BIO-BASED AIR DUCTS

Research in the applicability of bio-based materials for the construction of air ducts.

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Mentors
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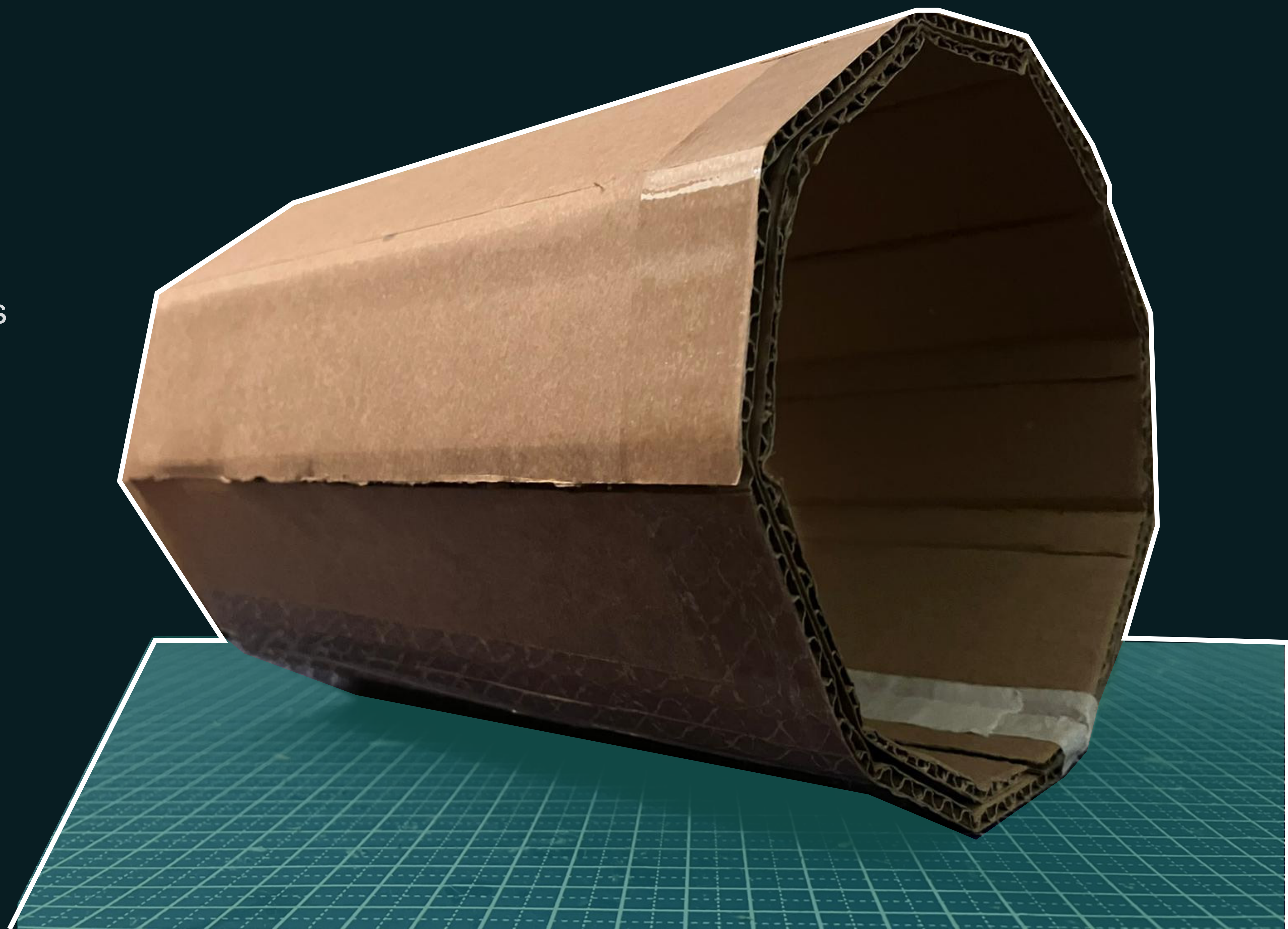
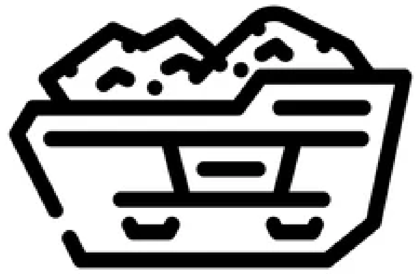


Content

Building industry

45%
global resource consumption



30%
global waste production

Circular economy

- 50% reduction of raw materials by 2030.
- Efficient use of materials.
- Use of renewable resources to prevent depletion of resources.

A circular economy in the Netherlands by 2050

Source: Rijksoverheid (2021)

Challenge

Source: Rijksoverheid (2021)

Problem statement

Currently, standard air duct solutions in buildings are made of **non-renewable** resources such as sheet metal resulting in **high embodied carbon usage** and material **depletion** overtime.

Objective

Non-renewable

Renewable


Research question

What are the potential and limitations of **bio-based materials** to replace **sheet metal** for the construction of air ducts by maintaining the same quality?

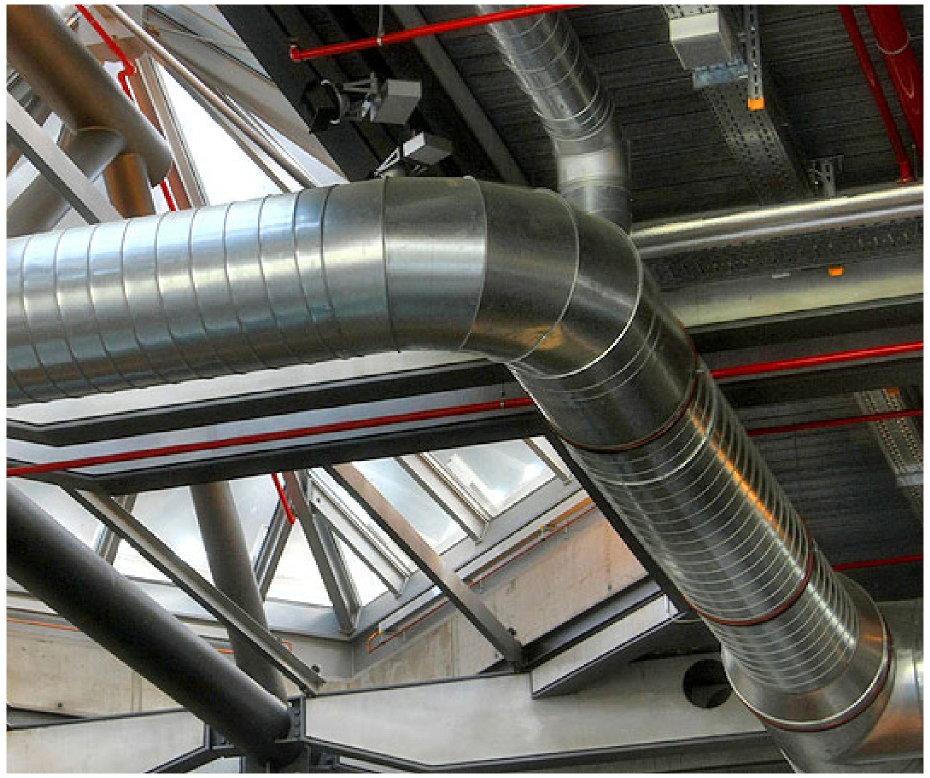
Methodology

1. **Introduction**
2. **Literature review**
   - Sheet metal air ducts
   - Circularity
   - Bio-based materials and manufacturing methods
3. **Design and analysis**
   - Design requirements
   - Analysis materials/LCA
   - Design problems
   - Design variations
   - Evaluation
   - Final design
4. **Prototyping**
   - Geometry
   - Connections
5. **Evaluation**
   - Moisture resistance
   - Chemical emission

Literature review

Sheet metal air ducts
Comparison duct types

- Performance, manufacturing, installation and cost.
- Spiral duct best solution, 30 % less material use.

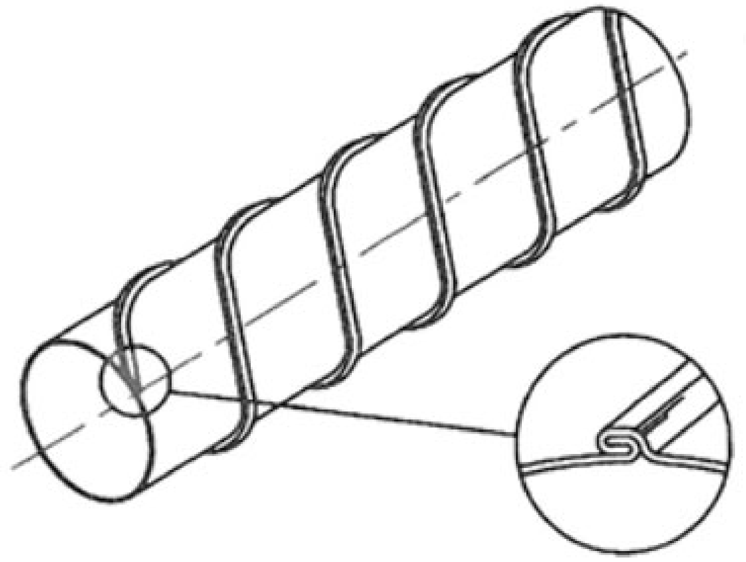

Spiral

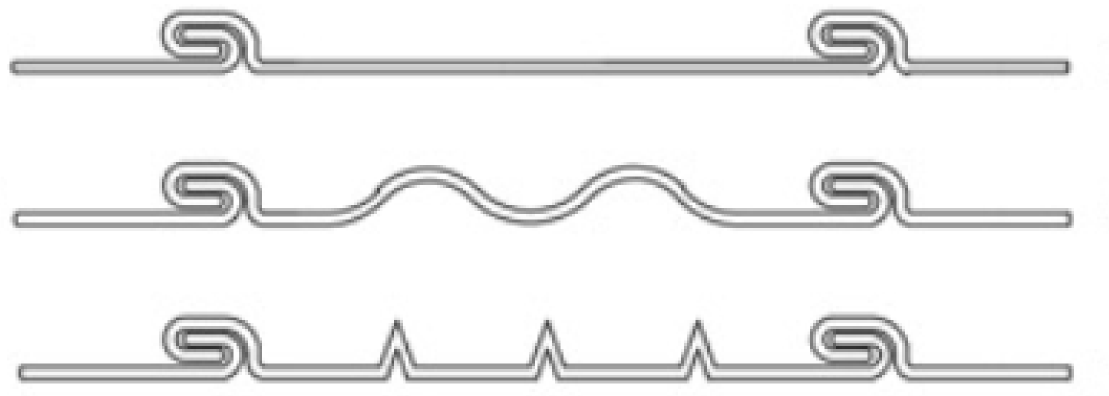

Oval


Rectangular

Source: Langer (2022) Dcduct (n.d.) Aircondloundge (n.d.)

Sheet metal air ducts
Spiral duct manufacturing





Source: Accu Duct (2006)

Spot (n.d.)

Sheet metal air ducts
Requirements for spiral air ducts

Requirements
spiral duct

General

- Dimensions
- Weight
- Ventilation rate
- Air velocity

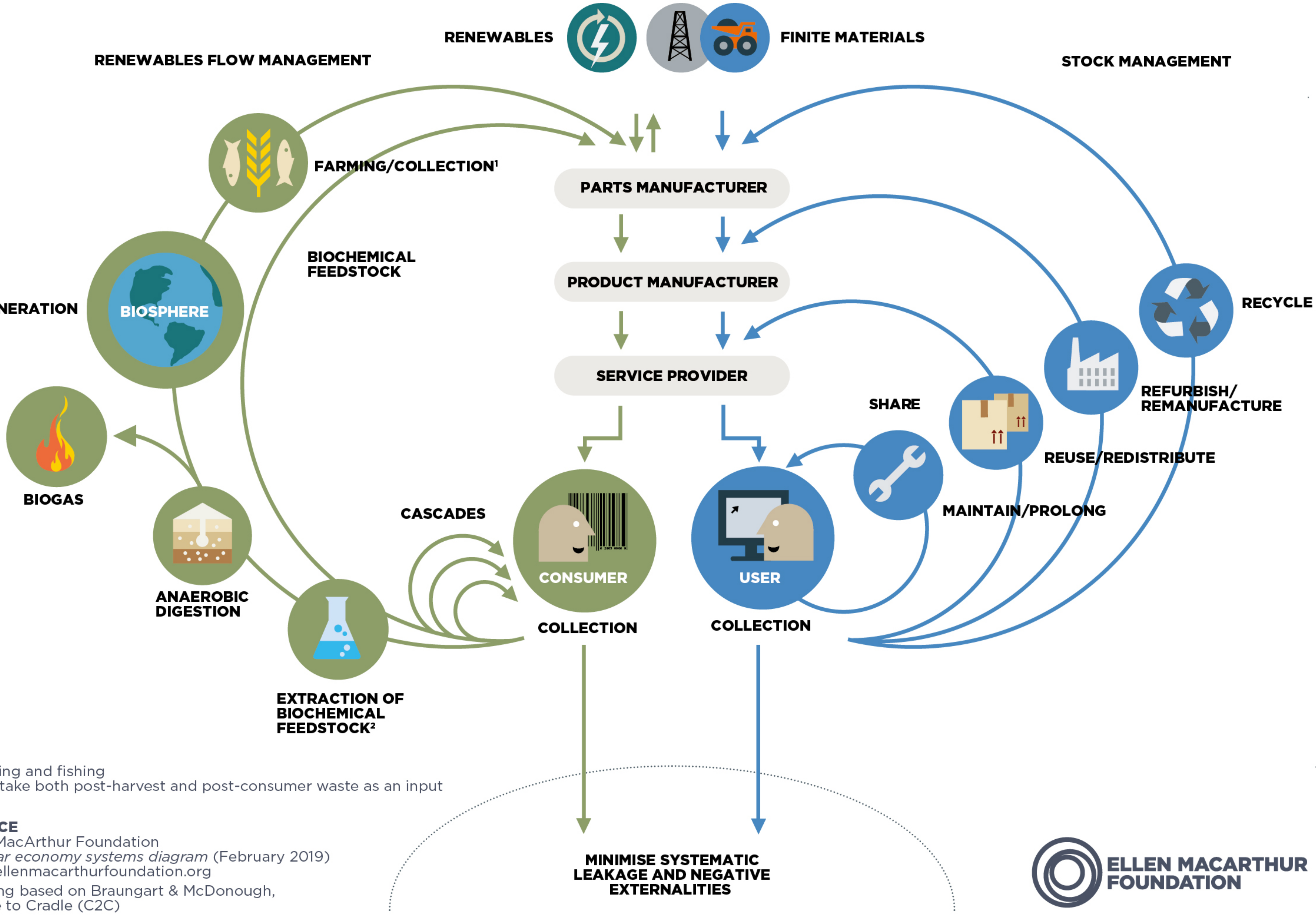
Functional

- Airtightness
- Pressure drop
- Installation noise
- Fire safety
- Moisture resistance
- Chemical emission

Maintenance

- Cleaning: access openings

Circularity
R-framework

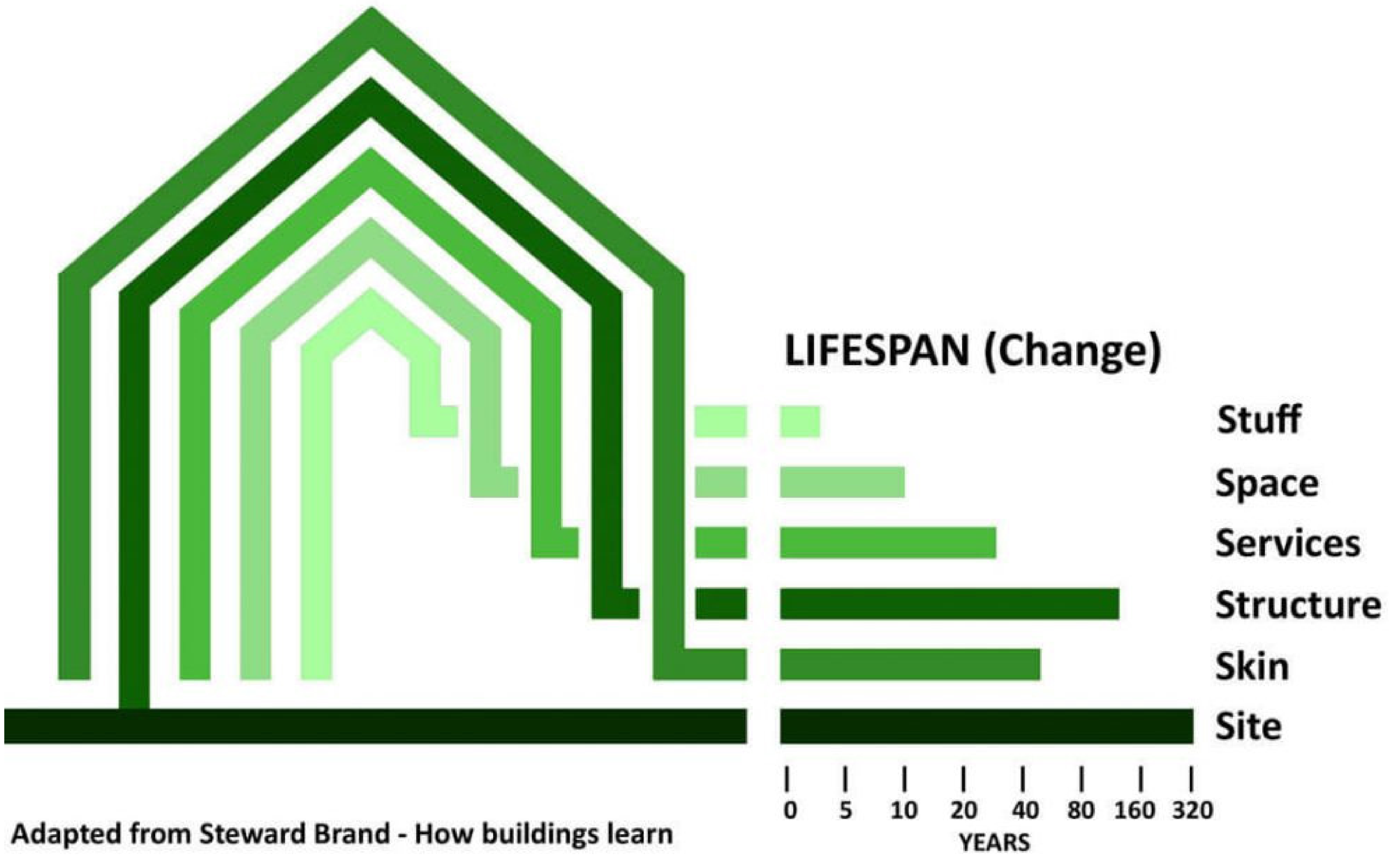


1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input

SOURCE
Ellen MacArthur Foundation
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough, Cradle to Cradle (C2C)

Source: McArthur (2015)

Circularity
Shearing layers



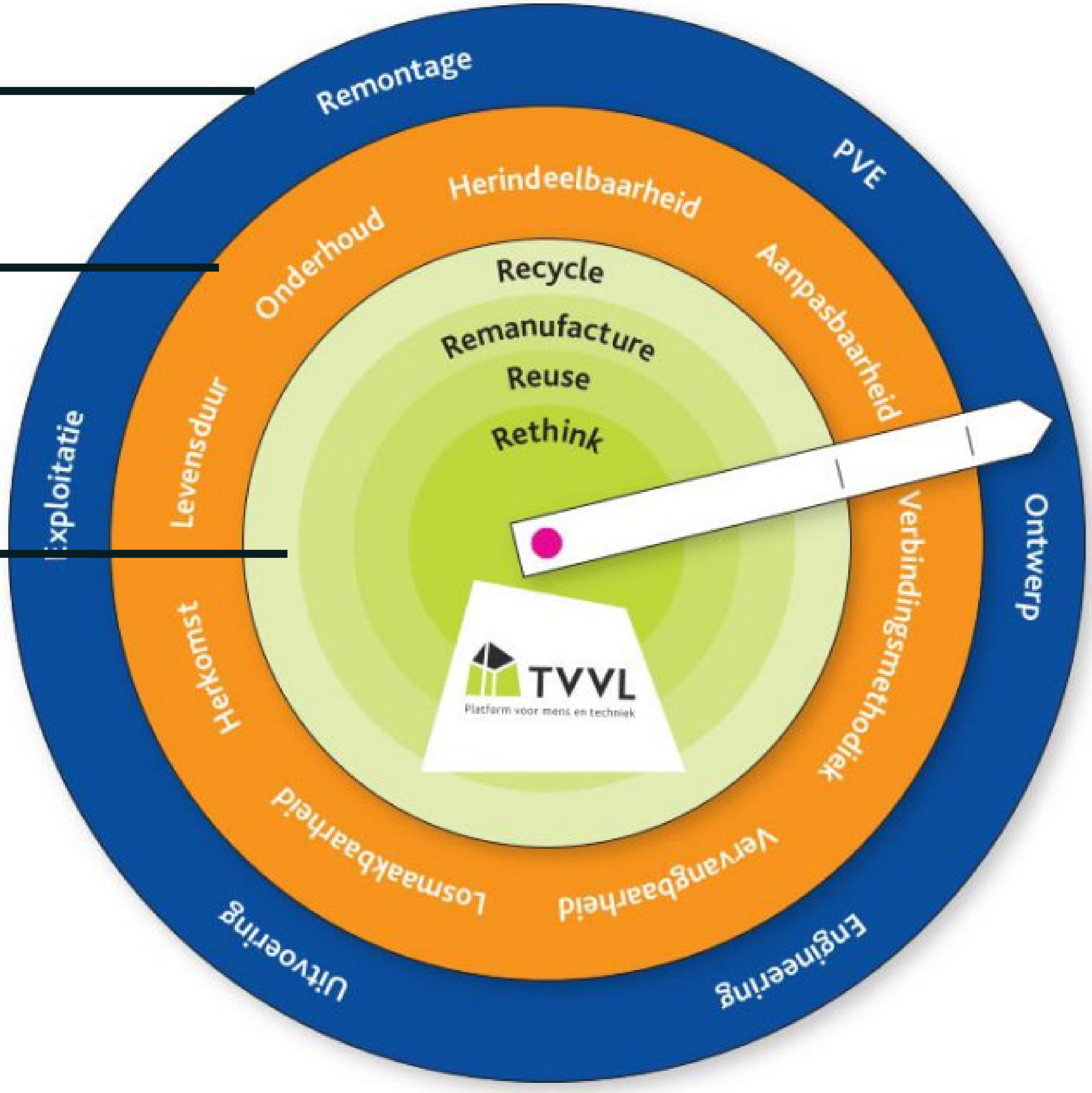
Source: Brand (1994)

Circularity
Building services circularity disk

Lifecycle of the building

Circular potential for future
for materials and components

Reducing environmental impact
of materials



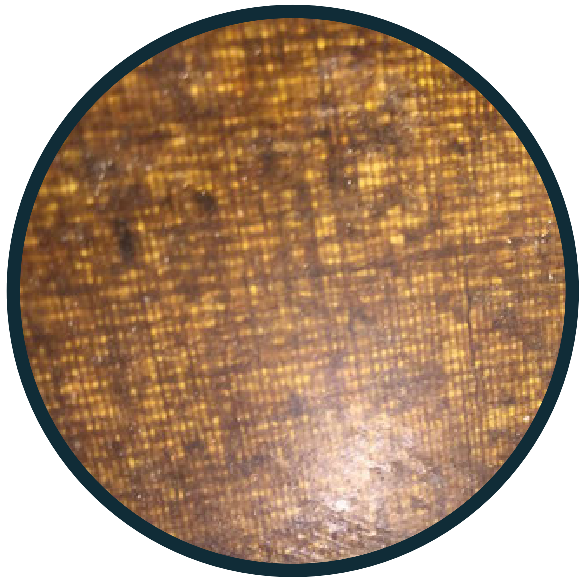
Source: TVVL (2020)

Bio-based materials
Categorization material types

Natural fibres
(Textiles)

Celullose
fibres (ECOR)

Bio-plastics



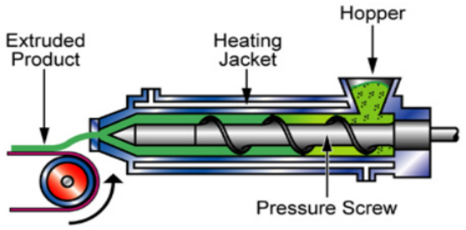
Bio-
composites

Wood
(veneer)

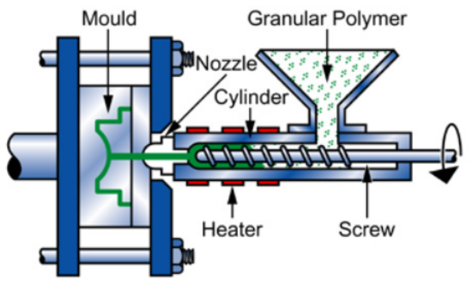
Cardboard
+
Tetra Pak

Fungi

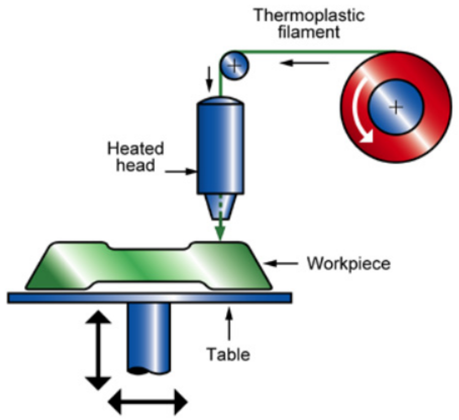
Bio-based materials
Manufacturing methods



Extrusion



Injection moulding



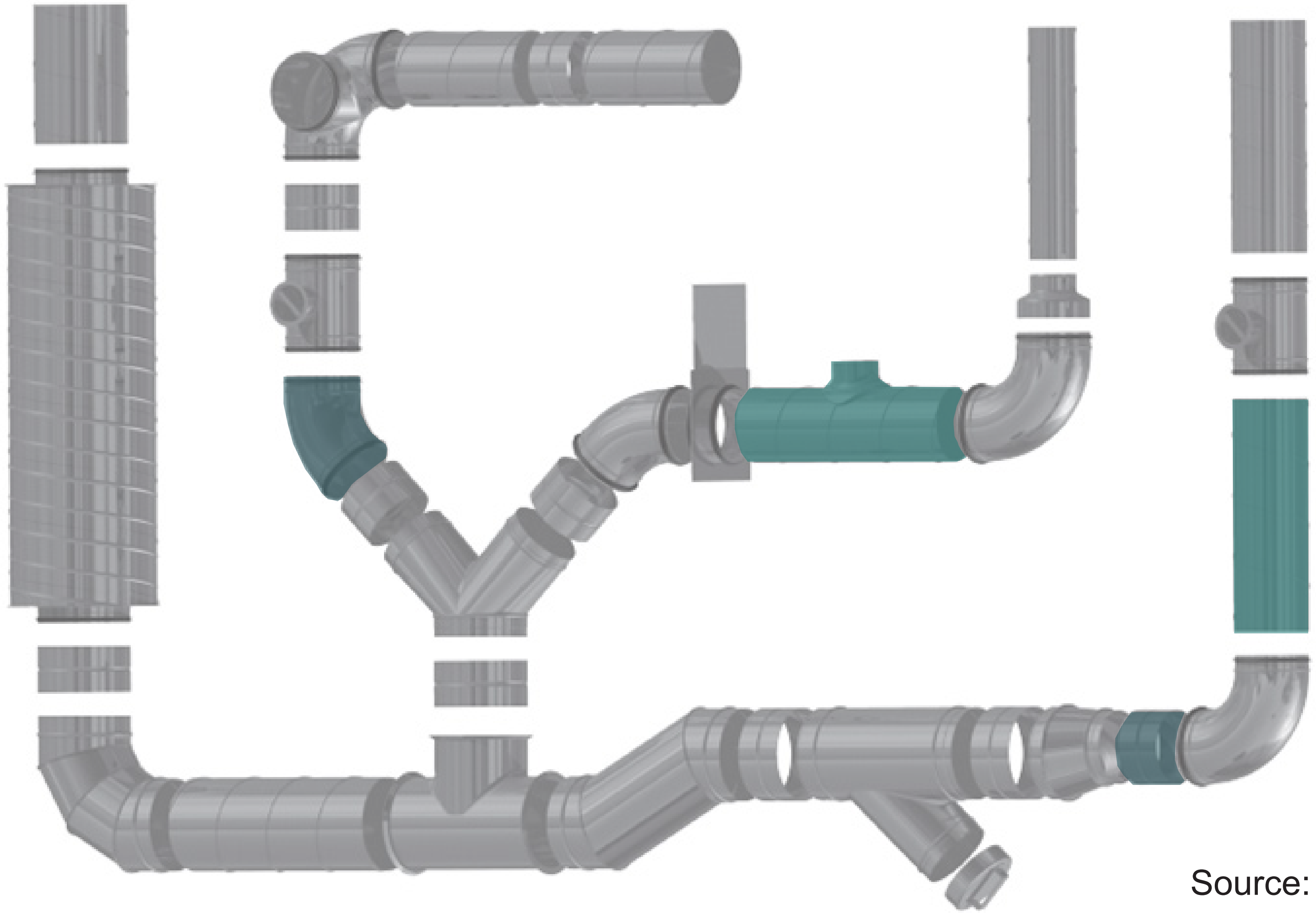
AM

Spiral winding cardboard

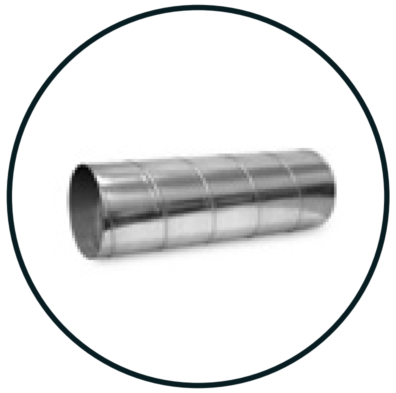
Source: Granta Edupack (2022)

Design research and analysis

Design goal

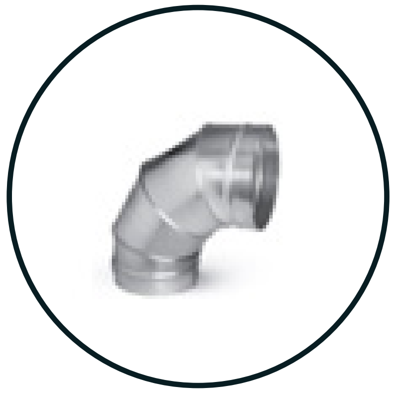


Source: Alnor (n.d.)



1. Linear duct

2. Joint



3. Bend

4. T-component

Design requirements

		Factor indicating importance (1-3)	Boundary conditions (yes or no)
Boundary conditions (for selection manufacturing method)	Geometry	●●	● ○
	Mass production	●●●	● ○
	Renewability	●●●	● ○
1. Functional	Weight	●	
	Airtightness	●●	
	Installation noise	●	
	Moisture resistance	●●●	
	Chemical emission	●●	
	Fire resistance	●●	
	Aesthetics	●	
2. Circularity	Local production	●●	
	Carbon footprint	●●●	
	Ease of dis(assembly)	●●	
3. Manufacturing	Material costs	●	
	Manufacturing costs	●●	
	Ease of production	●●	
4. Installation	**Material workability**	●●●	
5. Use	Maintenance (cleaning)	●●	
	Adaptability	●●	

Division manufacturing methods

Manufacturing method

Linear components
(linear duct)

Manufacturing method	Material
Cardboard spiral winding	Cardboard
Cardboard corrugated	Cardboard
Rotary cutting	Wood veneer
Extrusion	Bio-plastics
Foam moulding	Bio-plastics
Pultrusion	Bio-composites fibres
Filament winding	Bio-composites fibres
Weaving - textiles	Natural fibres
Water, heat, pressure moulding	Celullose fibres
Compression moulding (sheets)	Bio-composite non-woven fabric
Packaging manufacturing	Tetra Pak

Complex components
(joint, bend, t-component)

Manufacturing method	Material
Cardboard cutting	Cardboard
Hand lay-up	Bio-composites woven fabric
Spray lay-up	Bio-composites woven fabric
Vacuum bagging	Bio-composites woven fabric
Vacuum infusion	Bio-composites woven fabric
Compression moulding	Bio-composites non-woven fabric
Injection moulding	Bio-plastics
Moulding	Mycelium
AM	Bio-plastics
Packaging manufacturing	Tetra Pak

Solution matrix

Manufacturing method

Rotary cutting

Bio-based material

Veneer

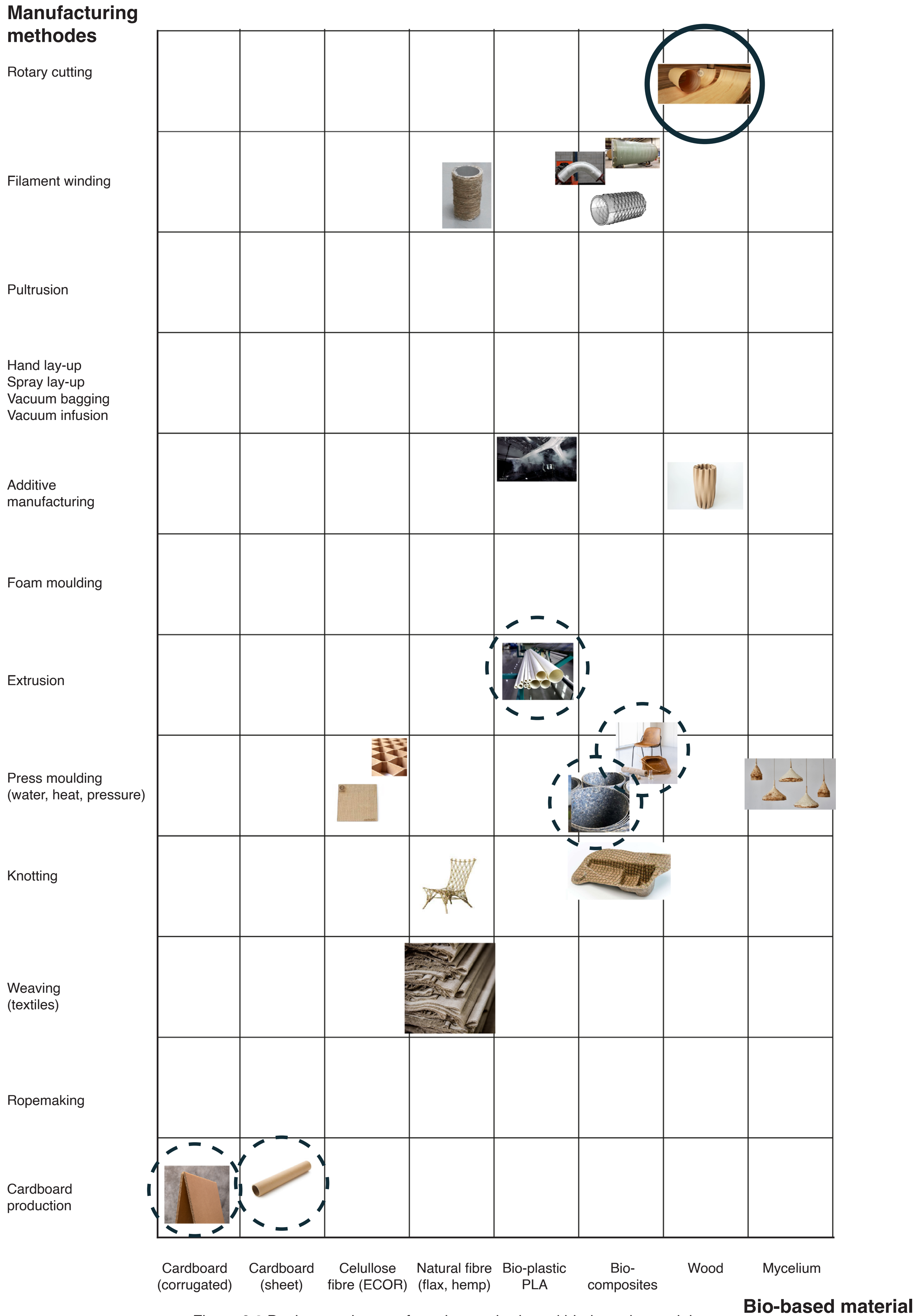
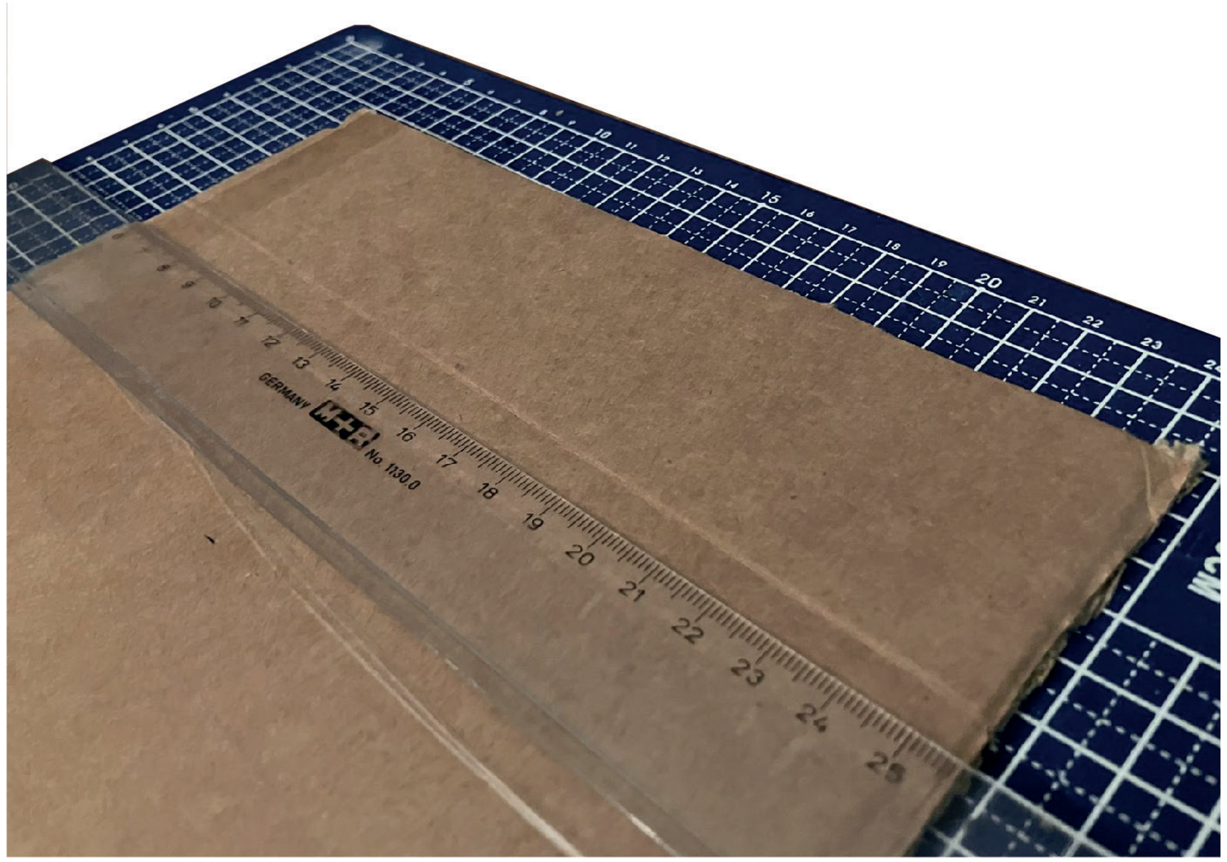
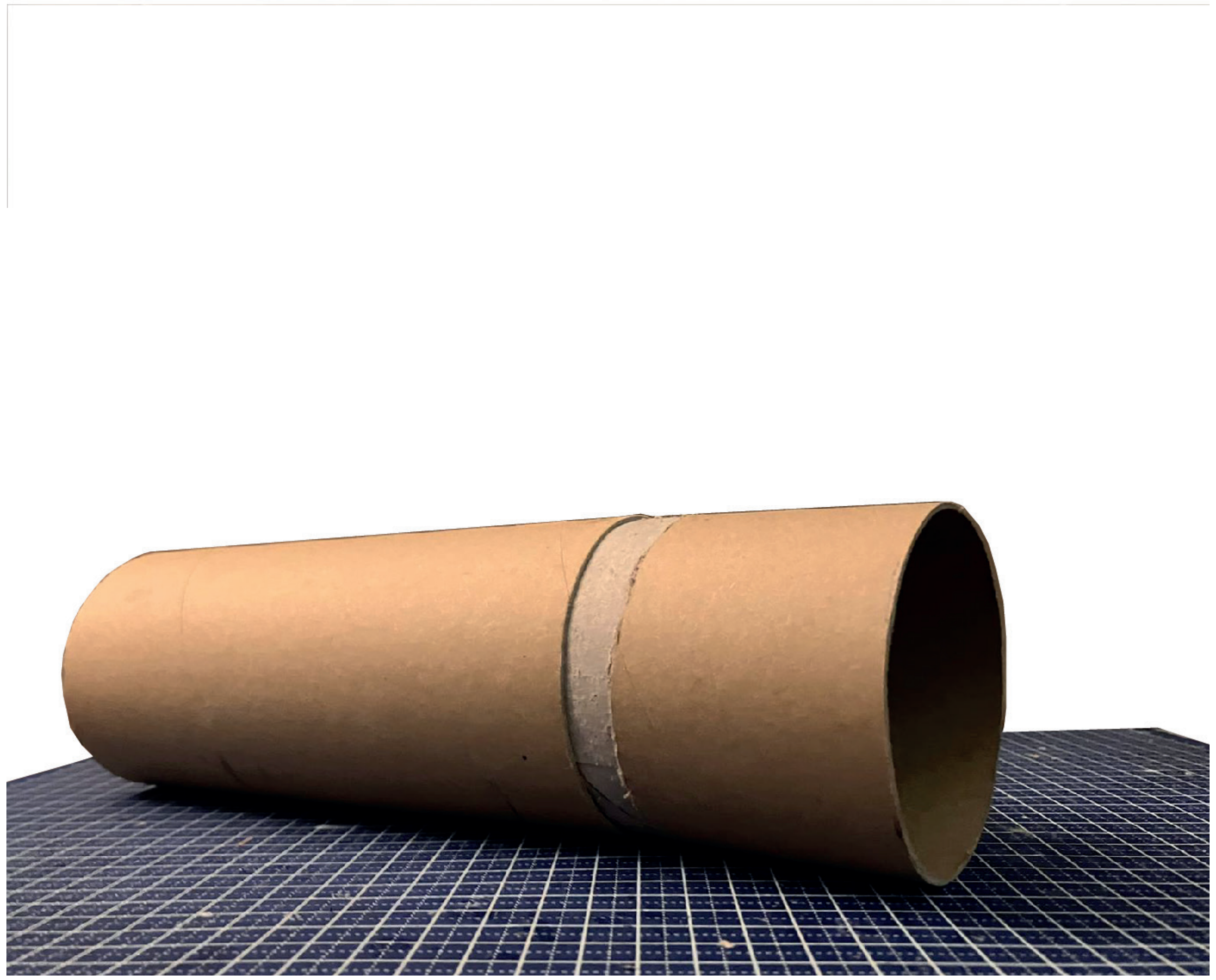
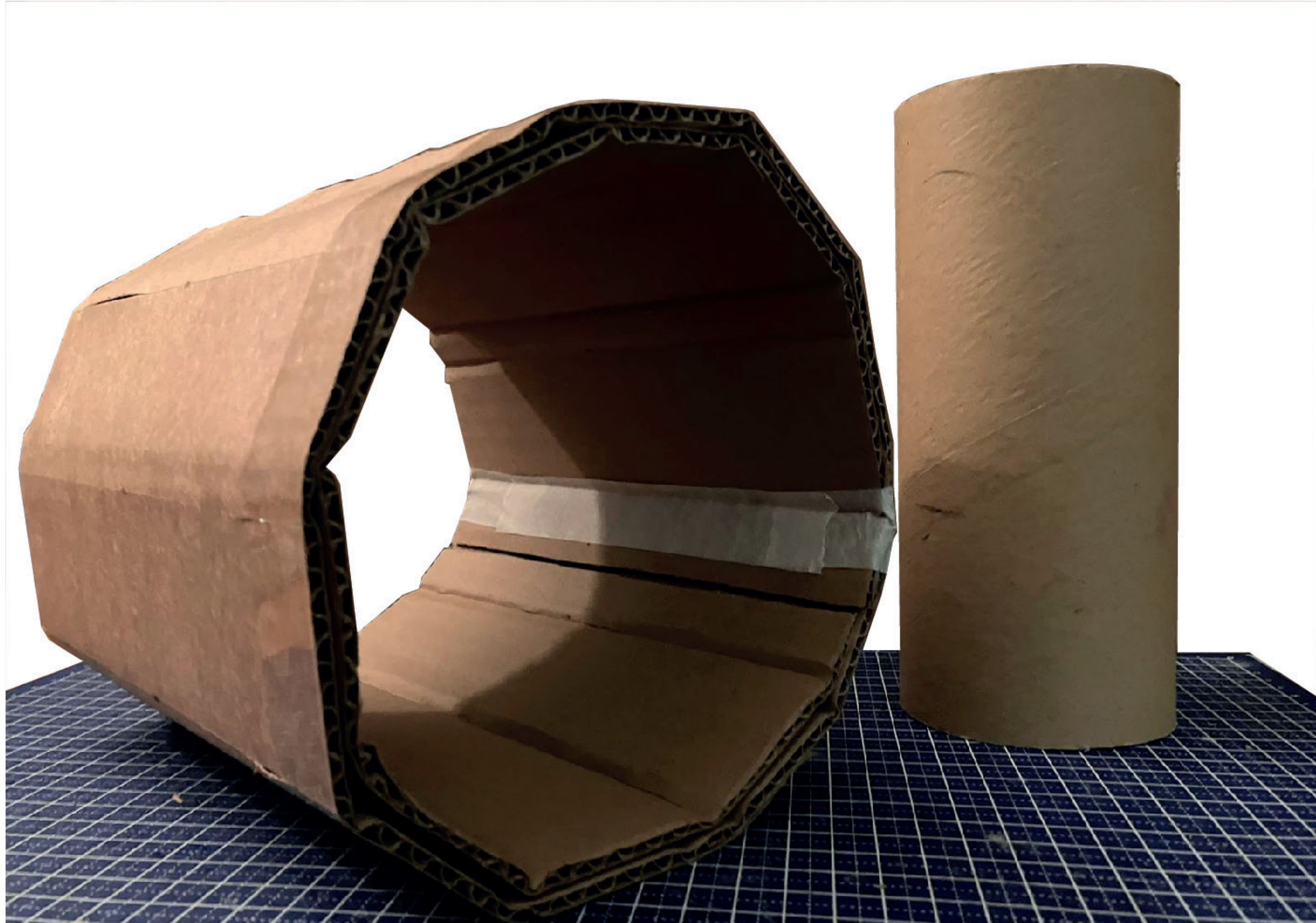


Figure 6.2 Design matrix manufacturing methods and bio-based materials.

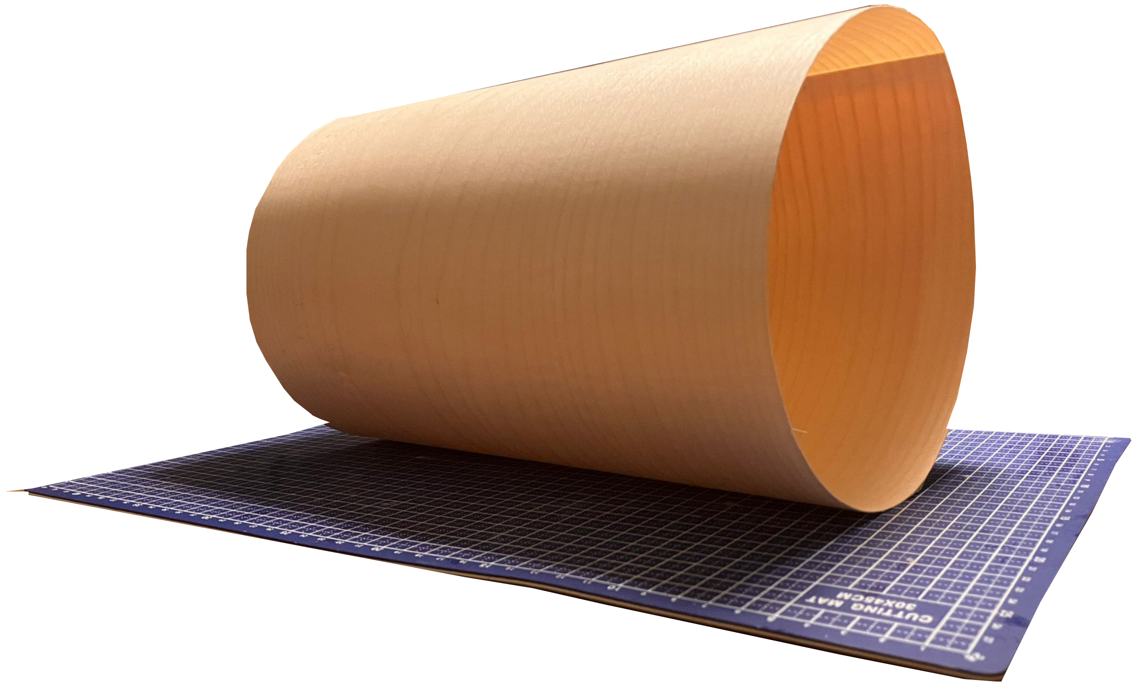
Cardboard

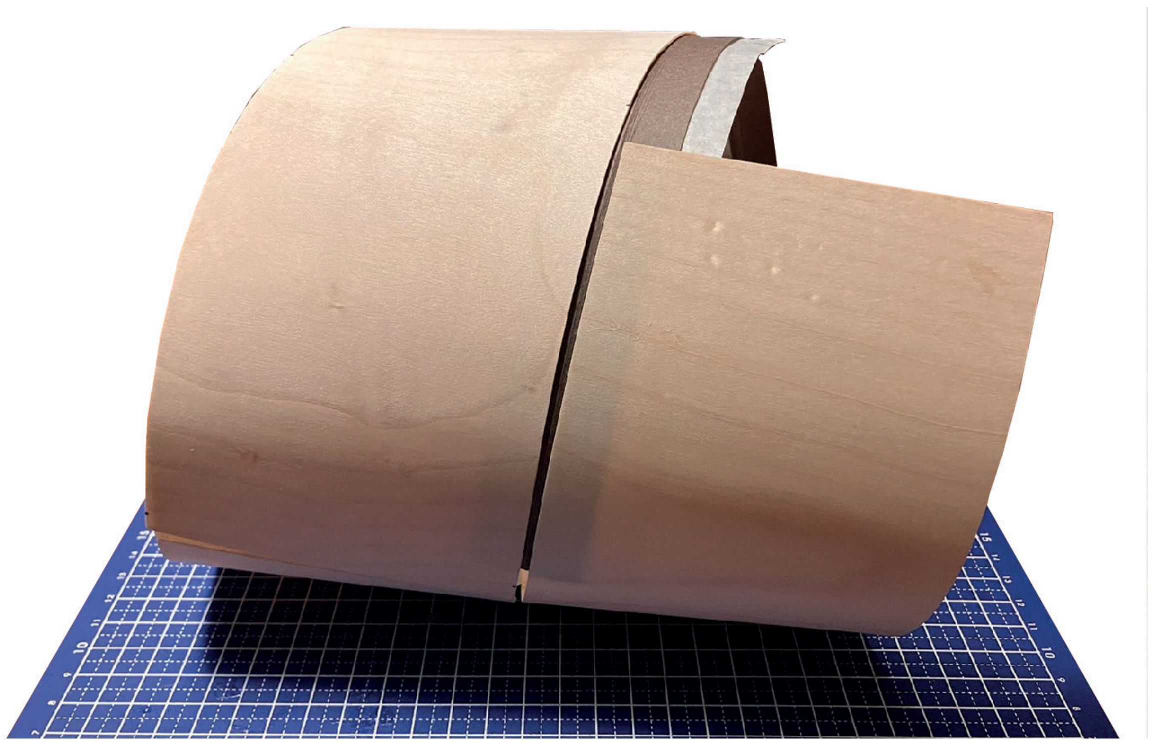


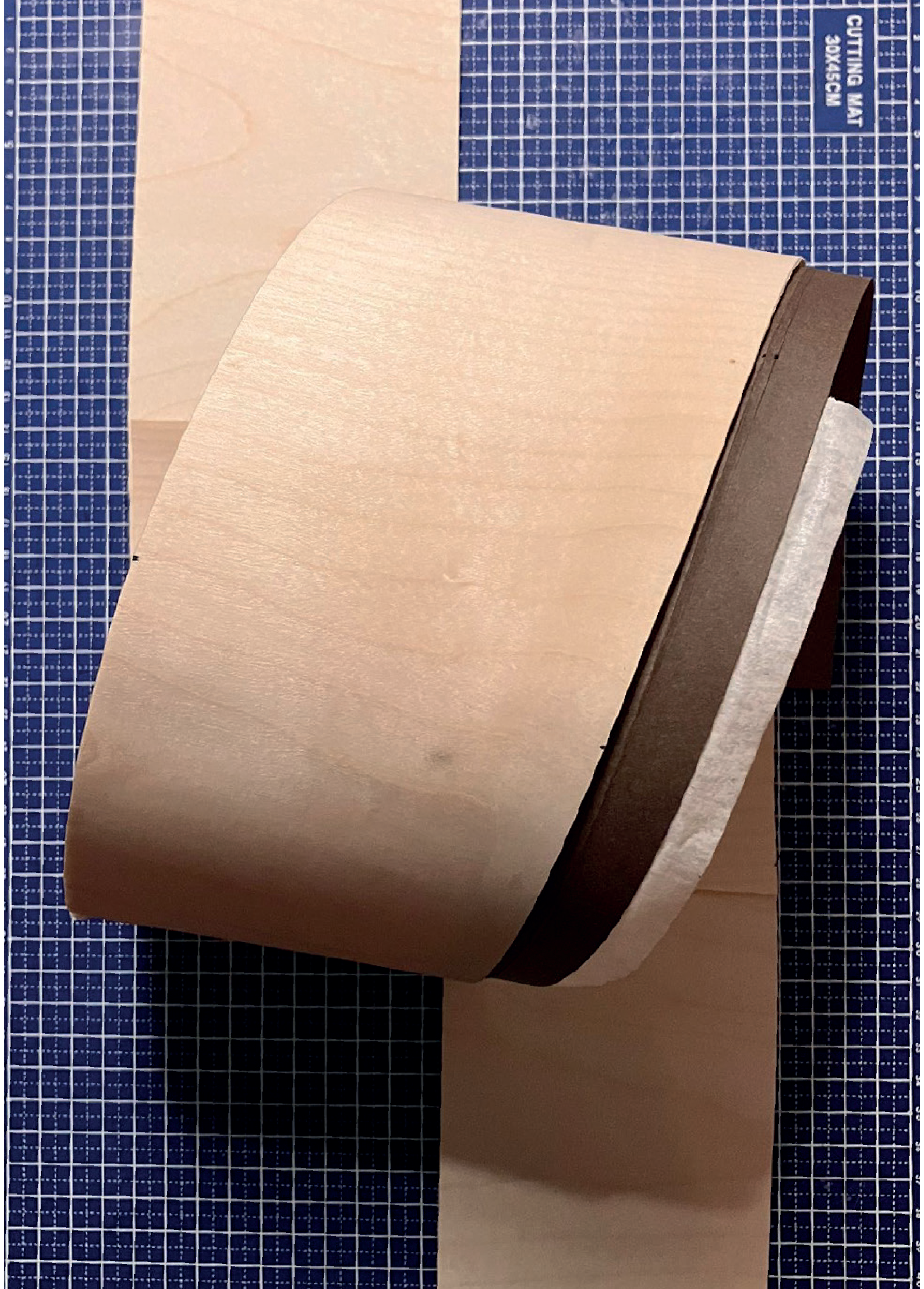




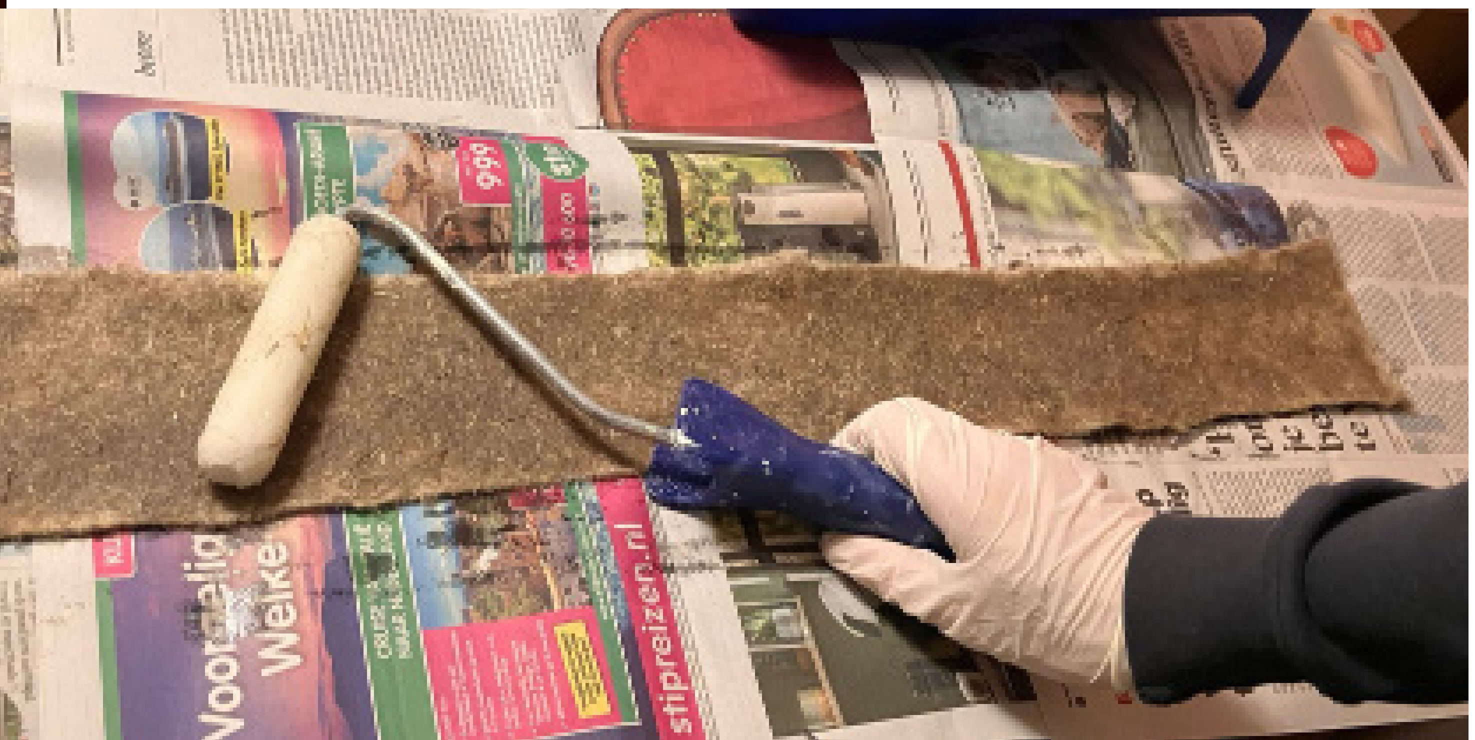
Veneer







Bio-composites



Non-woven flax fibres

Clothing waste
100 % cotton

Woven flax fibres

Bio-composites old jeans

Source: PlanQ (2022)

Tetra Pak packaging

Source: Dubbelfrisss (n.d.)

75% cardboard 20% bio-plastic 5% aluminium

95%

Bio-based


Dubbel Frisss
Per 100 ml 1 kcal
Appel & Perzik smaak
Heerlijk verfrissend & boordevol smaak!
Plant-based!!!


Per 100 ml 1 kcal
Appel & Perzik smaak


CUTTING MAT
30X45CM
Dubbel Frisss

Assessment materials

	Manufacturing method	Material	Geometry	Mass-production	Renewability
	Linear				
●	Spiral winding cardboard	Cardboard	●	●	●
	Corrugated cardboard production	Cardboard	O	●	●
●	Rotary cutting	Wood veneer	●	●	●
●	Extrusion	Bioplastic	●	●	●
	Foam moulding	Bioplastic	●	O	●
	Filament winding	Biocomposite fibres	●	●	O
	Pultrusion	Biocomposite fibres	●	●	O
●	Compression moulding: sheets	Biocomposite woven fabric*	●	●	●
	Weaving - textiles	Natural fibres: woven fabric	O	●	●
	Celullose fibres	Celullose fibres	●	O	●
●	Packaging manufacturing	Tetra Pak	●	●	●
	Complex				
●	Cardboard cutting	Cardboard	●	●	●
●	Injection moulding	Bioplastic	●	●	●
	Hand lay-up	Biocomposite woven fabric*	●	O	O
	Spray lay-up	Biocomposite woven fabric*	●	O	O
	Vacuum bag	Biocomposite woven fabric*	●	O	O
	Vacuum infusion	Biocomposite woven fabric*	●	O	O
●	Compression moulding	Biocomposite non-woven fabric*	●	●	●
	Moulding	Mycelium	O	O	O
	AM	Bioplastic	●	O	●
●	Packaging manufacturing	Tetra Pak	●	●	●

* including clothing waste made from bio-based materials: t-shirts, jeans etc.
including bio-based fibres: non-woven flax fibres

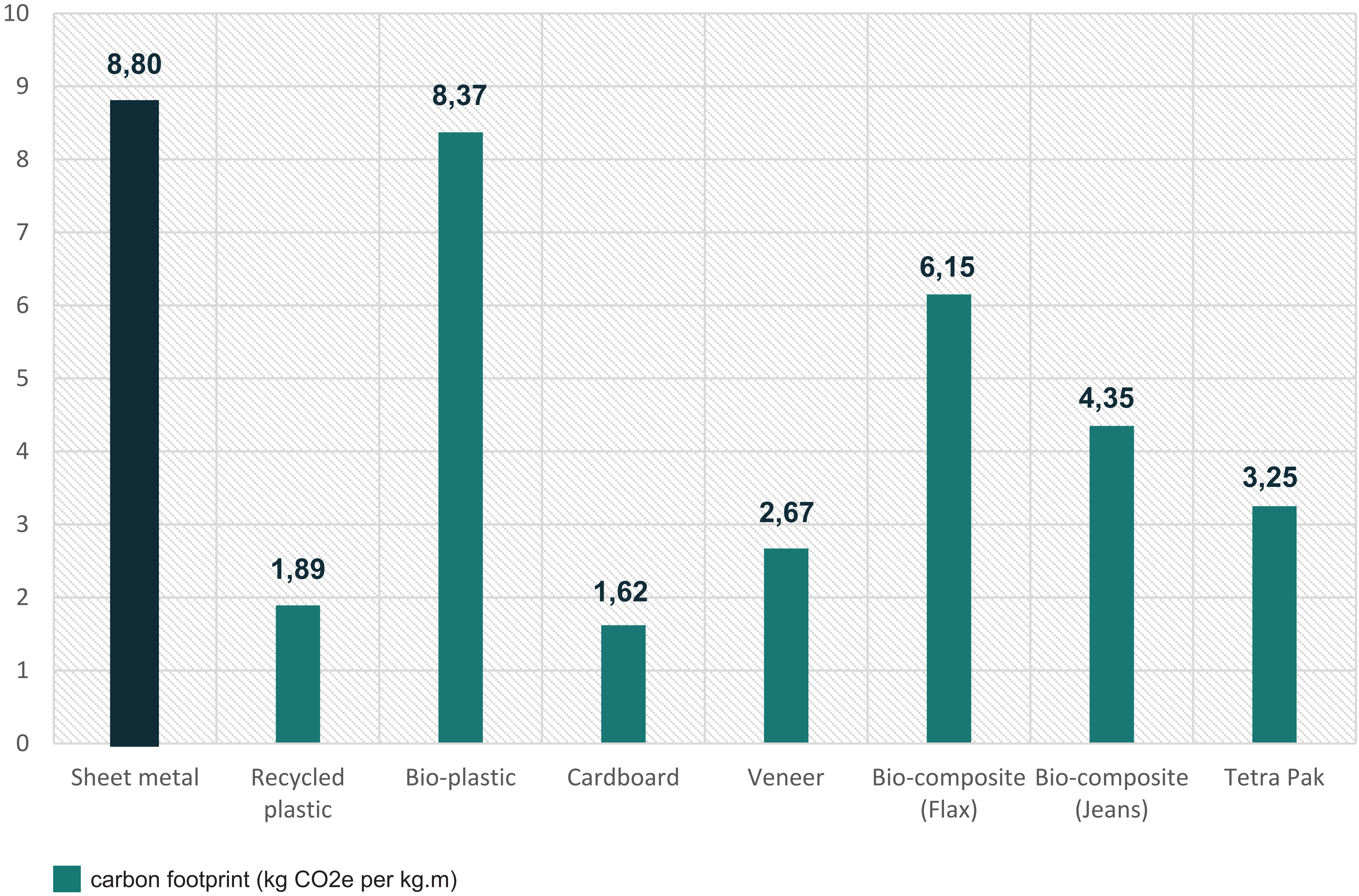
Product lifecycle

Product Stage			Construction Process Stage		Use Stage							End-of-Life Stage				Benefits and loads beyond the system boundary		
Raw material supply	Transport	Manufacturing	Transport to building site	Installation into building	Use/application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolition	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D

Source: OneClick (n.d.)

LCA - comparison with sheet metal

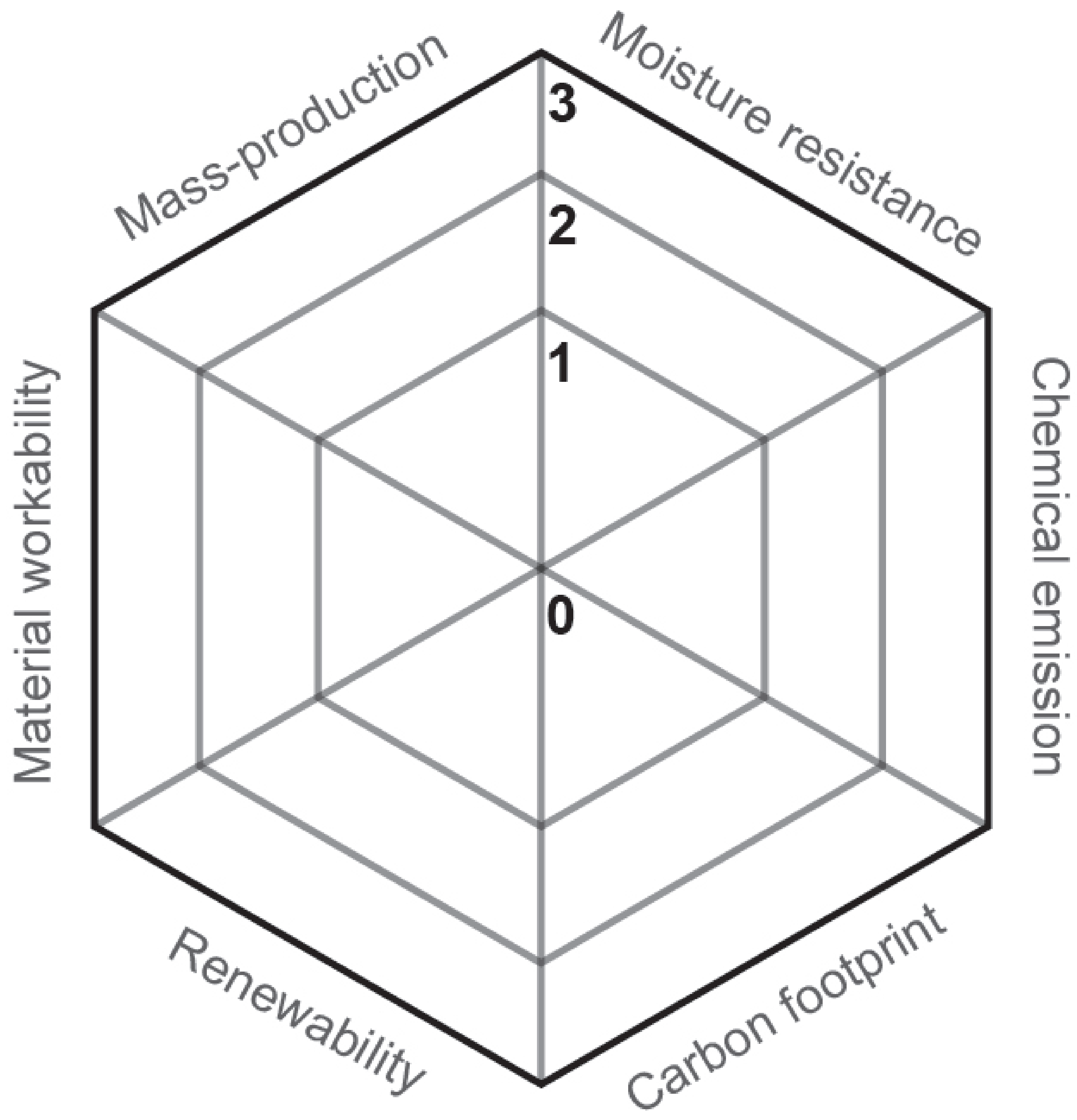
Based on 1 meter linear duct and 180 mm diameter



Overall assessment

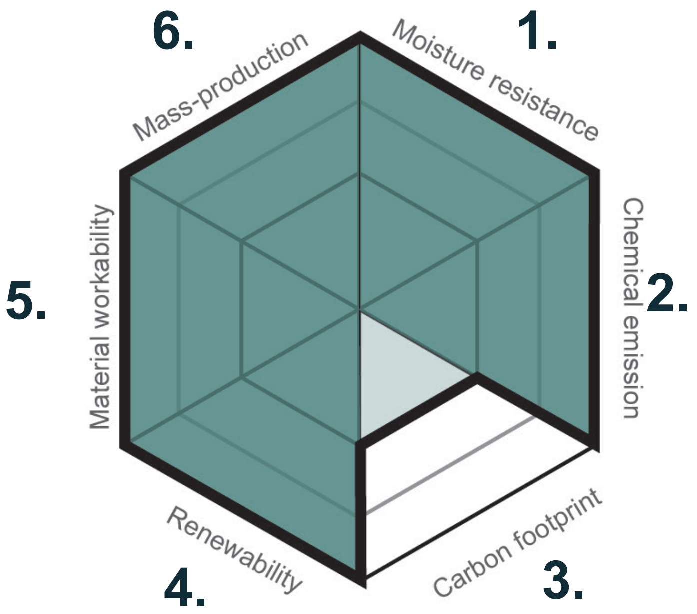
Based on linear duct

1. Moisture resistance - **Lifespan**
2. Chemical emission - **Health and comfort**
3. Carbon footprint - **Environmental impact**
4. Renewability - **End-of-life scenario**
5. Material workability - **Installation / weight**
6. Mass-production - **Scalability**

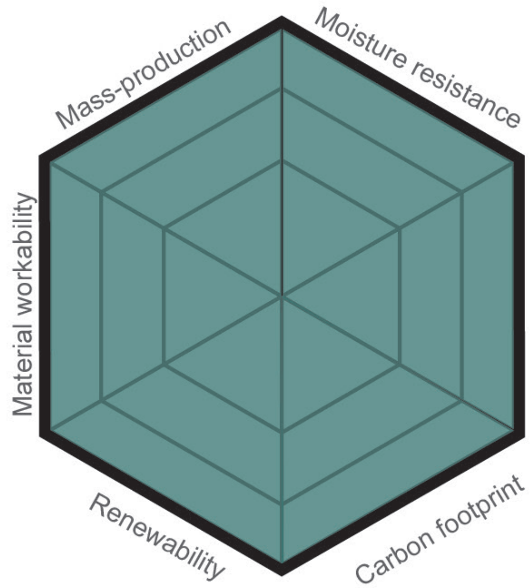


Assessment overview

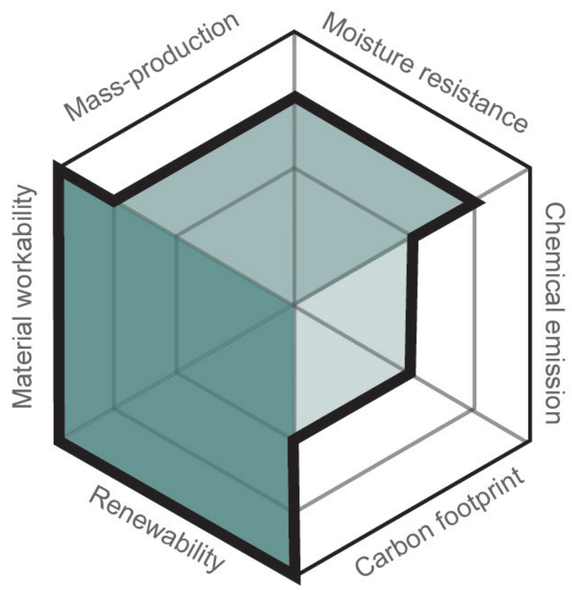
Sheet metal



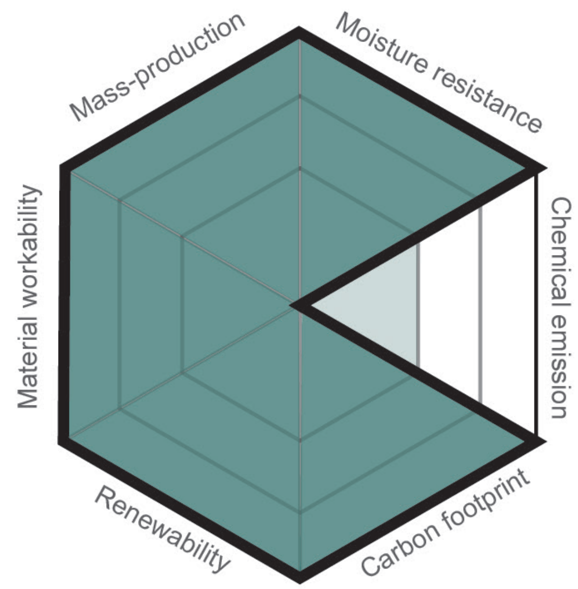
Tetra Pak



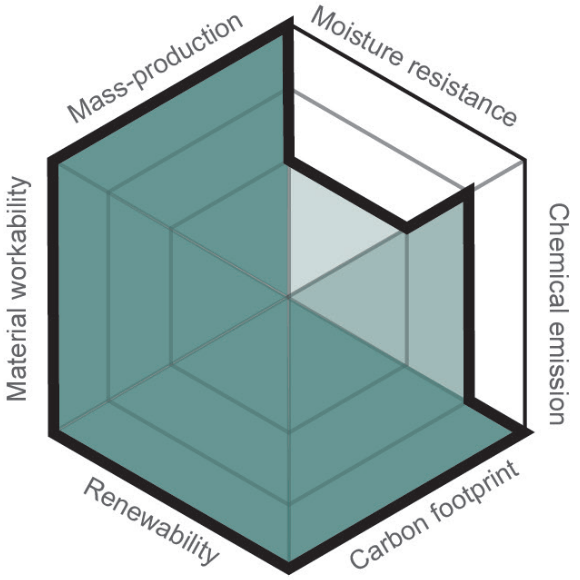
Bio-plastic



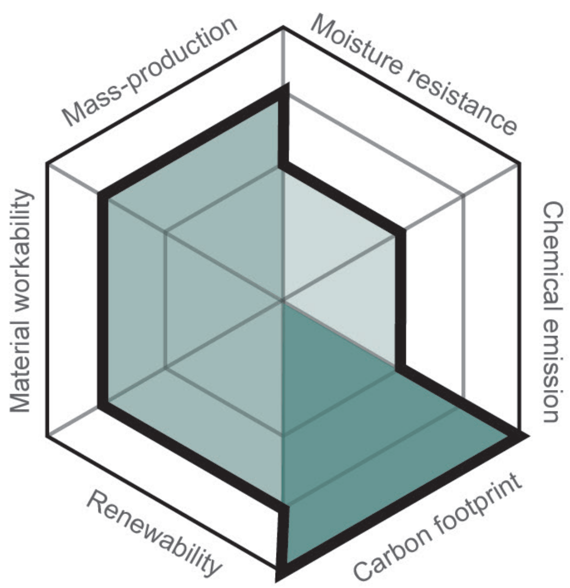
Recycled plastic



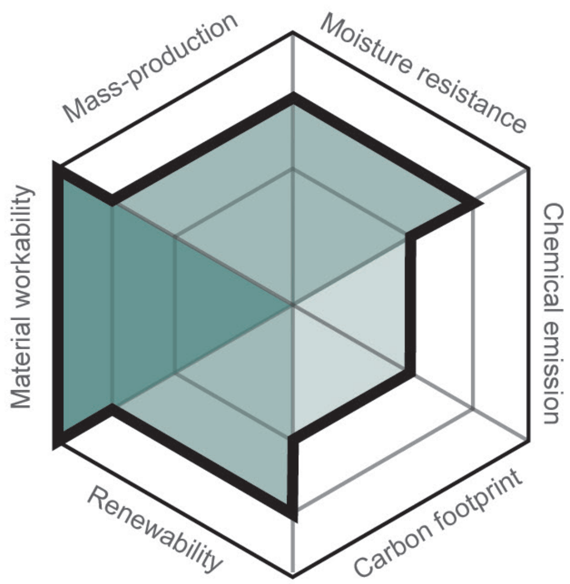
Cardboard



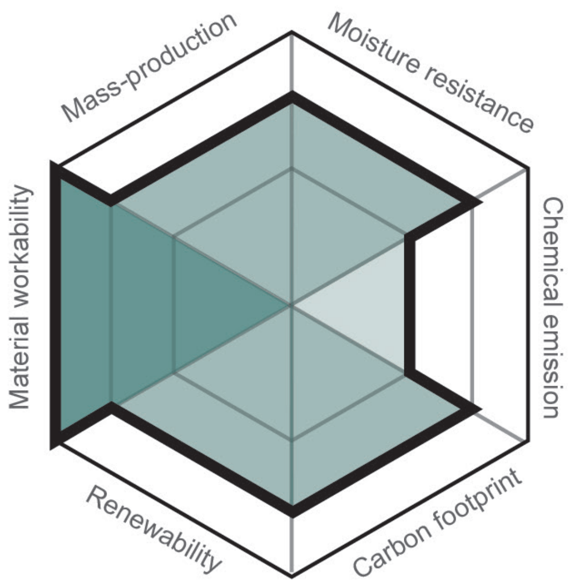
Veneer



Bio-composite (Flax)



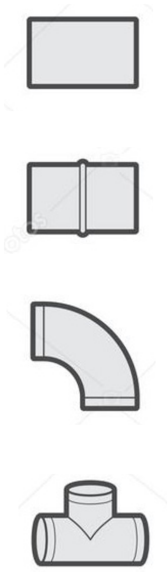
Bio-composite (Jeans)



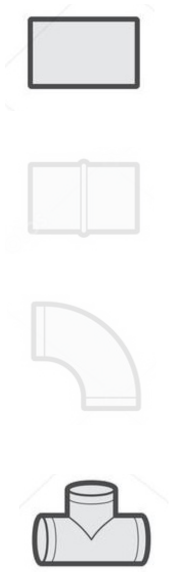
1. Moisture resistance **2. Chemical emission** **3. Carbon footprint** **4. Renewability** **5. Material workability** **6. Mass-production**

Suitable materials per component

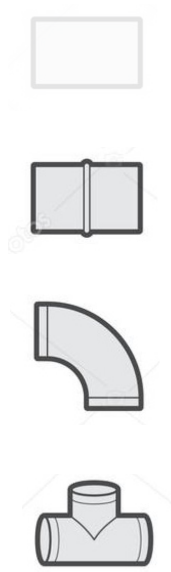
Sheet metal



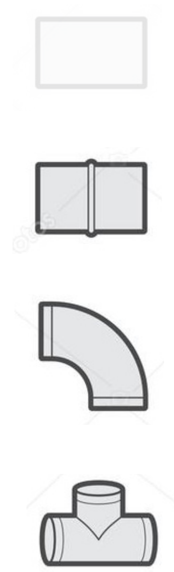
Tetra Pak



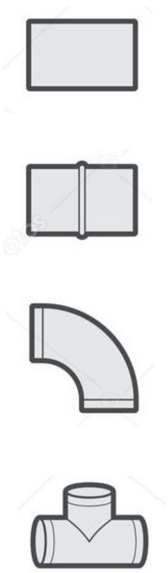
Bio-plastic



Recycled plastic*

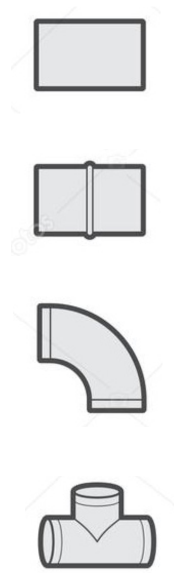


Cardboard

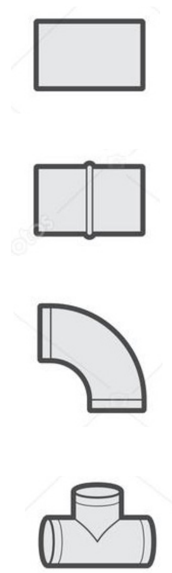


Veneer

Bio-composite (Flax)



Bio-composite (Jeans)



Concept

Design problems

Geometry

linear
joint
bend
t-component

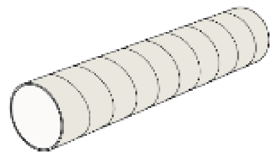
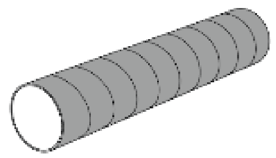
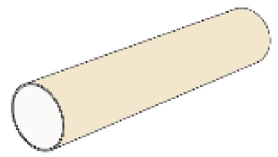
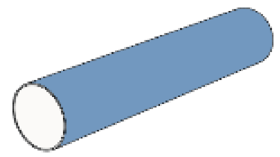
Connections

between
components

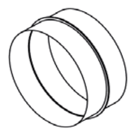
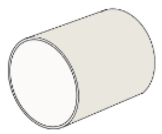
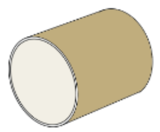
Coating

moisture

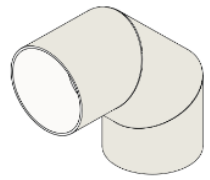
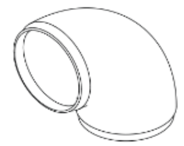
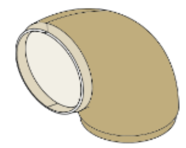
Concept selection

		Efficient, lower costs		Aeshetic, higher costs	
Linear component					
Criteria	Factor	Cardboard	Tetra Pak 75% bio-based	Veneer	Bio-composite (Jeans and bioresin)
Airtightness	●●	3	3	3	3
Moisture resistance	●●●	1	3	1	2
Chemical emission	●●	2	2	1	1
Aesthetics	●	1	2	3	2
Renewability	●●●	3	3	2	2
Carbon footprint	●●●	2	2	3	1
Ease of dis(assembly)	●●	3	3	2	2
Mass production	●●●	3	3	2	1
Material costs	●	3	2	1	1
Material workability	●●	3	3	2	3
Total		53	59	44	39

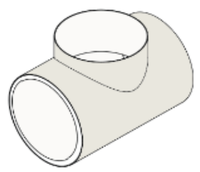
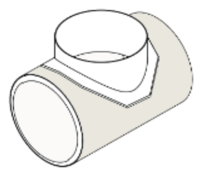
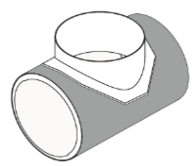
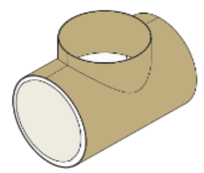
Joint

Criteria	Factor	 Recycled plastic	 Cardboard	 Bio-composite (Flax and bioresin)
Airtightness	●●	3	3	3
Moisture resistance	●●●	2	1	2
Chemical emission	●●	1	2	1
Renewability	●●●	3	3	2
Carbon footprint	●●●	3	3	1
Ease of dis(assembly)	●●	3	2	2
Mass production	●●●	3	3	2
Material costs	●	3	3	1
Material workability	●●	3	3	2
Total		56	53	38

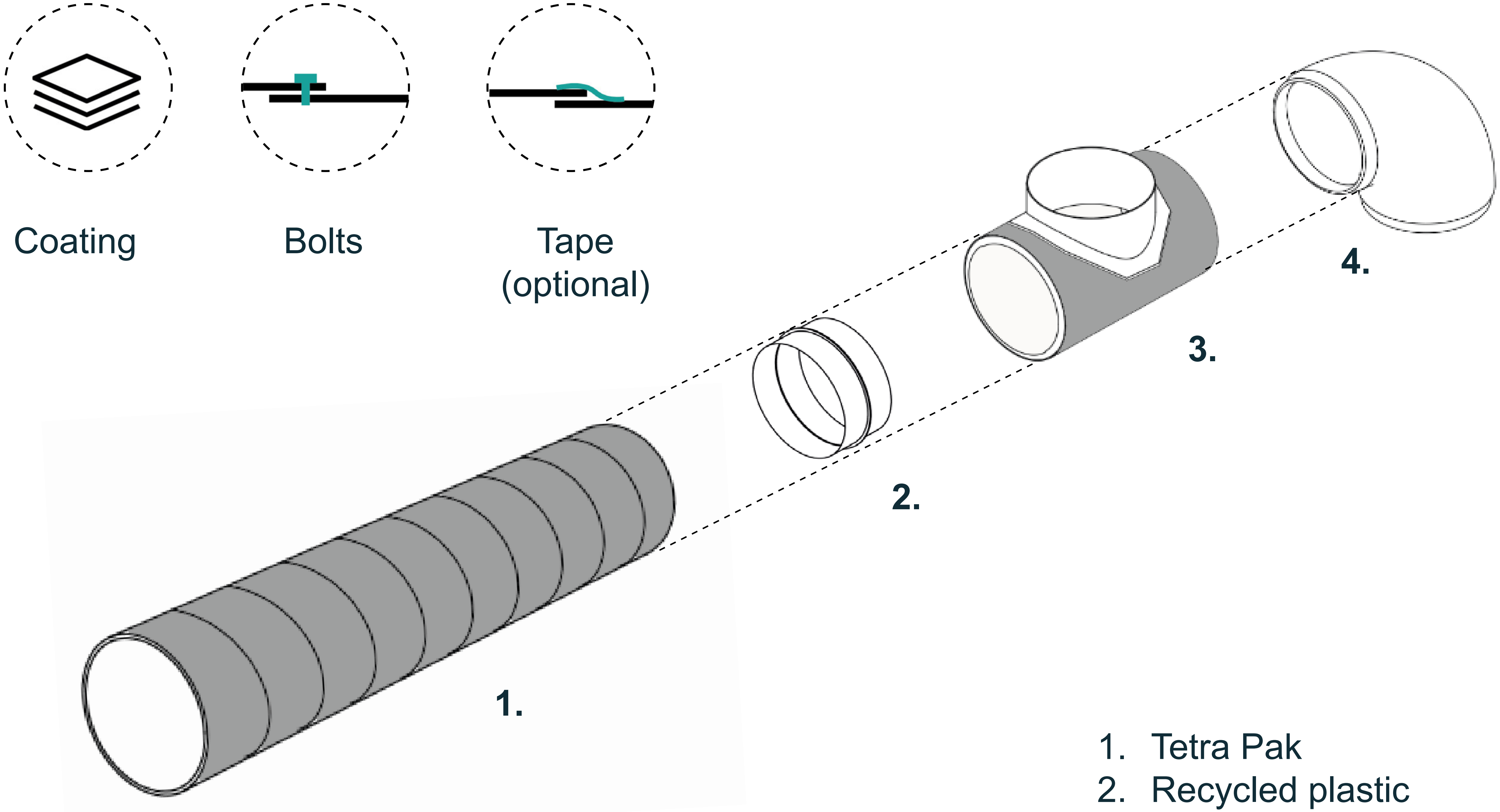
Bend

Criteria	Factor	 Cardboard	 Recycled plastic	 Bio-composite (Flax + bioresin)
Airtightness	●●	3	3	3
Moisture resistance	●●●	1	3	2
Chemical emission	●●	2	1	1
Renewability	●●●	3	3	2
Carbon footprint	●●●	3	3	1
Ease of dis(assembly)	●●	3	3	2
Mass production	●●●	3	3	2
Material costs	●	3	3	2
Material workability	●●	2	3	3
Total		53	59	41

T-component

Criteria	Factor	 Cardboard	 Cardboard + recycled plastic	 Tetra pack + recycled plastic	 Bio-composite (Flax + bioresin)
Airtightness	●●	2	3	3	3
Moisture resistance	●●●	1	2	3	2
Chemical emission	●●	2	1	2	1
Renewability	●●●	3	3	3	2
Carbon footprint	●●●	3	3	2	1
Ease of dis(assembly)	●●	3	3	3	1
Mass production	●●●	3	3	3	1
Material costs	●	3	3	3	2
Material workability	●●	2	3	3	2
Total		49	57	58	34

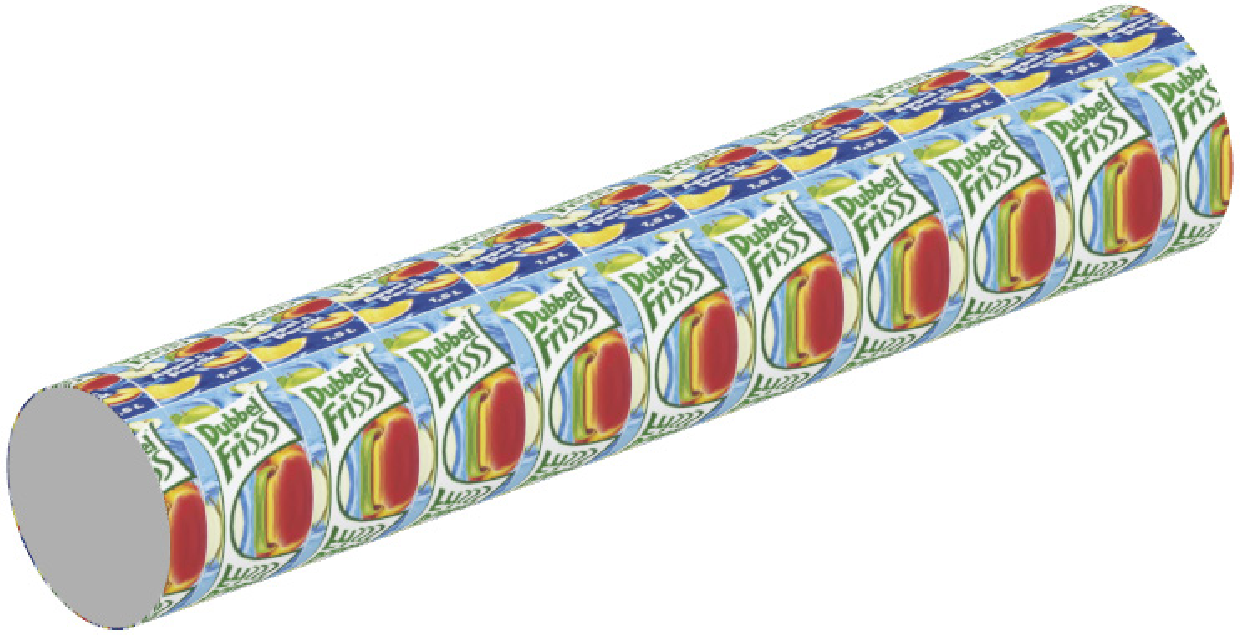
Final concept



1. Tetra Pak
2. Recycled plastic
3. Tetra Pak + recycled plastic
4. Recycled plastic

Final design

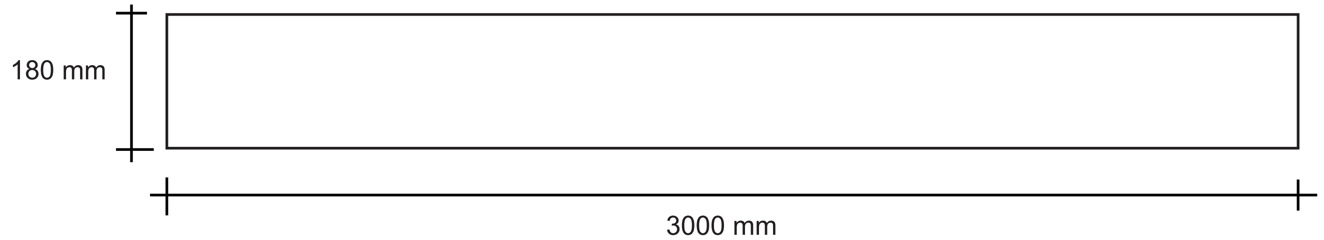
Linear component



Tetra Pak

Thickness 1,5-3 mm

Ø 180 mm



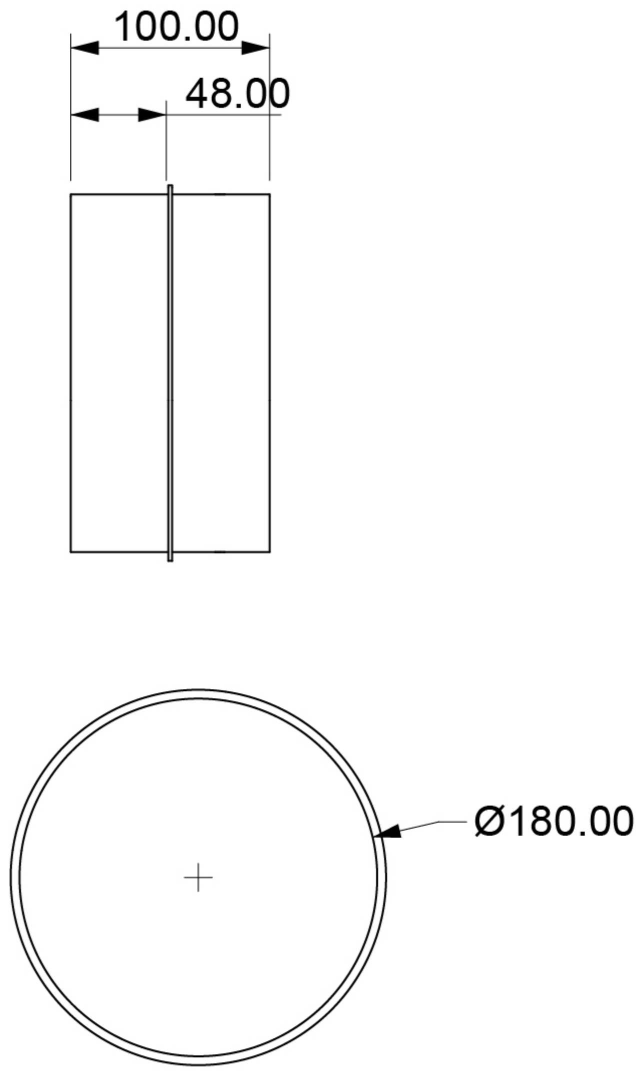
Dimensions

Joint

Recycled plastic

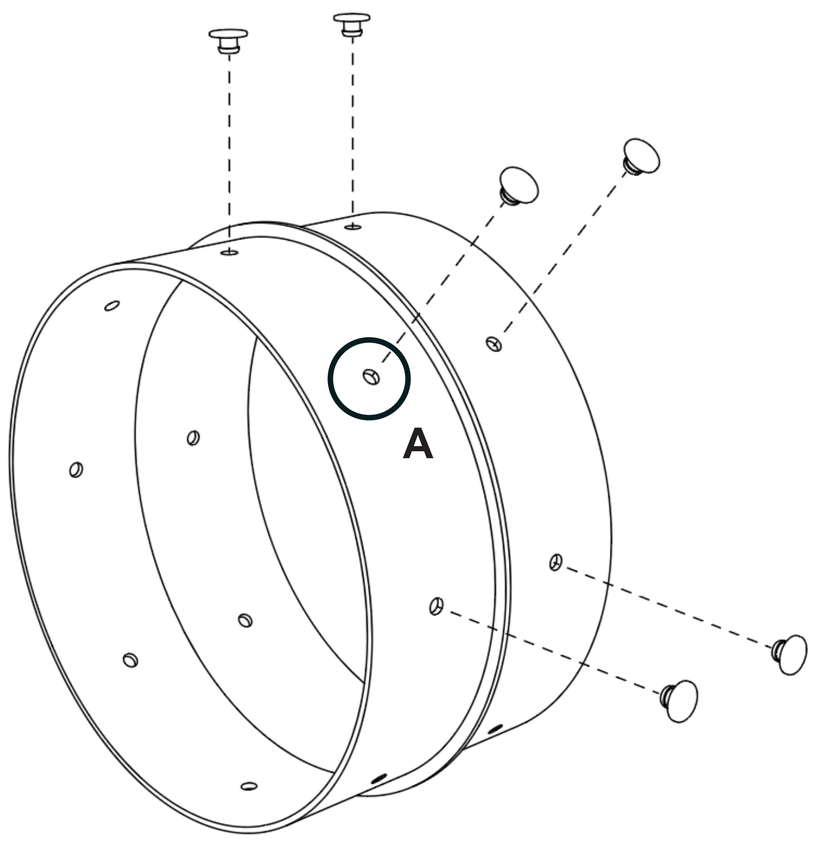
Thickness 2 mm

Ø 180 mm

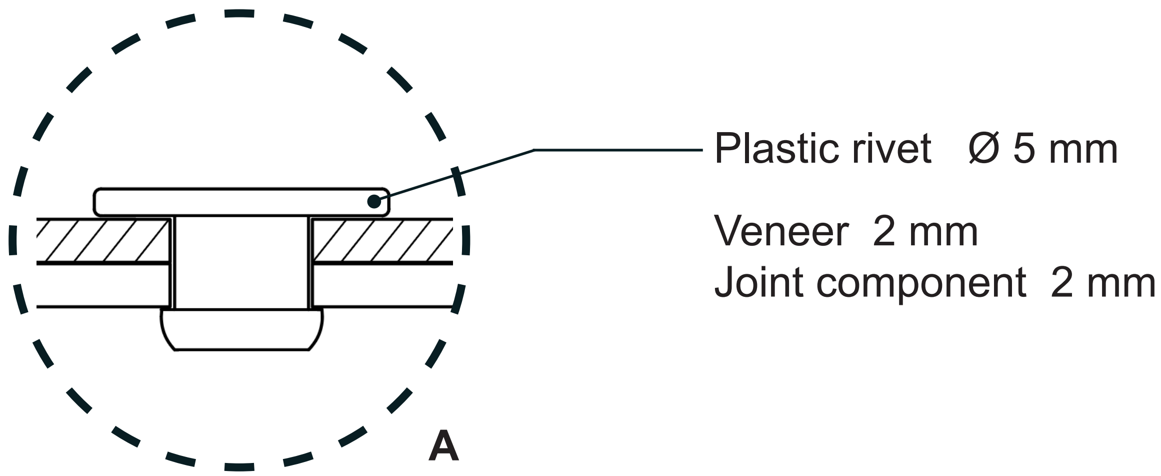


Dimensions

Joint

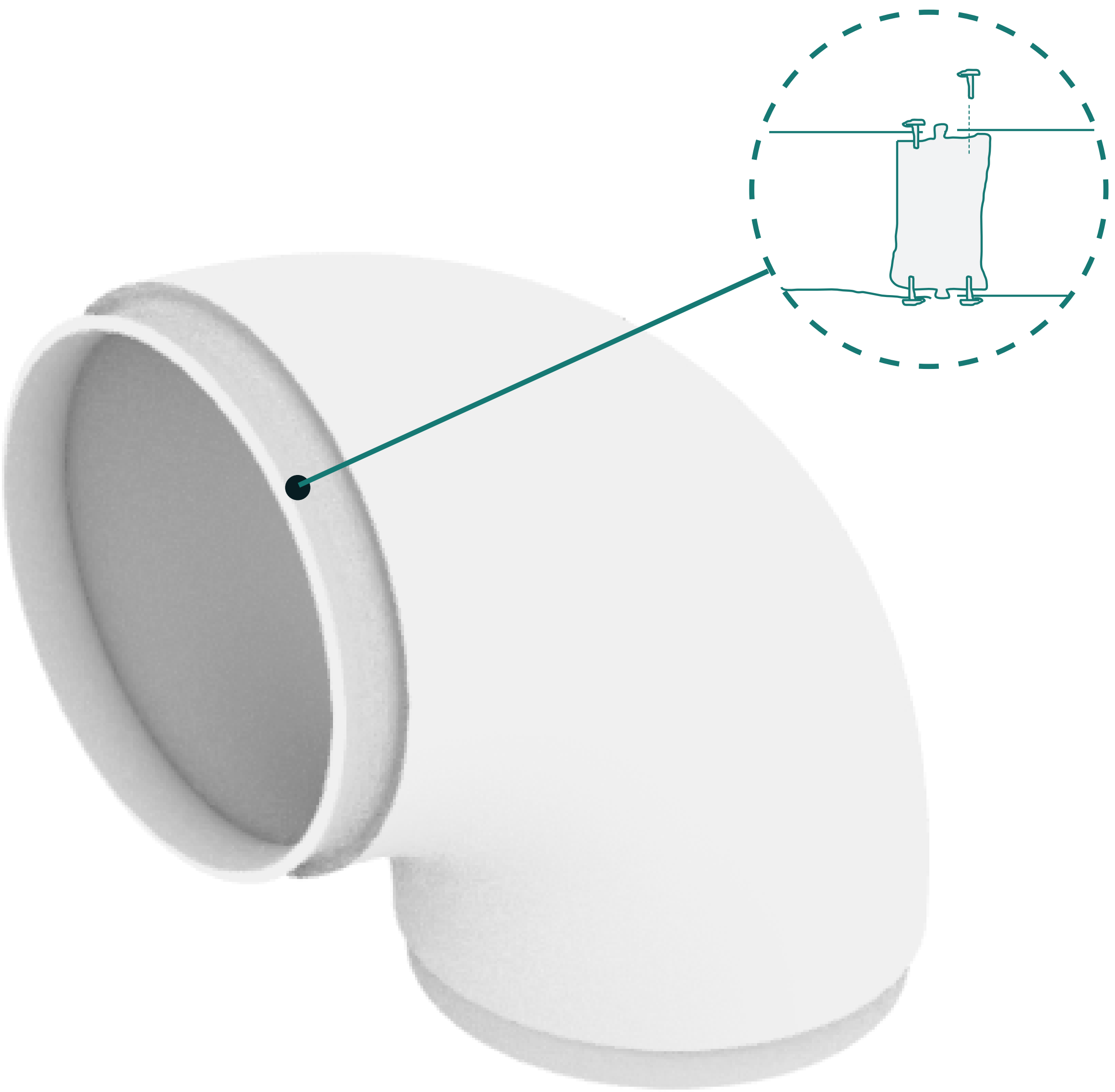


Exploded view



Connection

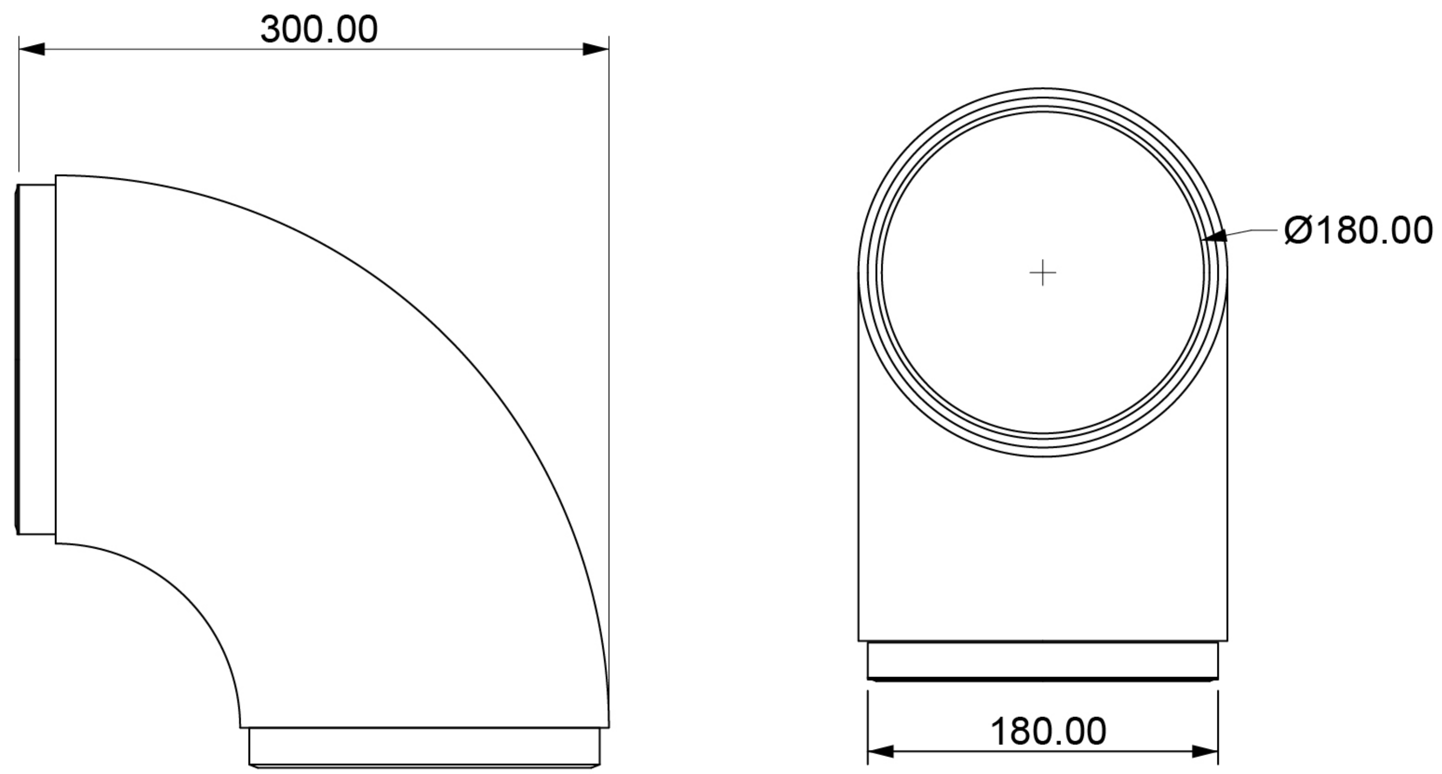
Bend



Recycled plastic

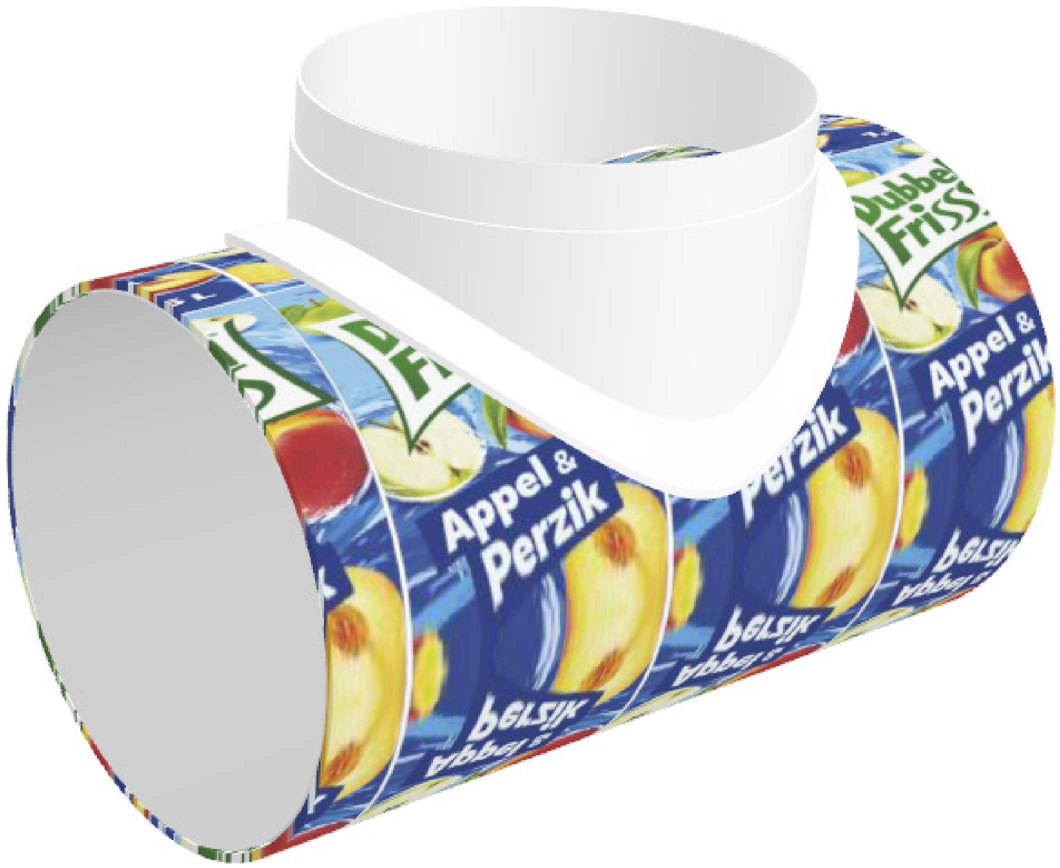
Thickness 2 mm

Ø 180 mm



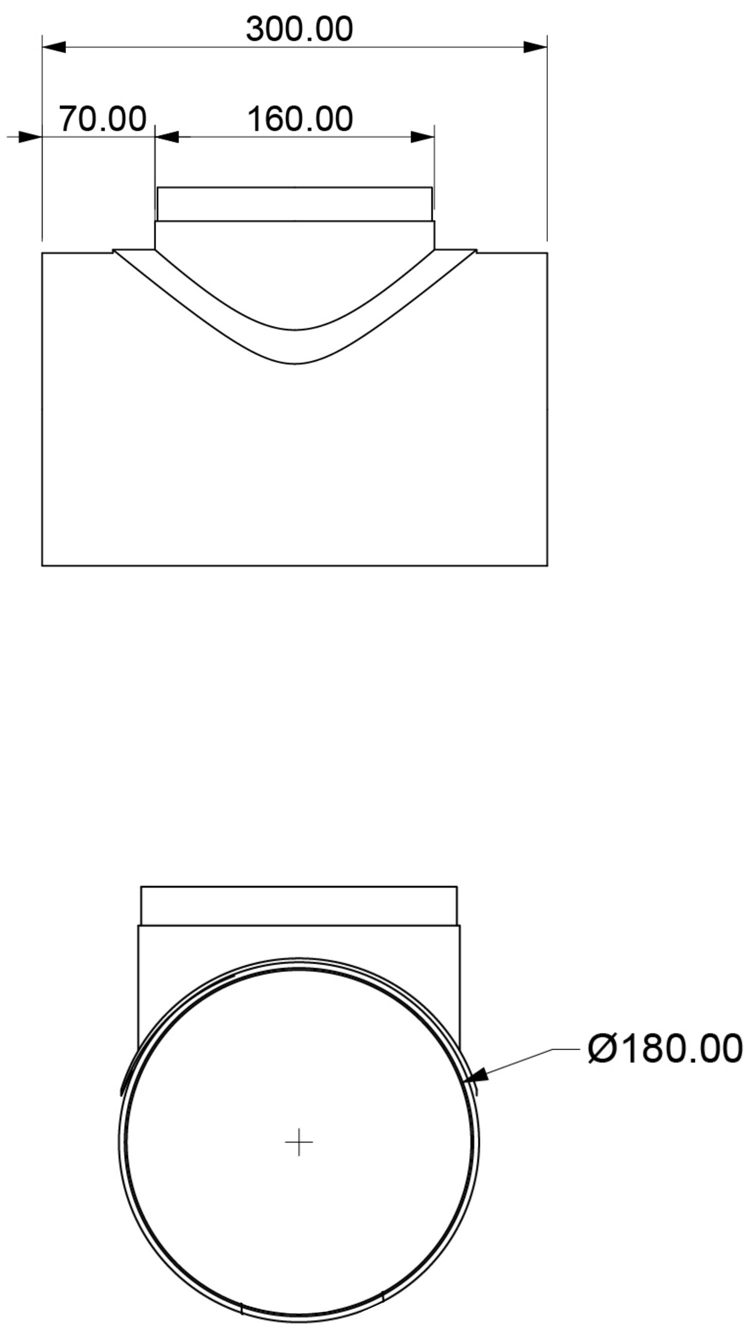
Dimensions

T-component

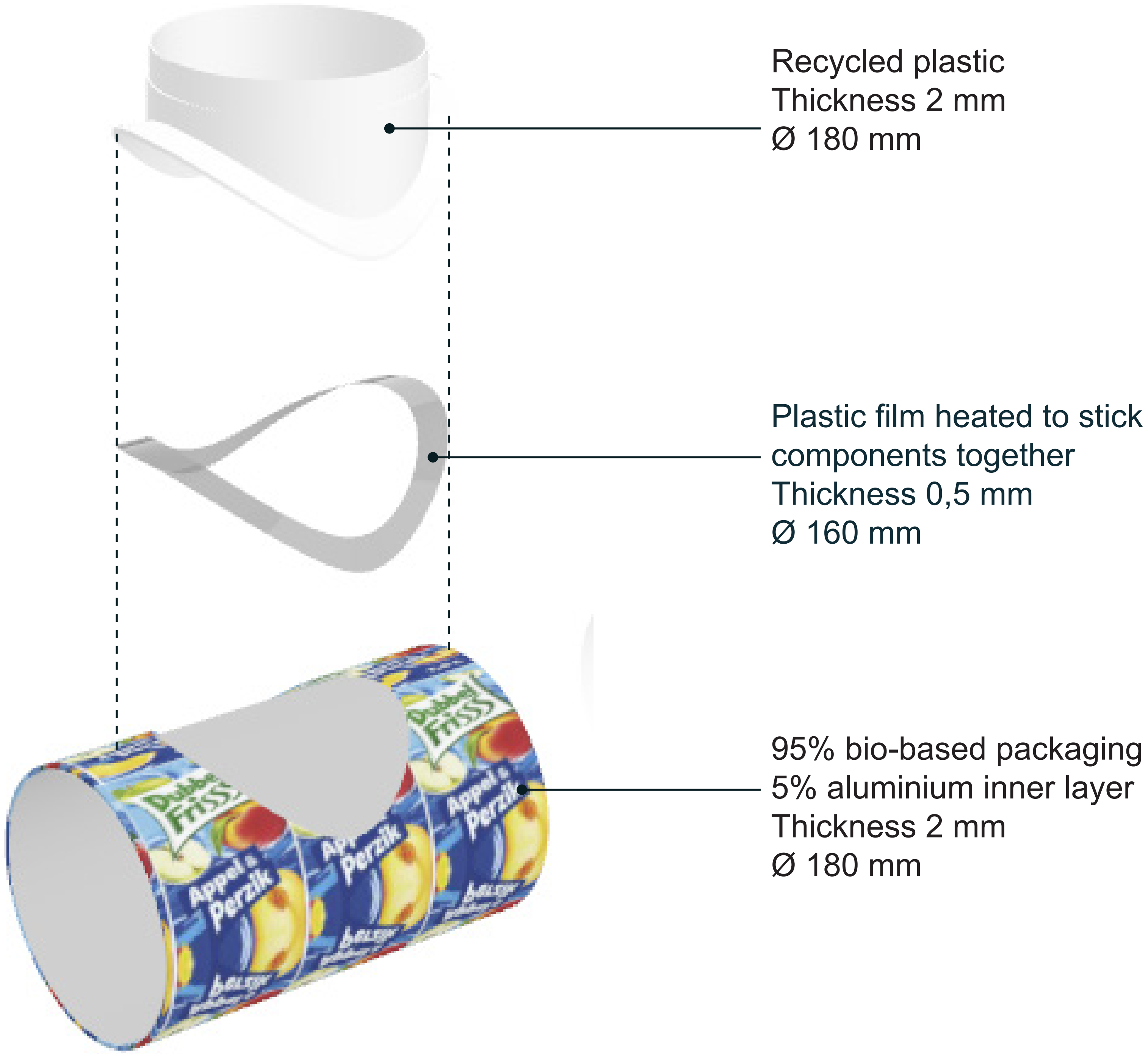


Sheets of Tetra Pak - 95% bio-based
Recycled plastic

T-component assembly



Dimensions



Exploded view

Prototyping

Geometry bend and linear component

Bend: recycled plastic

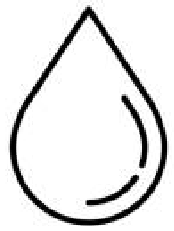
Linear: packaging material

Design variation

More development required

Evaluation

Performance evaluation



Moisture resistance

1. Water absorption test

2. Mold growth test

↓

Aim to indicate the molding potential of selected materials.

↓

Determines **lifespan** (moisture will affect the mechanical properties)

Chemical emission

1. TVOC emission test

↓

Aim to maintain good air quality with the use of materials which contain volatile compounds

↓

Determines **health** and **comfort** of the occupants

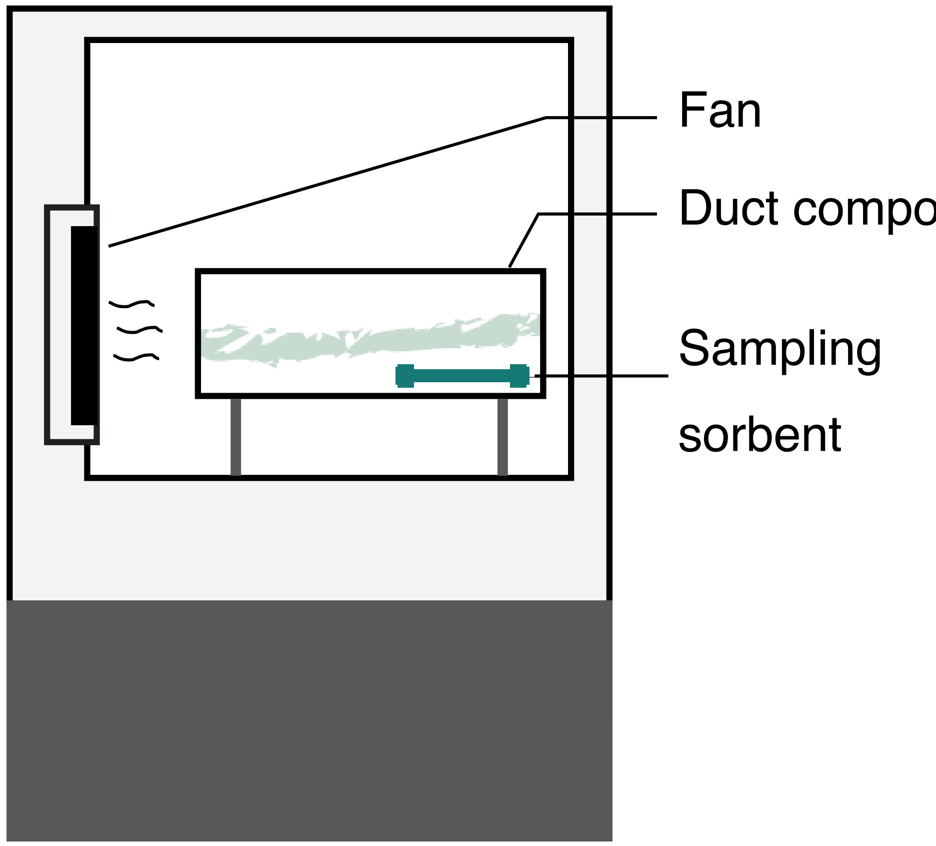
Chemical emission

(Bio)-plastics, bio-resins and coatings

The following test conducted bot with test chamber:

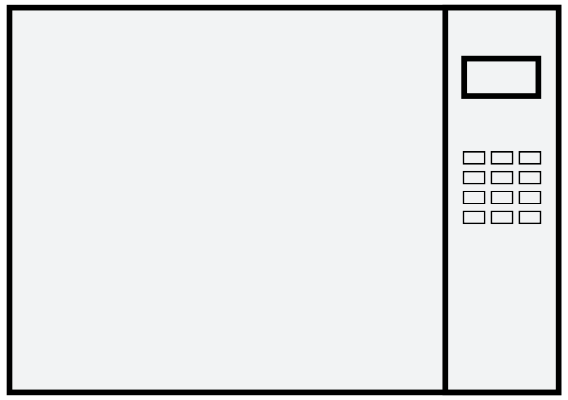
- Simplified VOCs emission test: TVOC meter
- Detailed: Gas chromatography and mass spectroscopy (GC-MS)

TVOC meter on bio-composite (simplified)

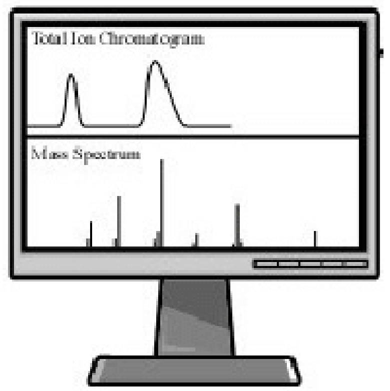


Test chamber

Tenax sorbent



GC-MS analysis (detailed)



Results

Conclusion

Conclusion

What are the potential and limitations for bio-based materials to replace sheet metal for the construction of air ducts by maintaining the same quality?

Potentials

- Possibilities for mass-production of bio-based air duct component, for linear components more advanced than complex components. Linear component: cardboard, bio-composites, packaging material.
- Lower carbon footprint.
- Applying circular strategies for most materials: recycling, reuse and energy recovery.

Limitations

- However meeting quality is challenging - moisture resistance and chemical emission.
- Constructing complex components; joint, bend and t-component efficiently with bio-based materials.
- Certain type of connections are more challenging.
- Lifespan unknown.

Further research recommendations

- Determine lifespan under increased temperature and humidity rates.
- Experimental research in terms of moisture resistance and chemical emission: recycled plastic, bioplastic and coatings; thin films and (bio)resins.
- The scalability of the used materials, larger diameters result in a thicker material, the optimal ratio between thickness and stiffness should be achieved.
- Explore other materials such as ECOR and giant bamboo.

Thank you for your attention.