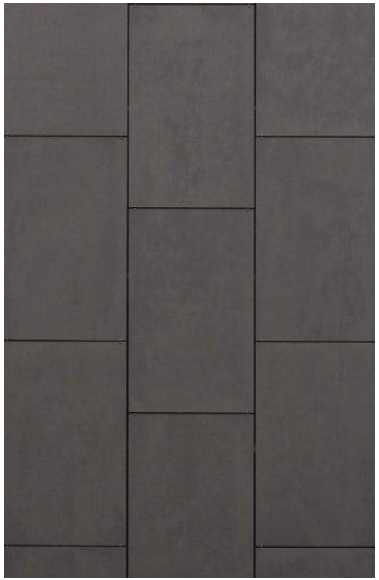
Rubble compartments



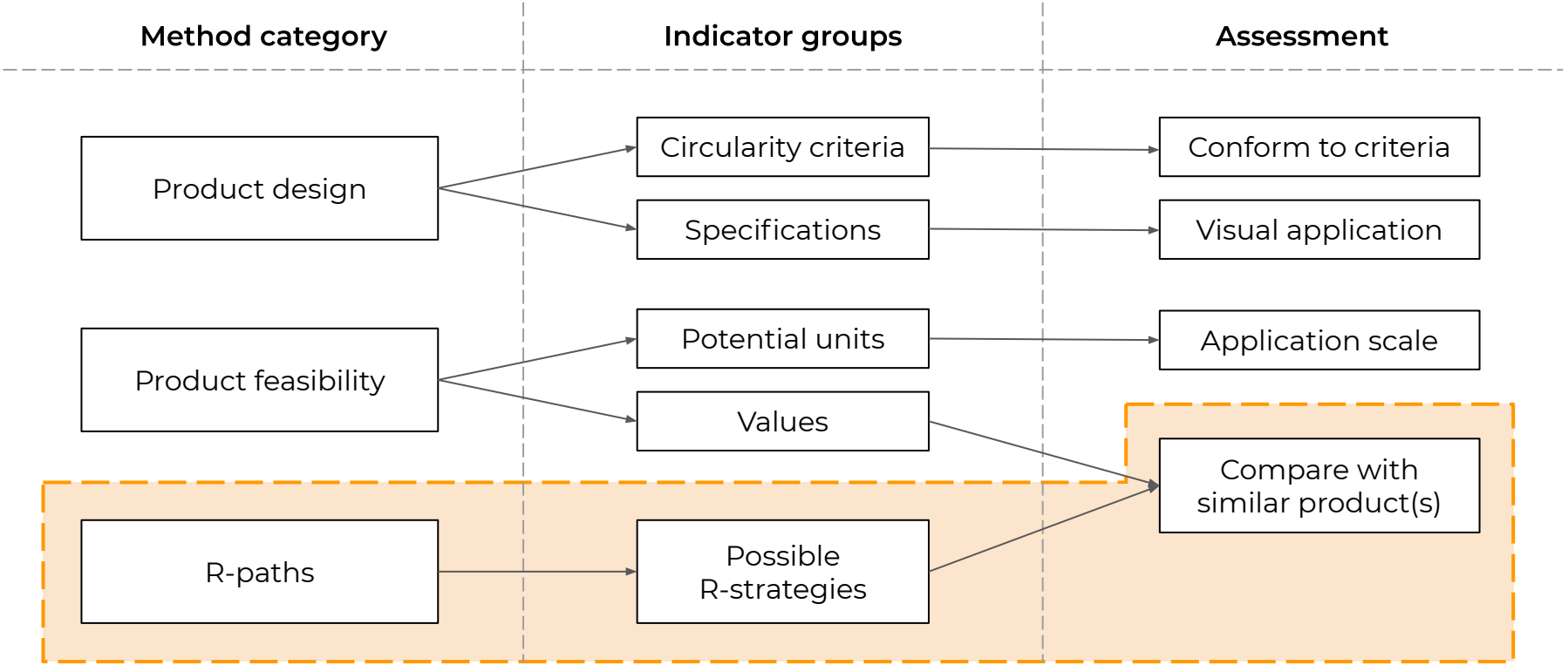
- Low resolution
- Rubble size inconsistency
- Rubble contamination

Brick and mortar (KnB Keramiek)

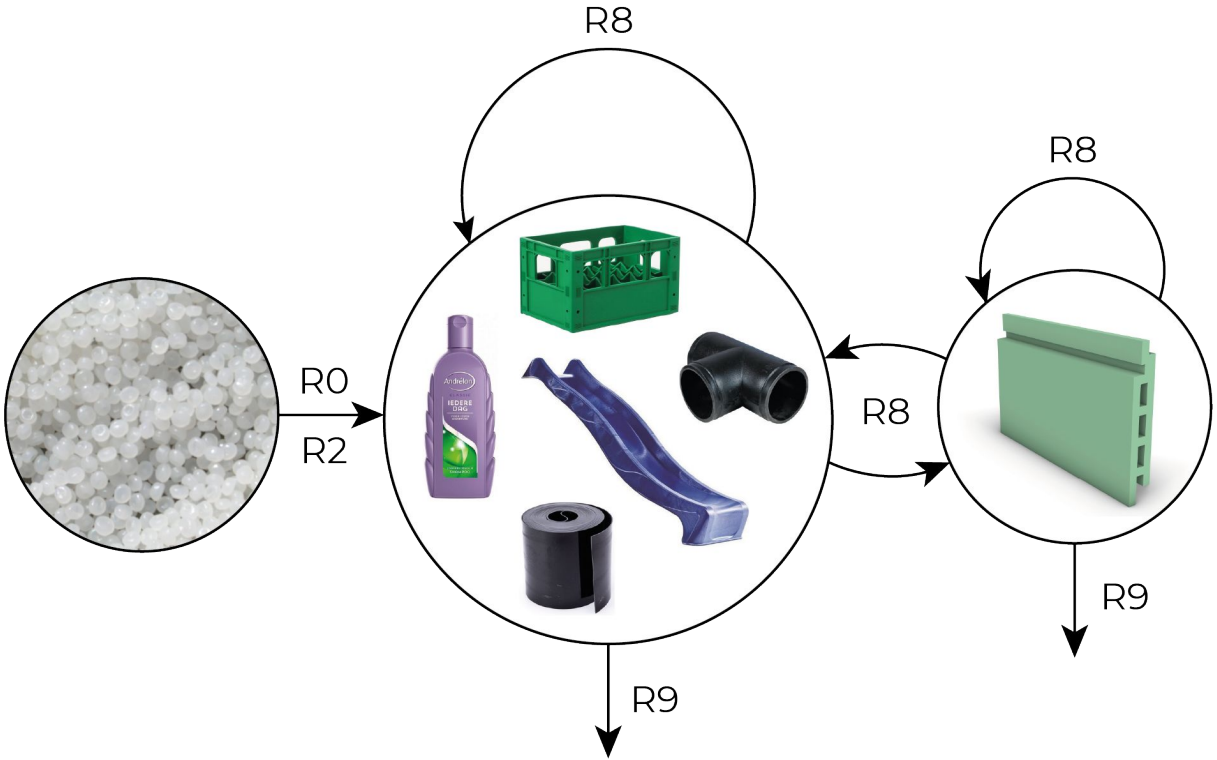
Ceramic panel (Mosa ®)



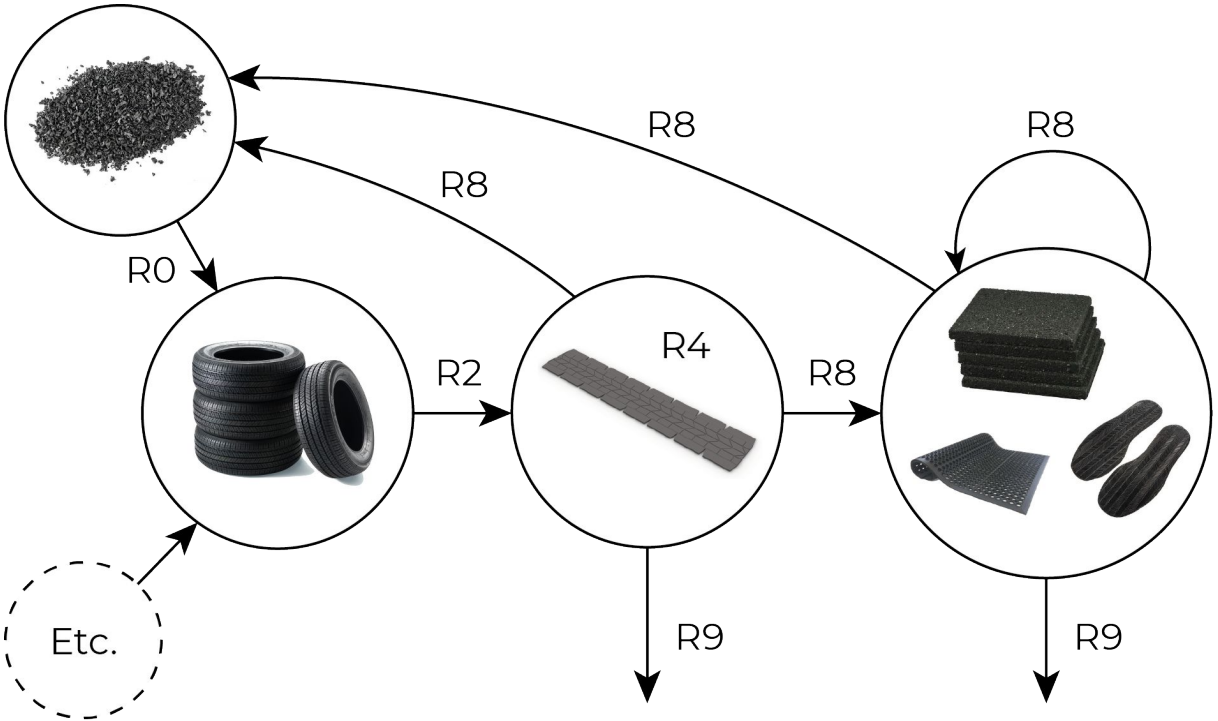
Measuring circular potential



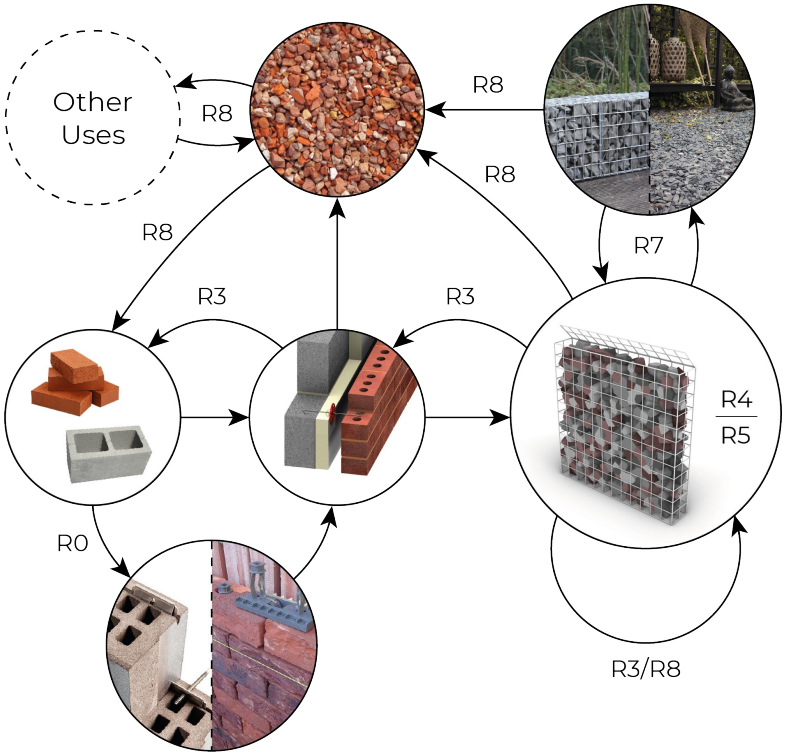
Case study 1 - HDPE R-paths



Case study 2 - Rubber tire R-paths

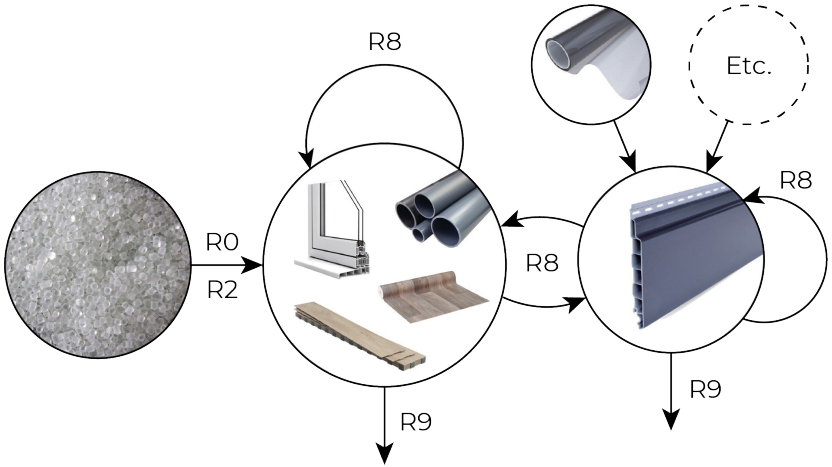


Case study 3 - Building stone R-paths

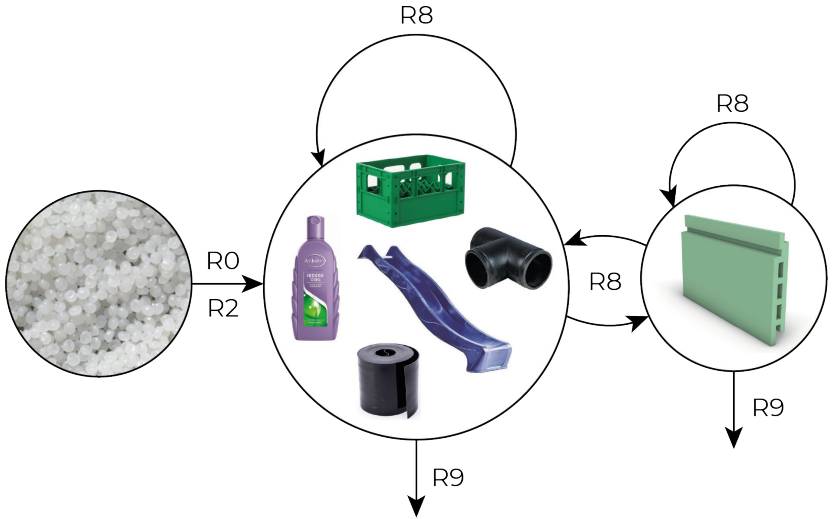


R-paths vergelijken

VinyPlus

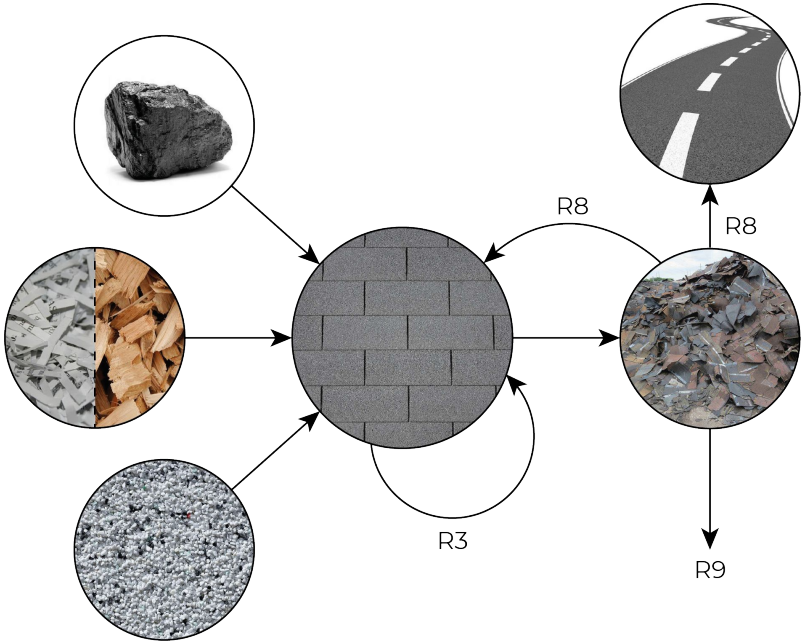


HDPE

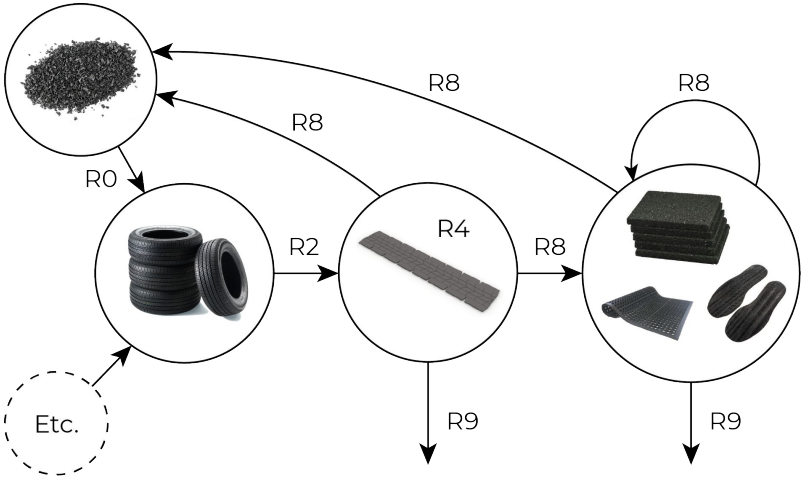


R-paths vergelijken

Bitumen

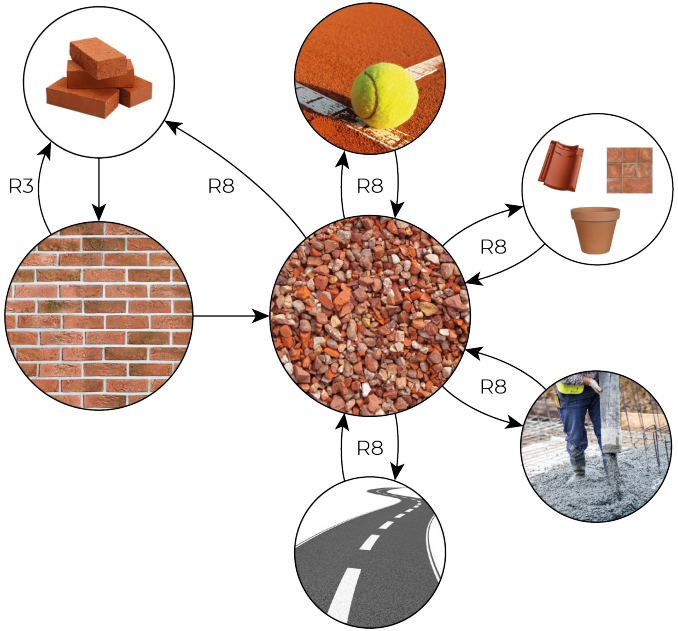


Rubber

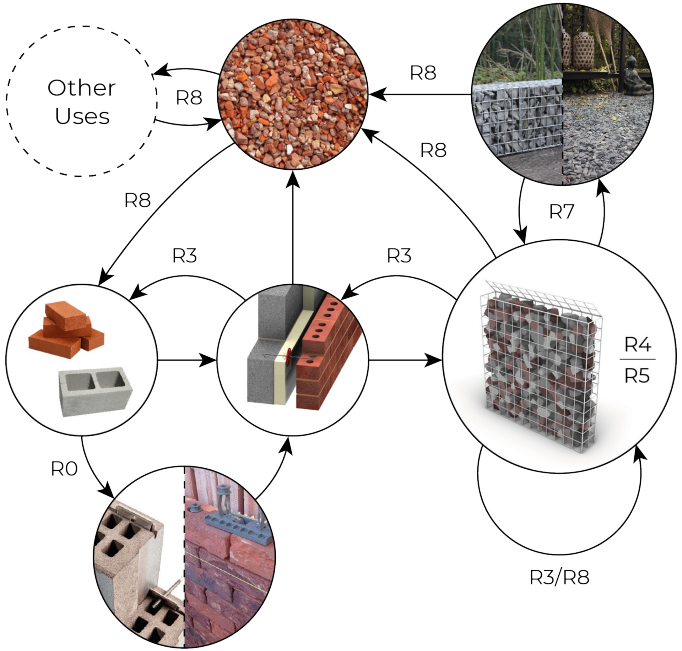


R-paths vergelijken

Brick



Rubble compartments + prevention strategies



Changes for residual materials

Barriers towards circular improvements

- Lack of pricing policies
- Lack of innovation
- Unexploited economies of scale
- Government policy/failure
- Lack of marketability for reuse of household waste
- Supply-driven markets for secondary materials
- Time needed for market transitions

1. Money
2. Policy
3. Time

Overcoming barriers

Policy

- Pricing policies for environmental damage
- Extended producer responsibility (EPR)
- Stimulating innovation
- Deposit-refund system
- Regulation
- Information / collection focussed on quality

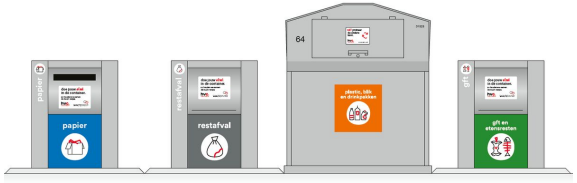
Pricing

- Market pricing
- Tiered / volume pricing
- Bundle pricing
- Geographical pricing
- Project based pricing

Material specific changes

Material pricing

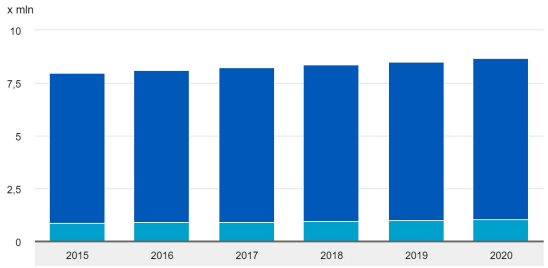
Separating of waste streams



Capacity & quality of recycling

Standards for secondary quality

Supply and demand



Innovations in composition

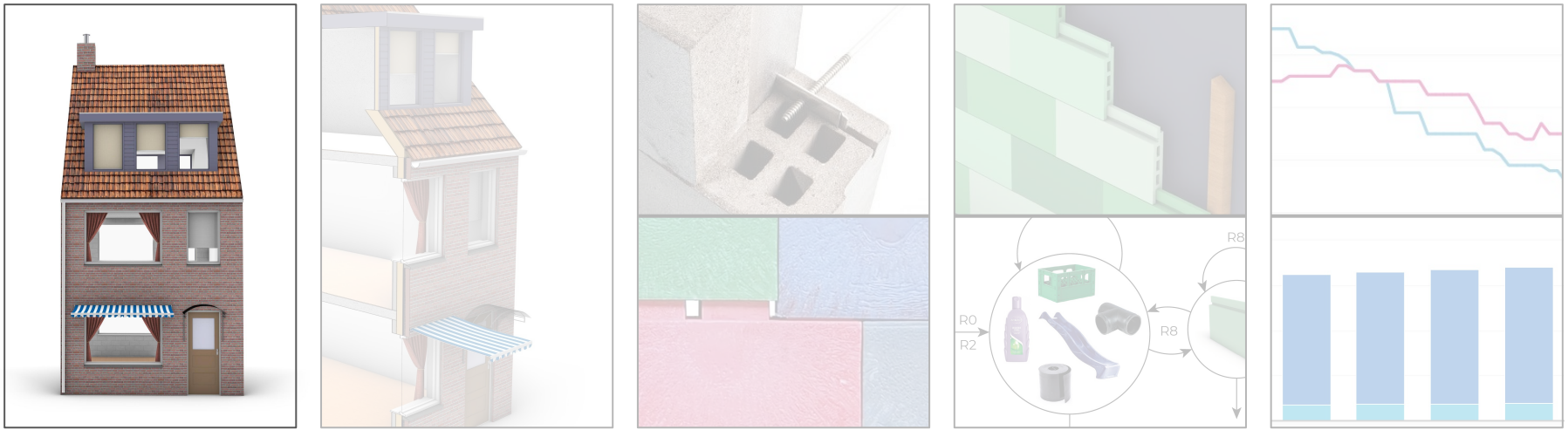
Advisory framework

Framework steps

1. Establish the desired goals of answering the research question, i.e. what the final product should be.
2. Distinguish all relevant elements towards the set goals, then:
    a. Find out which materials are commonly used for each distinguished element.
    b. Gauge the circularity of each element, for each of its common materials.
    c. Make a selection of elements and materials with the highest potential for circular improvement.
3. Think of potential (higher) R-strategies for each of the selected elements and materials and find/create examples, towards increasing their circularity either by:
    a. Utilising the conventional material of an element in a more circular way.
    b. Finding alternative materials with under-utilised circular potential.
4. Assess the potential circular improvement of the found/created examples compared to their similar conventional elements and materials, through:
    a. Designing a building product based on the examples
    b. Gauging the feasibility of the product through comparison with existing products.
    c. Thinking of all possible R-strategy paths for utilising the product and its materials, across multiple lifecycles, and comparing these to those for conventional building products/materials.
5. Consider how general future changes towards a circular economy may affect the design proposals.

Framework steps

1. Establish the desired goals of answering the research question, i.e. what the final product should be.



Framework steps

2. Distinguish all relevant elements towards the set goals, then:
   a. Find out which materials are commonly used for each distinguished element.
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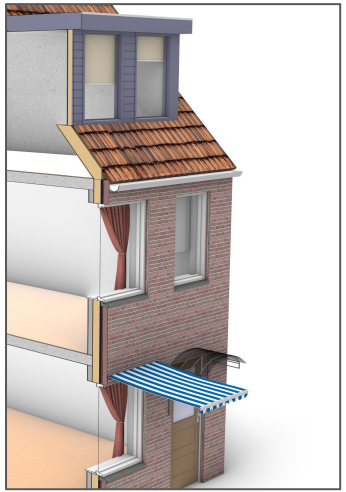
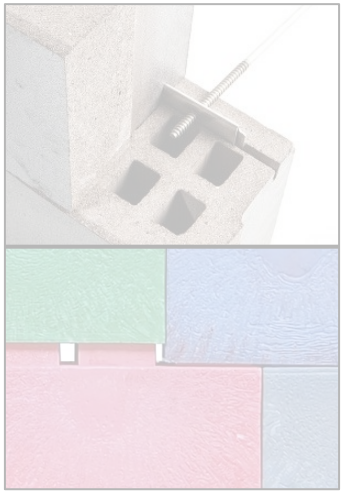
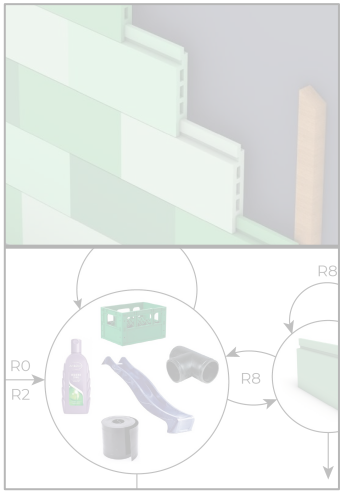
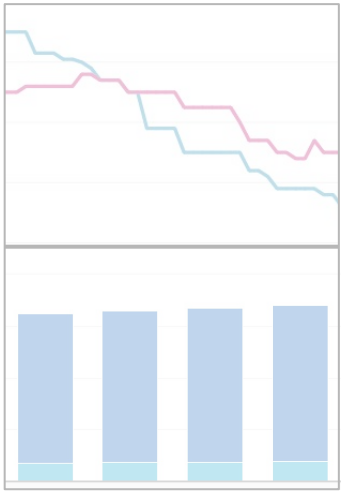
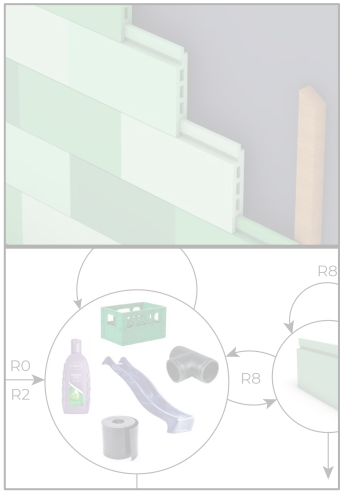




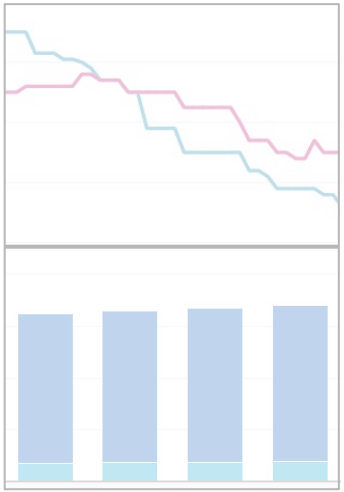


Framework steps

3. Think of potential (higher) R-strategies for each of the selected elements and materials and find/create examples, towards increasing their circularity either by:
    a. Utilising the conventional material of an element in a more circular way.
    b. Finding alternative materials with under-utilised circular potential.



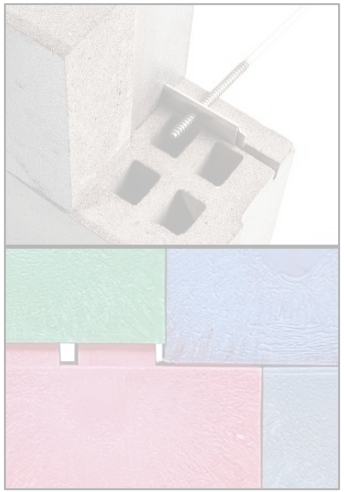
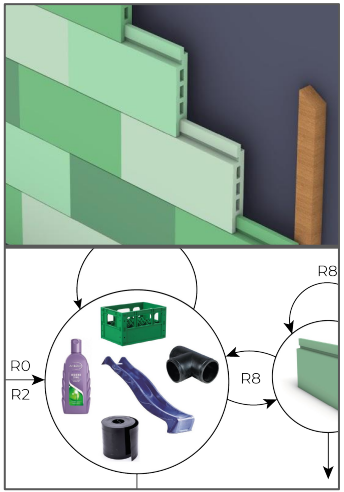



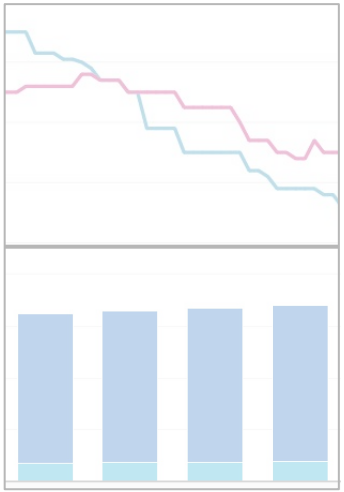


Framework steps

4. Assess the potential circular improvement of the found/created examples compared to convention:
    a. Design a building product based on the examples
    b. Gauge the feasibility of the product through comparison with existing products.
    c. Think and compare of all possible R-strategy paths for utilising the product and its materials.

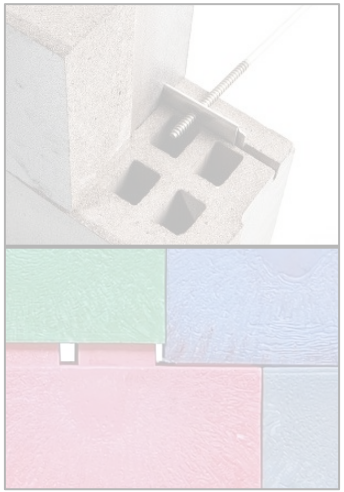


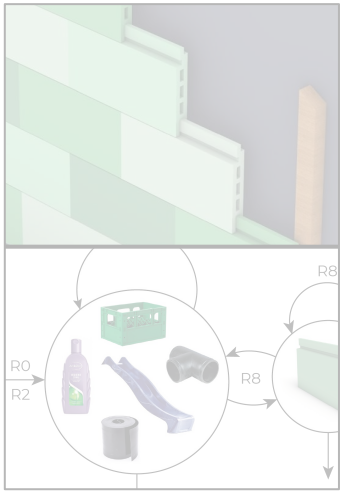



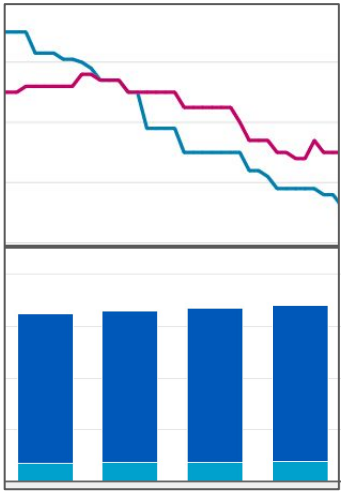


Framework steps

5. Consider how general future changes towards a circular economy may affect the design proposals.

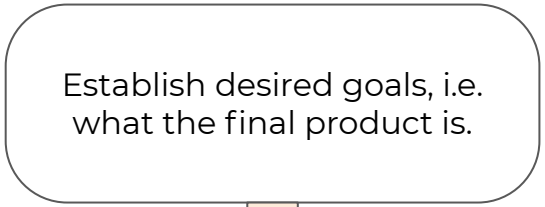






Framework assessment

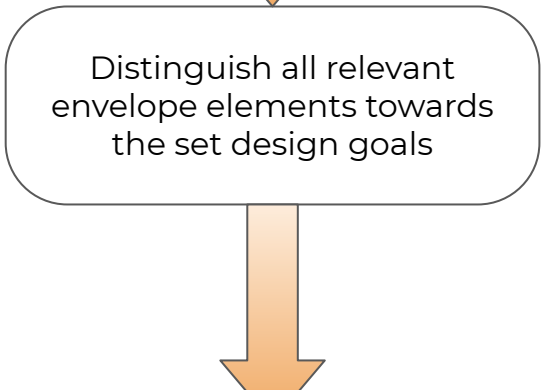
1.



Points of attention

- Goals and criteria can differ from those used in this report, though later measuring indicators for circular potential are based on the goals and criteria of this project.

2.



Points of attention

- If one already has certain elements in mind, (parts of) this step may be skipped.
- For a low amount of options, it is recommended to gauge circular potential using R-paths during this step as well.

Results

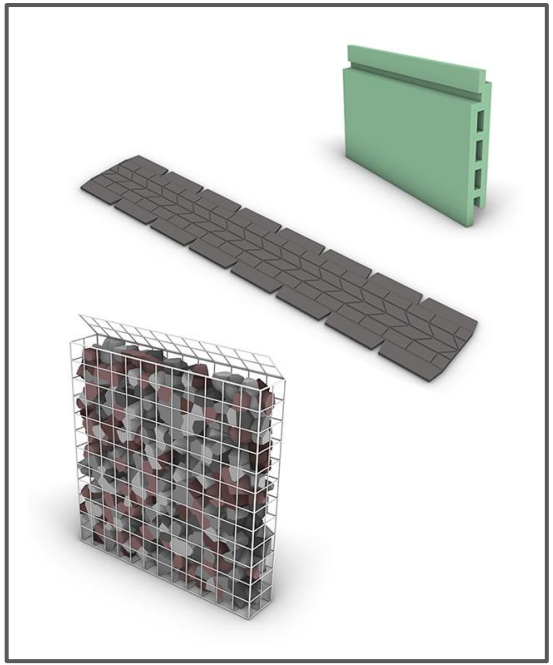
Catalogue

Element (group)	Materials	R-strategy	Improvement
Insulation	EPS / XPS	Reuse	Extending the lifespan
		Reuse	Reuse from former applications
		Recycle	Higher grade recycling (Upcycling)
	PUR	Rethink	Using more ecological compounds
		Rethink / Reuse	Using sheets instead of spray
		Reuse	Reuse from former applications
		Recycle	Higher grade recycling
	PIR	Reuse	Extending the lifespan
		Recycle	Higher grade recycling
	Glass wool	Reuse / Recycle	Prevent mixing and contamination
	Wood fibre	Reuse	Use wood from former applications
	Cellulose	Reuse	Reuse from former applications
		Refurbish	Adding cellulose to wornout section
Cladding & roofing	Bitumen	Repair	Adding bitumen or sealant for repa
		Recycle	Making new bitumen from residuals
	Brick	Reuse	More adaptive connections
		Reuse / Recycle	Using / making bricks from rubble
	Ceramics / stone	Reuse	Reuse from former applications
		Reuse	More adaptive connections
		Repair	Gluing broken tiles (like a vase)
		Recycle	Making new bricks from rubble
	Polymer	Reuse / Repurpose	Reuse from former applications
		Recycle	Use of lower grade recycled polym
		Recycle	Higher grade recycling (Upcycling)
	Reed	Repair / Refurbish	Repairing damaged sections
	Steel	Reuse / Repurpose	Reuse from former applications
	Wood	Reuse	Reuse from former applications
		Repair / Refurbish	Remove individual planks/boards
Curtains & shading	Acrylic / Polyester	Reuse / Repurpose	Reuse from former applications
		Repair / Refurbish	Fixing tears or raffling / adding new
		Recycle	Higher grade recycling (Upcycling)

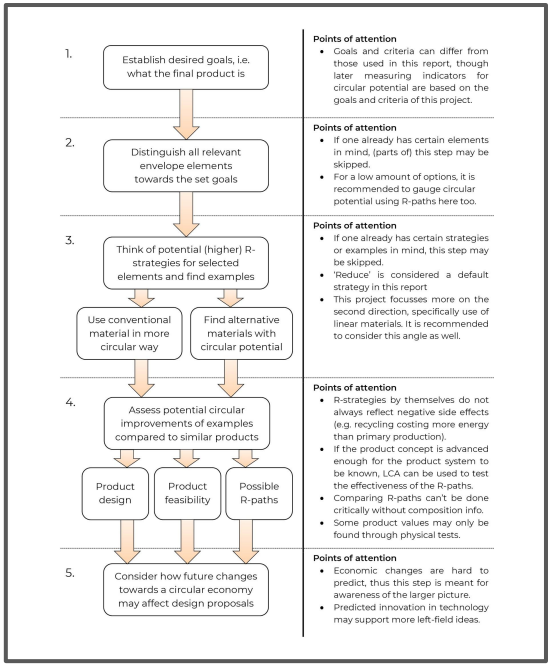
ALTERNATIVE MATERIAL

Element (group)	Materials	R-strategy	Alternative material
Insulation	General	Recycle	Textile (e.g. denim)
		Repurpose	Matresses
		Recycle	Hemp
		Recycle	Flax
		Recycle	Textile

Case studies



Framework



Future research

- Realising the idea of a visual catalogue of circular improvement ideas, such as through an interactive website. This would also strengthen aesthetic assessment.
- Further development of case studies, to expand measurements through LCA.
- Considering influence from promising developing methods, such as by CB’23.
- Research on how product systems can be made more predictable and transparent, e.g. through the use of material passports.
- More in depth research on predicted changes towards a circular economy. The results could be used to put a stronger emphasis on the use of particular residual streams.
- Trying out the method beyond housing envelopes, e.g. office buildings
- How to optimize on material efficiency in a product, i.e. maximise on its properties

Questions?