Development of a Demountable Connector: Increasing the Circular Potential of Additive Manufactured Mono-Material Façade Blocks

Doris van Uffelen

First mentor: Paul de Ruiter

Second mentor: Olga Ioannou

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Presentation structure

- Introduction
  - Background
  - Problem statement
  - Objective
  - Research Questions
  - Method
- Context
  - Definitions
  - AM for CBP
  - Spong3D analysis
  - Design principles
  - Design requirements
  - Decision matrix
- Designs
  - System
  - Concept designs
  - Evaluation
  - Improved designs
  - Evaluation
  - Final design
- Conclusion
  - Conclusion
  - Recommendations
  - Questions

Introduction

Background

C&D waste

Resource depletion

C&D energy

Plastic waste

Problem statement

Shift towards a circular economy

"The circular economy is a system where

materials never become waste and nature is regenerated"

(Ellen Macarthur Foundation, n.d.)

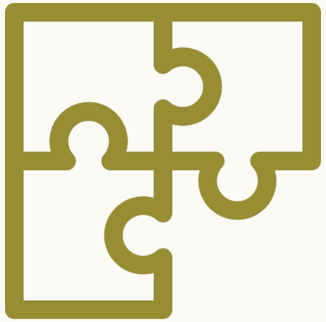
Problem statement

Different materials mixed - Hard to separate - New/critical materials are used

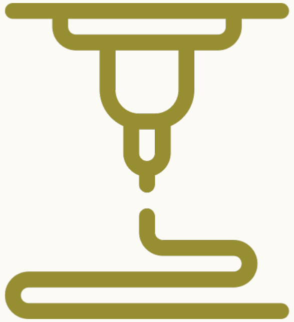
Objectives

Additive manufacturing for Circular Building Products

Demountable connectors for façade elements using PET through FDM

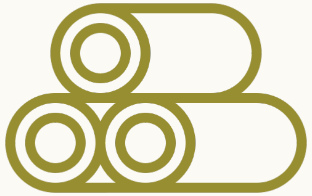


Design for Disassembly



Additive manufacturing

Waste as Source



Mono-material

Research Question

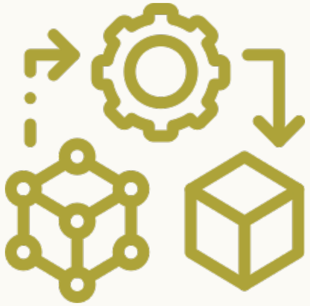
How to design a Mono-Material Demountable Connector for a Circular Façade system using PET through Additive Manufacturing?

Method

Literature study

Analysis

Decision matrix



Research through prototyping

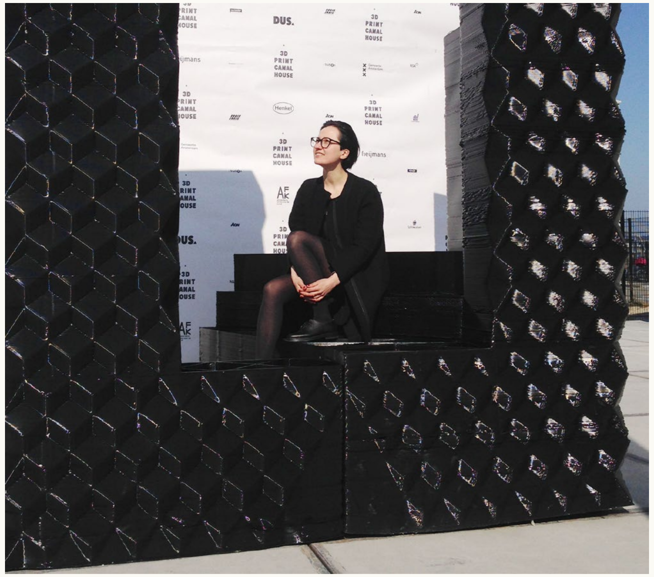
Evaluation of results

Context

Definitions

Additive Manufacturing (AM)

- Extruding objects layer by layer from digital model
- Thermoplastic façade elements



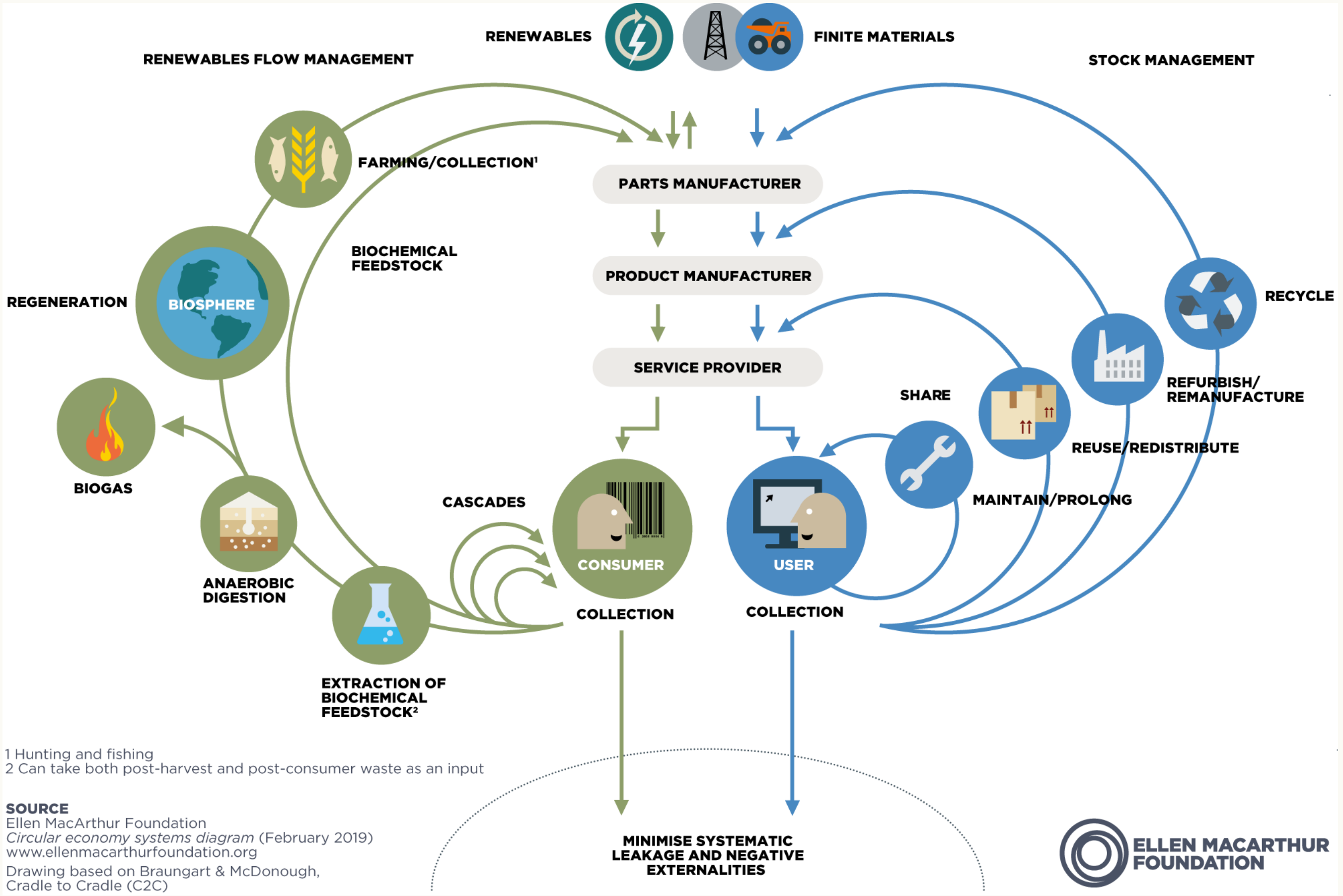
Definitions

Circular Economy (CE)

- Materials are valuable
- Keep products and materials in circulation

Circular Building Product (CBP)

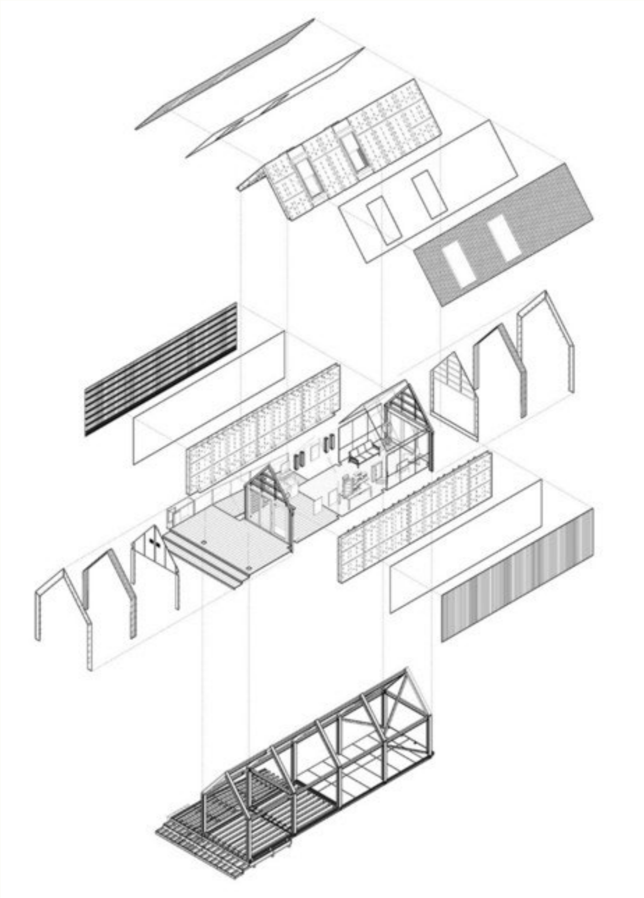
- 4 Domains
- R-strategies



Definitions

Design for Disassembly (DfD)

- Takes into account end-of-life
- Maintenance, remanufacturing, reuse, recycle



AM for CBP

Reduce	→ Material use	→ shape optimization
		→ lightweight material
		→ waste materials (rPET)
		→ Mono-material elements
	→ Transportation	→ localized printing
		→ local materials
Reuse	→ Design for Disassembly	→ Printing of complex shapes
		→ Modular design
Repair	→ Print replacement parts	
Recycle	→ Materials	→ PET
		→ Mono-material elements

Spong3D analysis

Spong3D

Mono-Material

Fused Deposition Modelling

Insulation

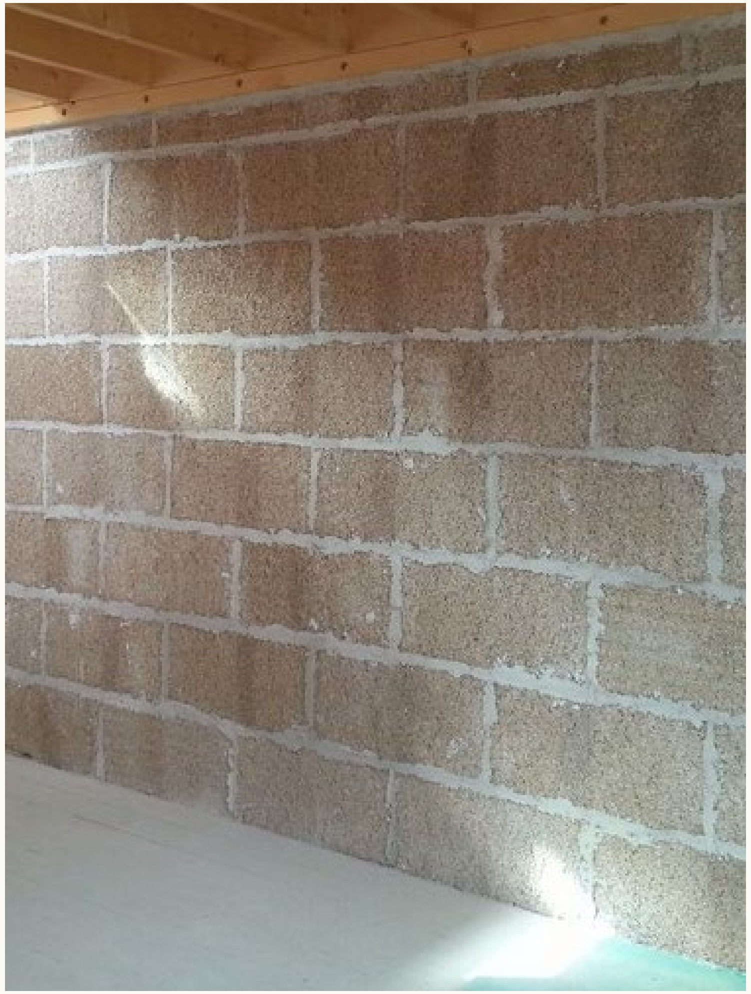
Spong3D analysis

Hempcrete

Mono-Material

Bio-based material

Insulation and strength



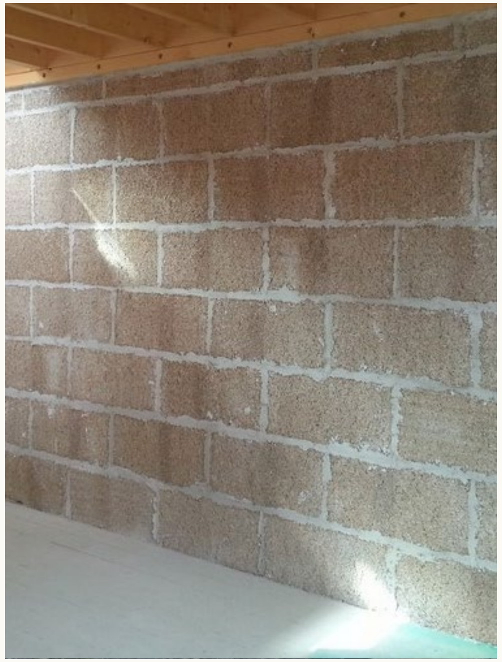
Spong3D analysis

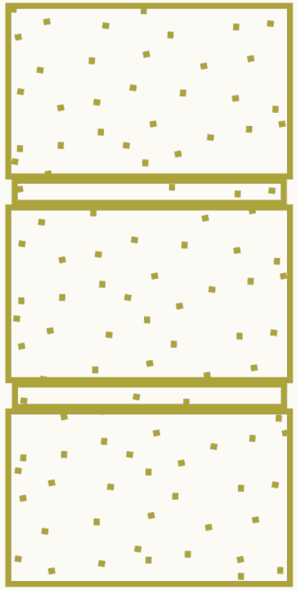
SPONG3D – PET

A=1M² – T=470MM – RC=4,7M²K/W

HEMPCRETE – HEMP – LIME –WATER

A=1M² – T=329MM – RC=4,7M²K/W





Spong3D analysis - Material

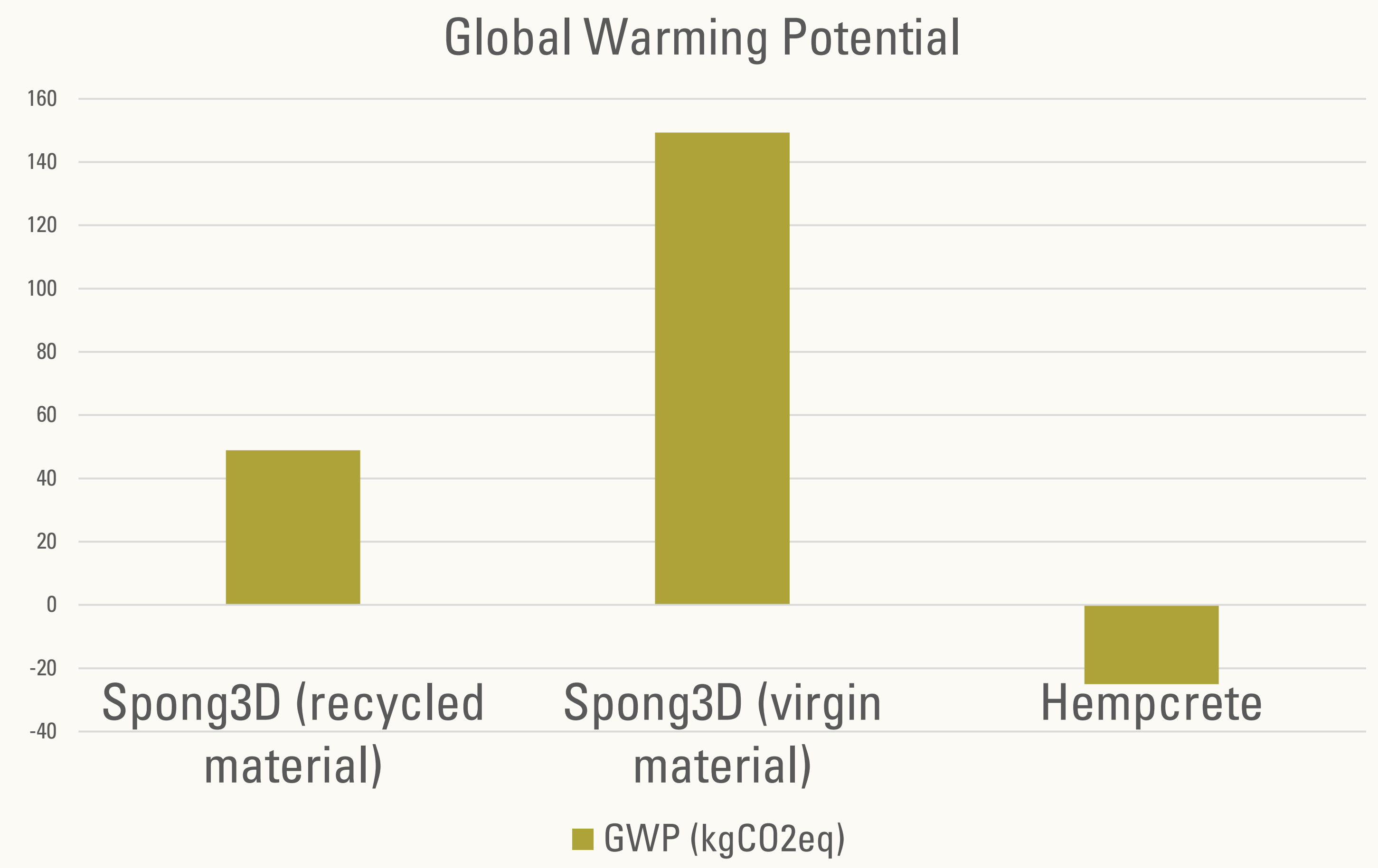
SPONG3D

+ Mono-Material
– Raw material – High GWP
– Technical materials are used
+ Low weight - cell structure (53,7 kg per m²)

HEMPCRETE

+ Mono-Material
+ Low GWP
+ Biobased material
– High weight - solid elements (98,7 kg per m²)

Spong3D analysis - Material



Spong3D analysis - Material

SPONG3D

- \+ Mono-Material
- – Raw material – High GWP
- +- Technical materials are used
- \+ Low weight - cell structure (53,7 kg per m²)

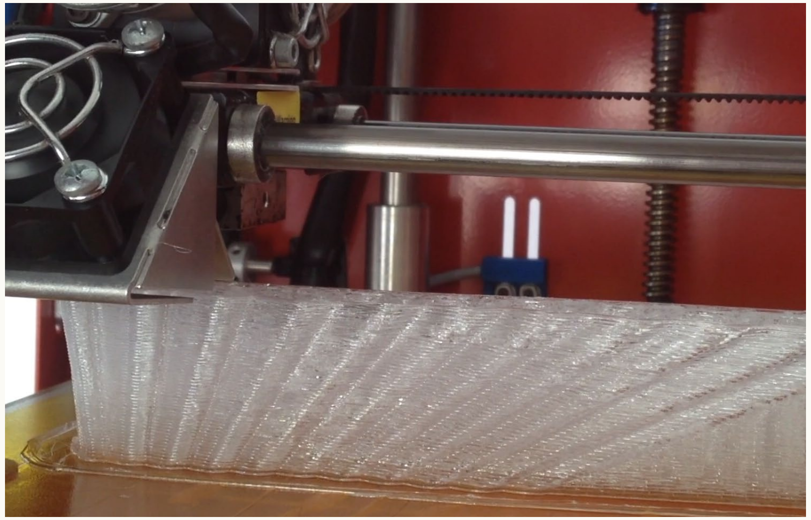
HEMPCRETE

- \+ Mono-Material
- \+ Low GWP
- +- Biobased material
- – High weight - solid elements (98,7 kg per m²)

Spong3D analysis - Manufacturing

SPONG3D

- \+ Automated process
- – Long printing time (216hr for 750X500X360 mm)
- – Low production energy (146,2 MJ per m²)

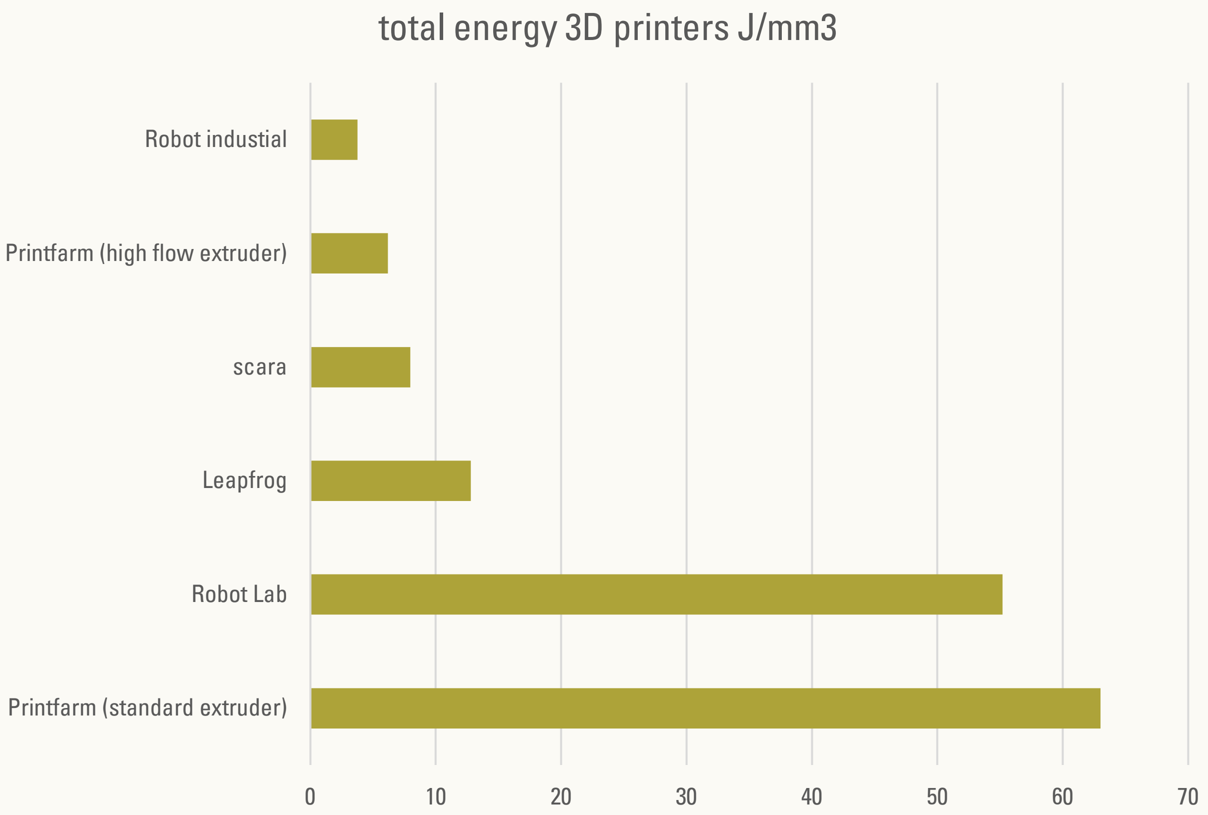


HEMPCRETE

- – High in manual labour
- – High production energy (1020,6 MJ per m²)

Spong3D analysis - Manufacturing

- Industrial robot is the most energy efficient
- With printfarm adapt design



Spong3D analysis - Design

SPONG3D

+ Mono material - multiple functions
+ No internal connections/interfaces

+- Translucent aesthetic

HEMPCRETE

+ Mono-Material – multiple functions
+ No internal connections/interfaces

+- Rustic aesthetic

Spong3D analysis - Management

SPONG3D

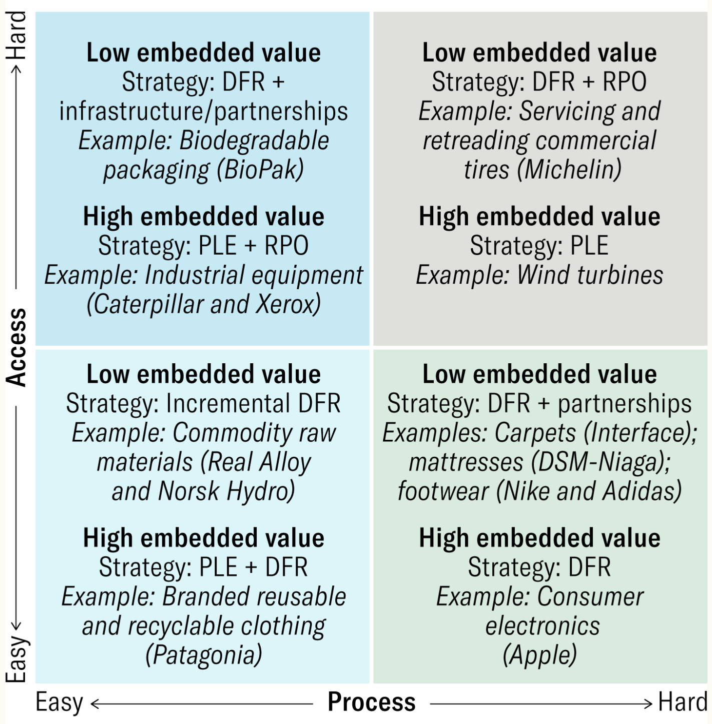
Improvement: Leasing system or extent lifespan

- High material value
- Easy to process - reuse

HEMPCRETE

Improvement: Extent lifespan or design for recycling

- Low material value
- Hard to process

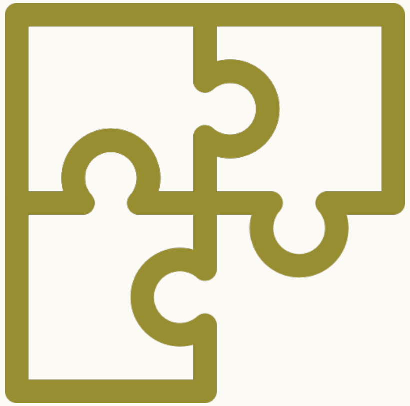


Spong3D analysis - Conclusion

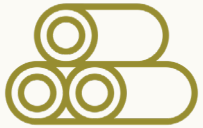
If improvements are implemented, Spong3D has circular potential

- Material optimization
- Locally recycled waste
- Improve printing time and energy use
- Add demountable connector
- Use a leasing system

Principles



Design for Disassembly



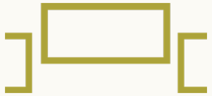
Mono-material

FDM

Based on Spong3D

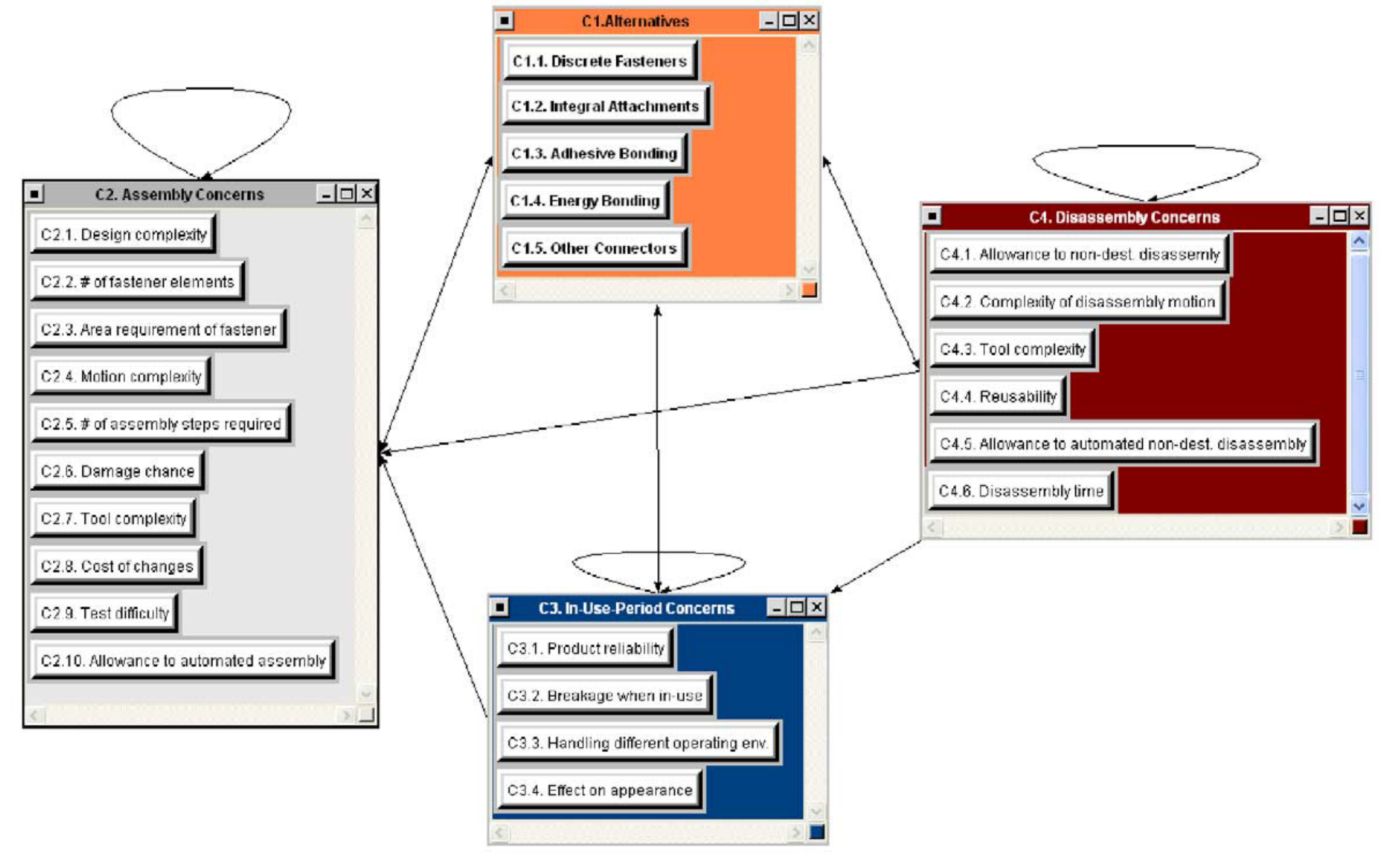
Horizontal connector

Watertight



Take one out

DfD decision model Güngör (2005)



Requirements

Categories:	Requirements:	Category importance:
• Manufacturing	Materials, energy, extruder movement	1
• Assembly	Horizontal installing, damage chance, ease of assembly	1
• In-Use	Reliability, watertightness, appearance	2
• Disassembly	Damage chance, ease of disassembly, reusability	2

Decision matrix

Category and Requirements	Preferred state	Category weight	Importance	Relative importance	Clips		Hinge		Snap Fit	
					raw	weighed	raw	weighed	raw	weighed
Manufacturing		1								
amount of material needed	Low		2	0,11	3	0,32	2	0,21	1	0,11
number of different materials	Low		4	0,21	3	0,63	3	0,63	3	0,63
Extruder movement	Organic		3	0,16	3	0,47	1	0,16	-1	-0,16
Material supports needed	Low		3	0,16	3	0,47	3	0,47	3	0,47
Energy needed for printer	Low		5	0,26	3	0,79	2	0,53	1	0,26
Printing time	Low		2	0,11	3	0,32	2	0,21	-1	-0,11
			19	*1,00*		3,00		2,21		1,21
Assembly concerns		1								
Number of fastener elements	Low		2	0,13	3	0,38	3	0,38	3	0,38
Area requirement of fastener	High		2	0,13	-1	-0,13	2	0,25	3	0,38
Motion complexity	Low		2	0,13	1	0,13	3	0,38	3	0,38
Number of assembly steps required	Low		2	0,13	3	0,38	3	0,38	3	0,38
Damage chance (include anisotropic behaviou	Low		3	0,19	2	0,38	2	0,38	1	0,19
horizontal installing			5	0,31	3	0,94	3	0,94	3	0,94
			16	*1,00*		2,06		2,69		2,63
In-use-period concerns		2								
Product reliability	High		5	0,25	-1	-0,25	1	0,25	3	0,75
Breakage when in-use	Low		4	0,20	3	0,60	2	0,40	3	0,60
Effect on appearance	Minimal		3	0,15	1	0,15	3	0,45	3	0,45
water tight	High		4	0,20	3	0,60	3	0,60	3	0,60
Ability to disassemble from the outside	Low		4	0,20	3	0,60	3	0,60	3	0,60
			20	*1,00*		3,40		4,60		6,00
Disassembly concerns		2								
Allowance to non-destructive disassembly	High		5	0,26	2	0,53	-1	-0,26	1	0,26
Allowance to take one panel out	High		4	0,21	-3	-0,63	2	0,42	-1	-0,21
Complexity of disassembly motion	Low		2	0,11	3	0,32	3	0,32	3	0,32
Reusability	High		4	0,21	2	0,42	2	0,42	2	0,42
Disassembly time	Low		2	0,11	3	0,32	3	0,32	3	0,32
number of disassembly steps required	Low		2	0,11	3	0,32	3	0,32	3	0,32
			19	*1,00*		2,53		3,05		2,84
Total					**48**	**10,99**	**53**	**12,55**	**48**	**12,68**

Decision matrix

Category and Requirements	Preferred state	Category weight	Importance	Relative importance	Clips raw	Clips weighed
Manufacturing		**1**				
amount of material needed	Low		2	0,11	3	0,32
number of different materials	Low		4	0,21	3	0,63
Extruder movement	Organic		3	0,16	3	0,47
Material supports needed	Low		3	0,16	3	0,47
Energy needed for printer	Low		5	0,26	3	0,79
Printing time	Low		2	0,11	3	0,32
			19	*1,00*		3,00

Decision matrix

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Energy needed for printer	Low		5	0,26	3	0,79
Printing time	Low		2	0,11	3	0,32
			19	*1,00*		3,00

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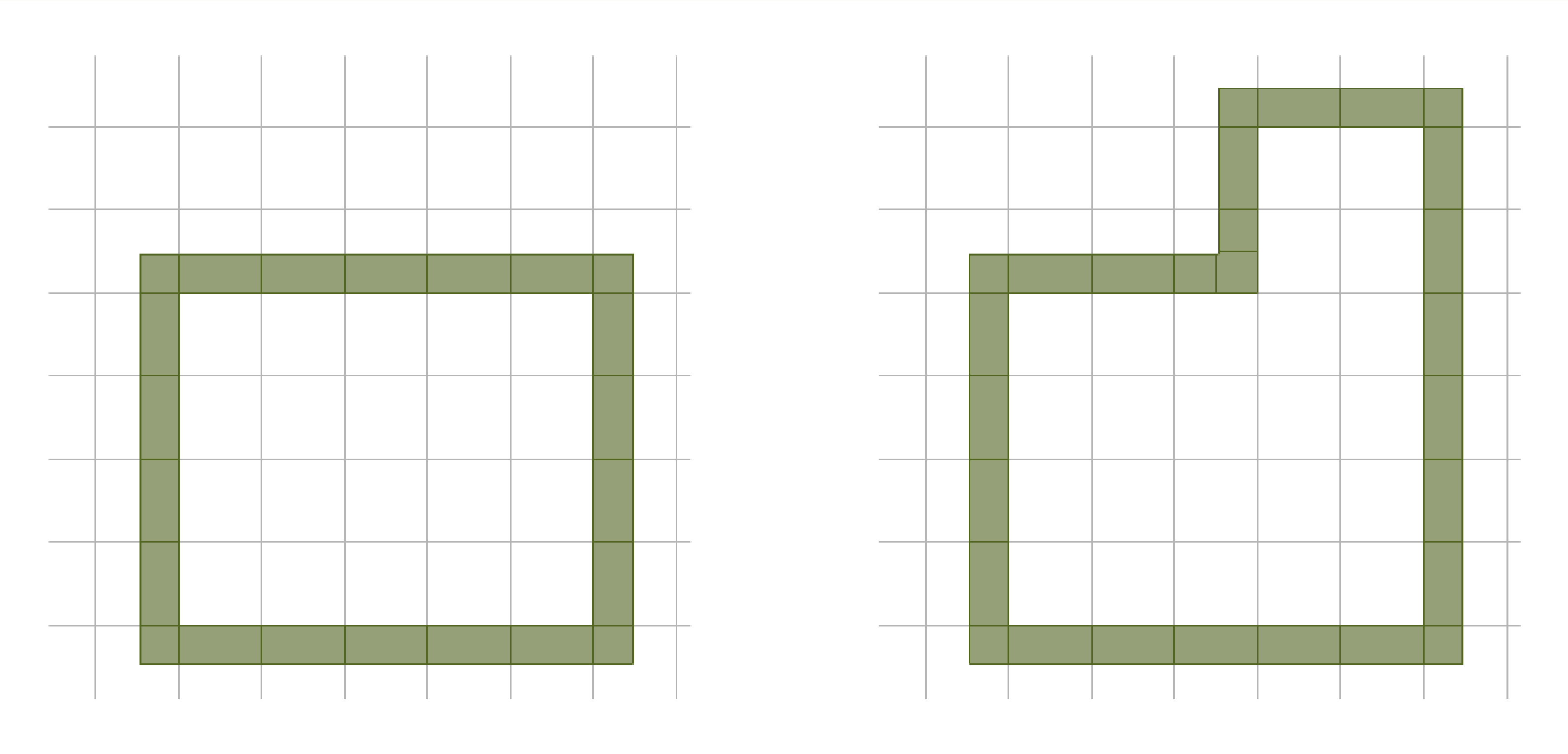
Energy needed for printer	Low		5	0,26	3	0,79
Printing time	Low		2	0,11	3	0,32
			19	*1,00*		3,00

Decision matrix

Category and Requirements	Preferred state	Category weight	Importance	Relative importance	Clips raw	Clips weighed
Manufacturing		**1**				
			19	*1,00*		3,00
Assembly concerns		**1**				
			16	*1,00*		2,06
In-use-period concerns		**2**				
			20	*1,00*		3,40
Disassembly concerns		**2**				
			19	*1,00*		2,53
Total						**10,99**

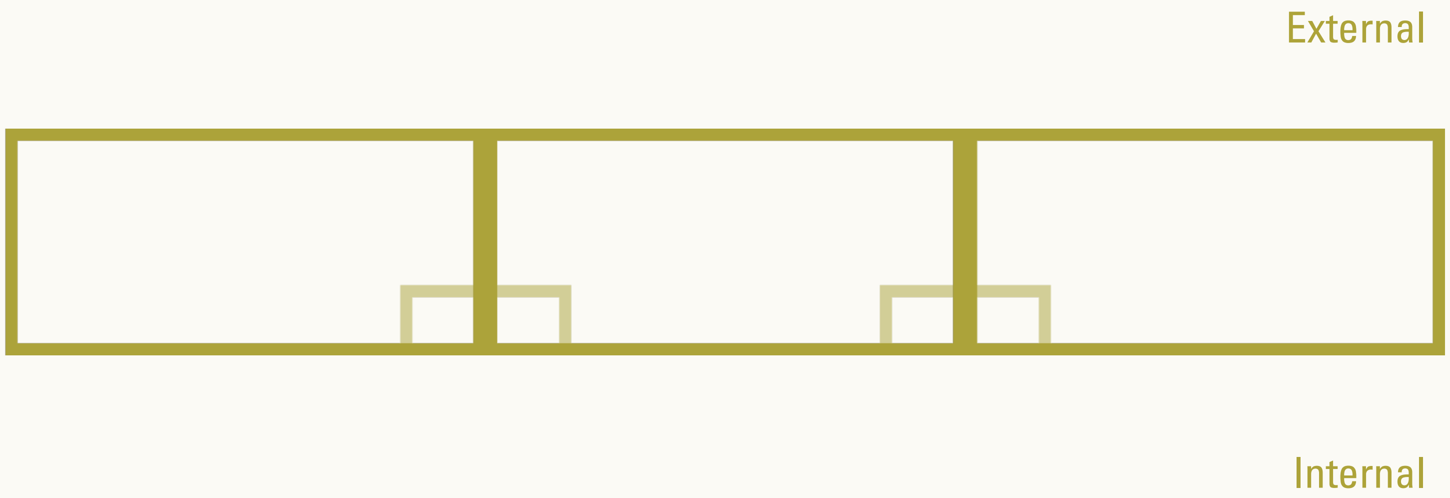
Design

System

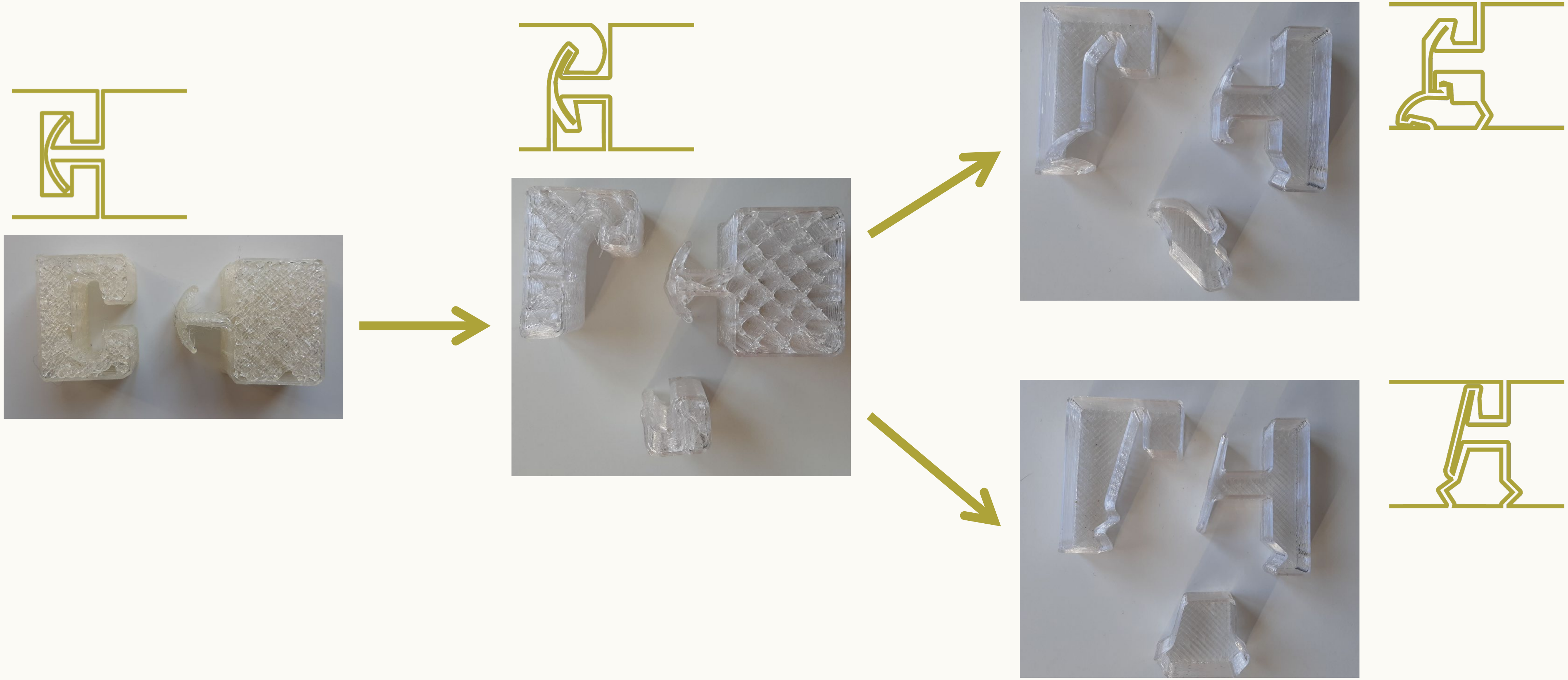


System

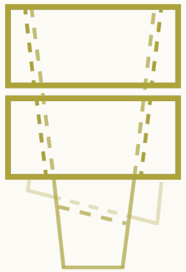
System

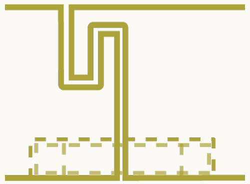


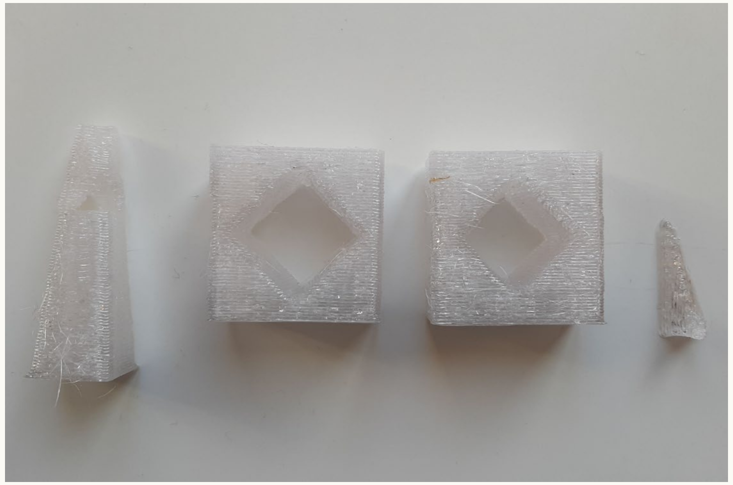
Concept designs



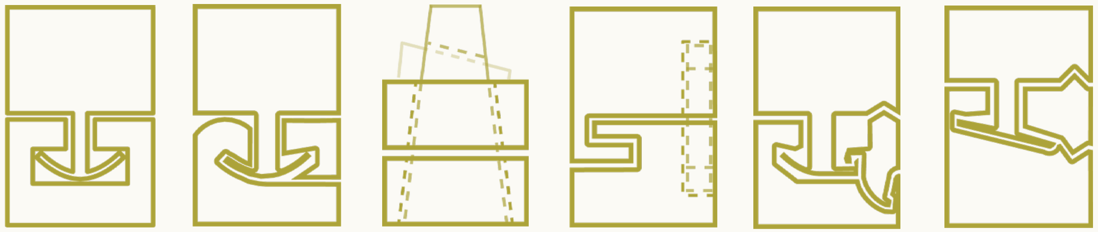
Concept designs





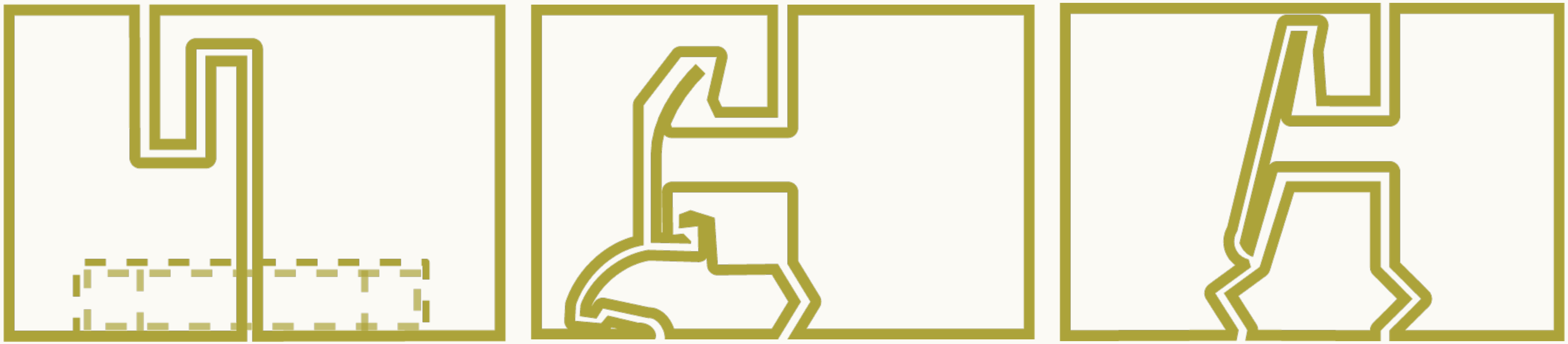


Concept designs - Evaluation

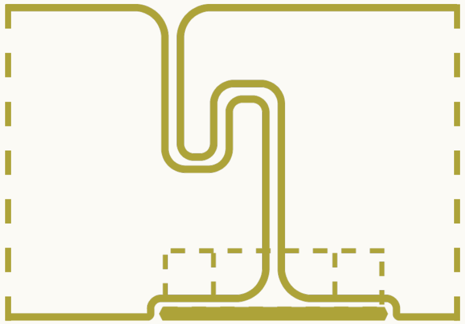


category and requirements	Preferred state	Category weight	Importance	Relative importance	T-spring		T-spring + locking element		mortise and tenon		clips connection		hinging		snap fit 3 elements	
					raw	weighted	raw	weighted	raw	weighted	Raw	weighted	Raw	weighted	Raw	weighted
Manufacturing		**0,5**														
			10	*1,00*		1,20		1,20		0,75		0,75		0,90		0,75
Assembly		**1**														
			16	*1,00*		0,50		1,44		-0,50		1,00		2,00		2,00
In-use		**2**														
			20	*1,00*		3,20		-0,20		-2,80		3,90		3,60		1,40
Disassembly		**2**														
			15	*1,00*		-0,13		4,00		1,20		2,13		5,47		4,53
Total						**4,77**		**6,44**		**-1,35**		**7,78**		**11,97**		**8,68**

Concept designs



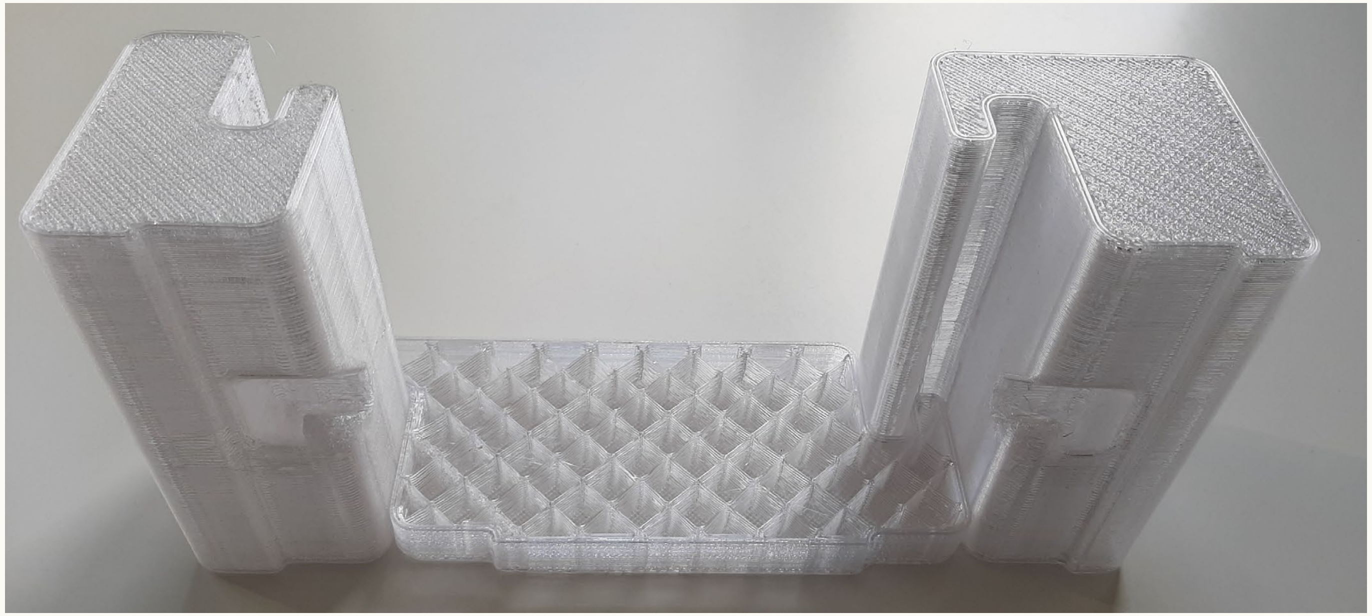
Improved designs

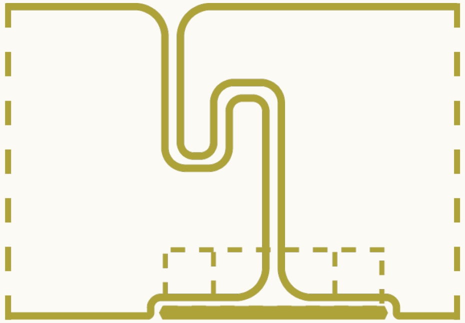


Clips

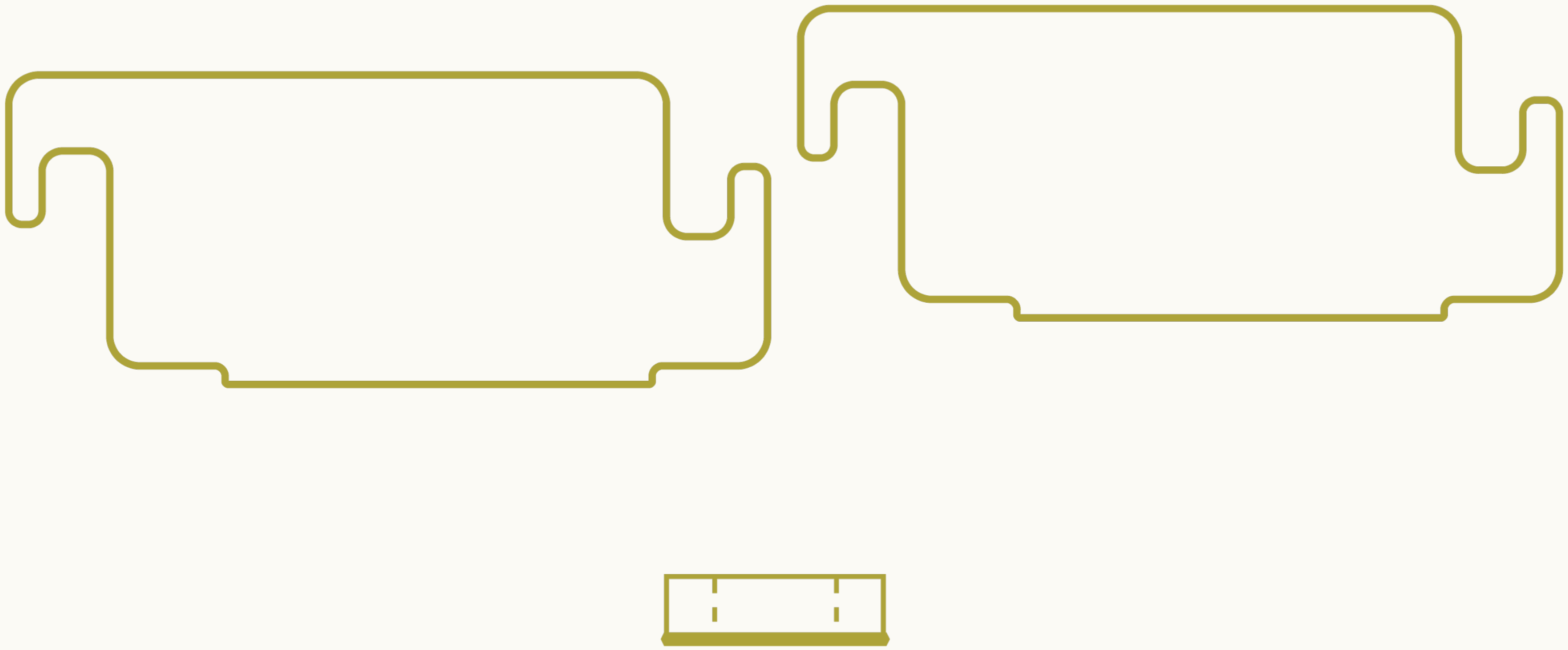
- \+ Fastener elements reduced
- \+ Low energy needed for print
- – Cannot take out one panel
- – Negative effect on appearance
- – Loose tolerances

Improved designs

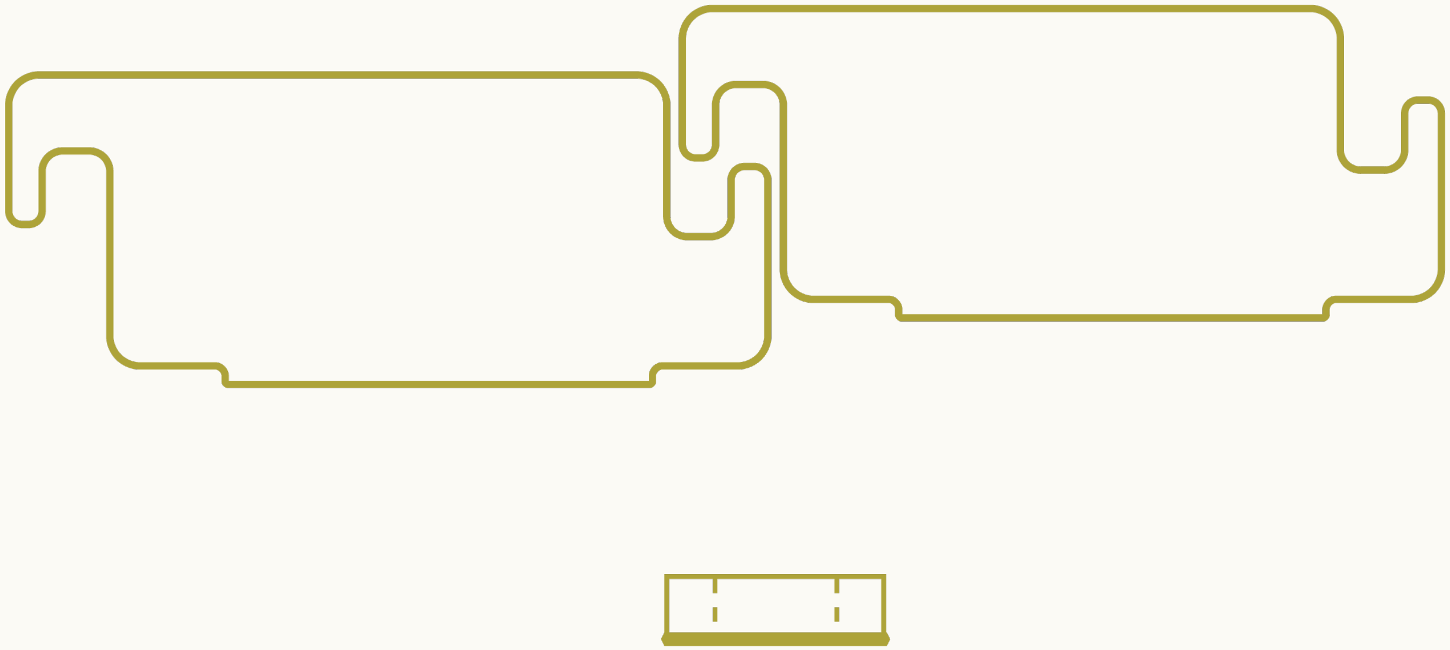




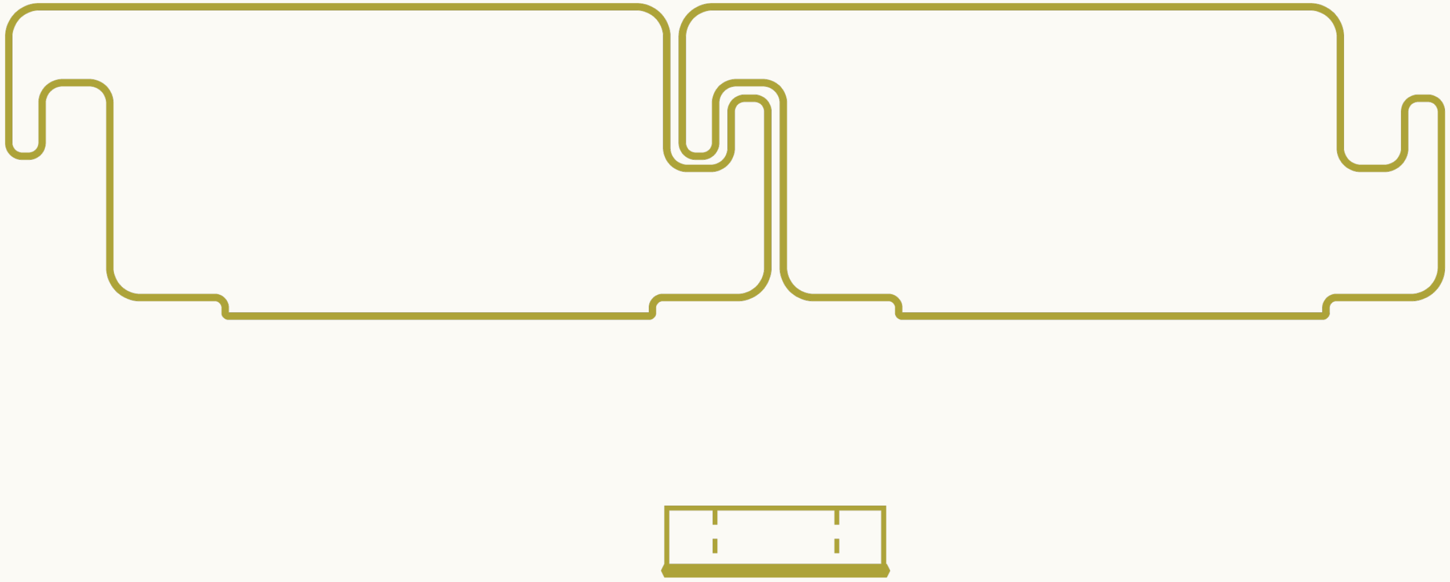
Improved designs



Improved designs



Improved designs



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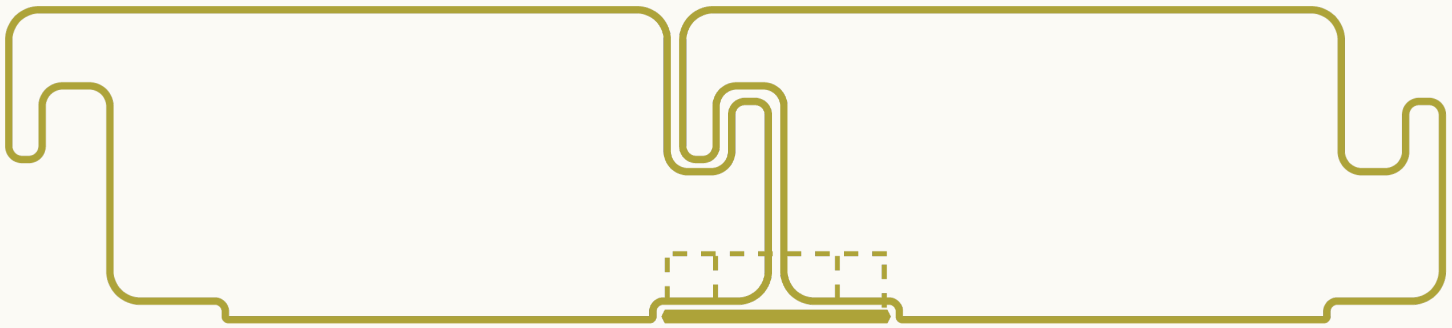
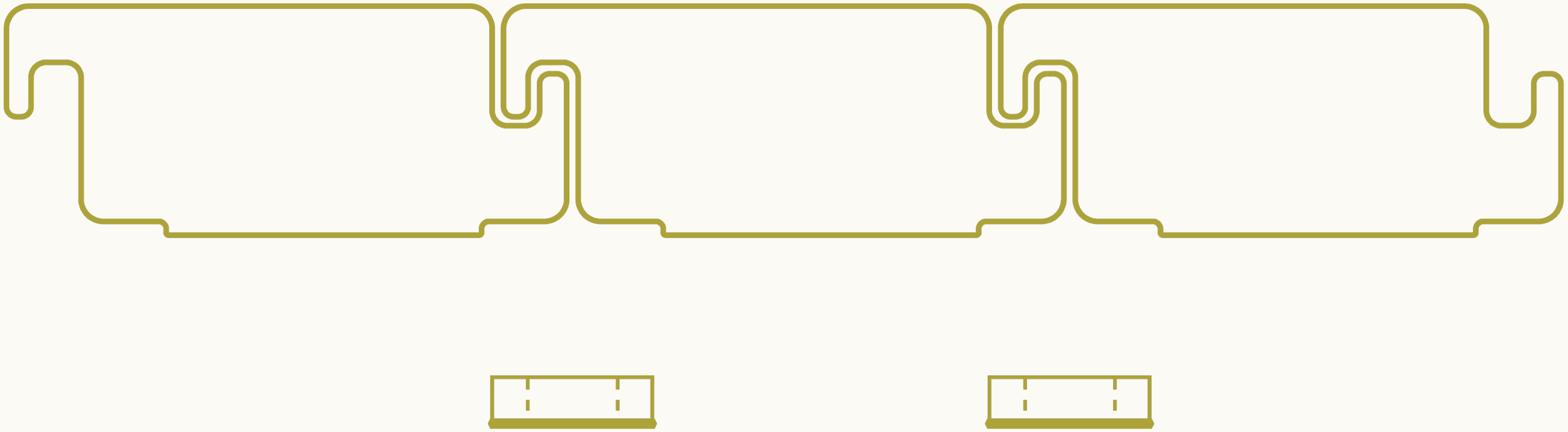
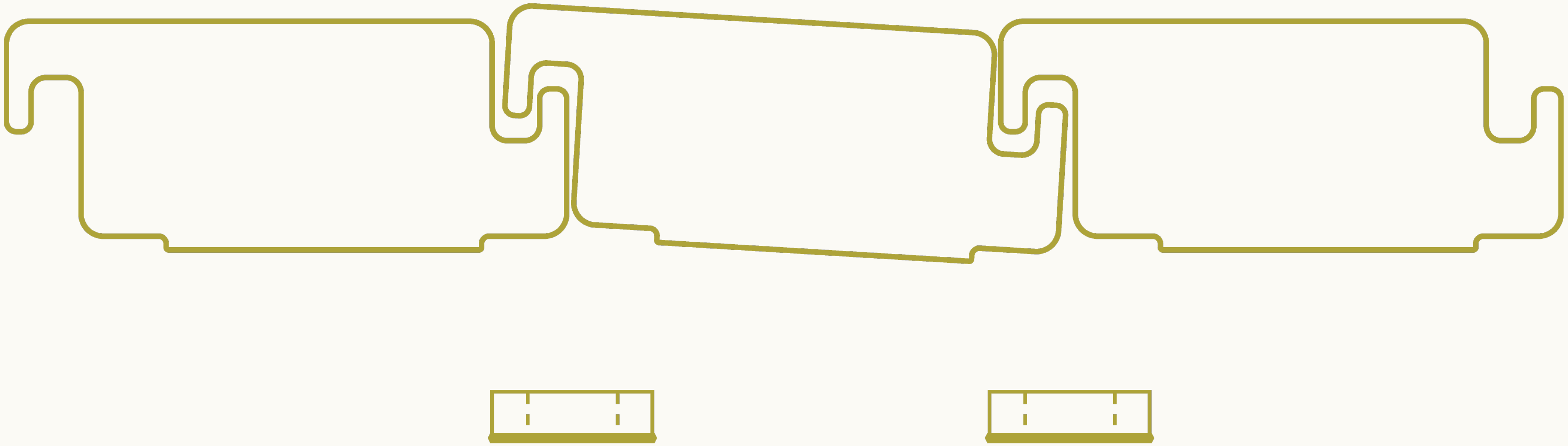


Improved designs

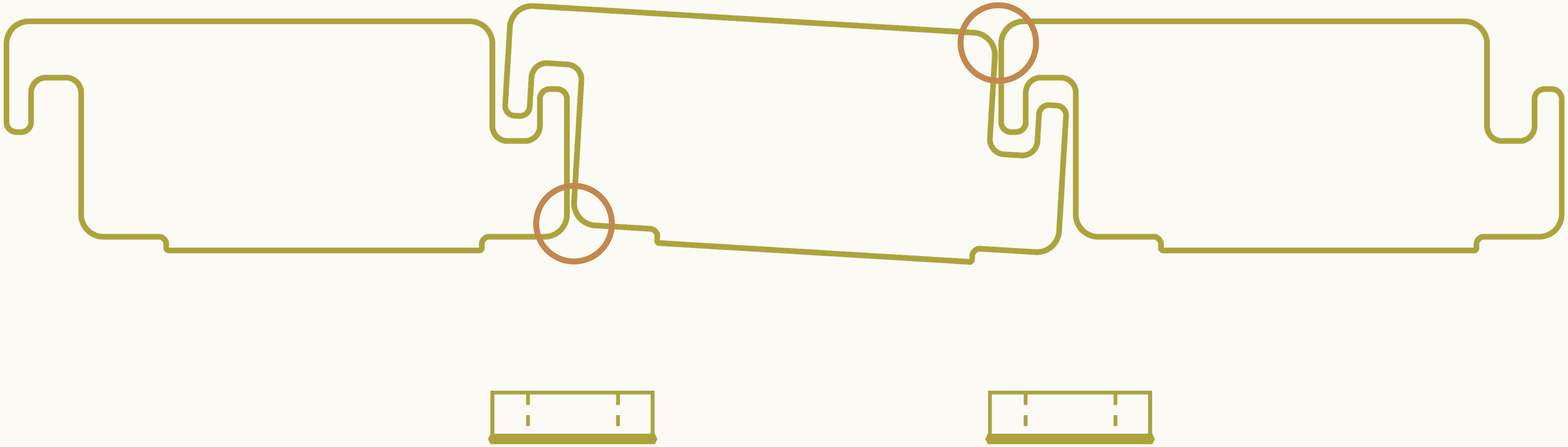
Improved designs



Improved designs



Improved designs



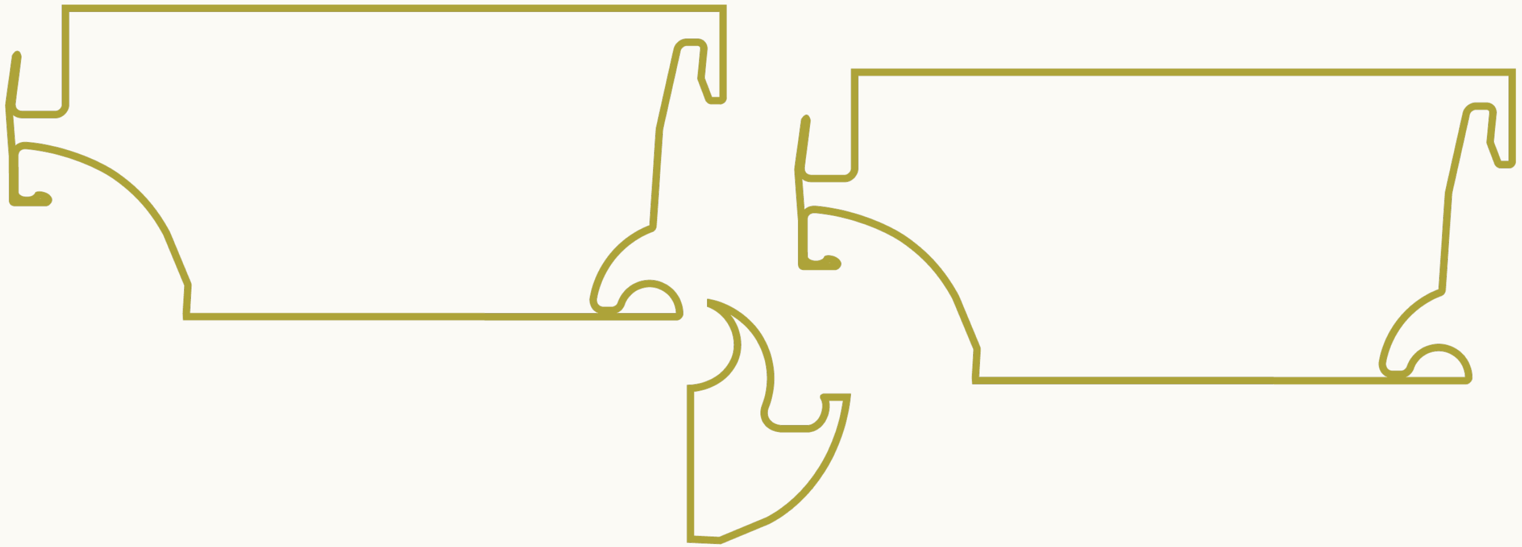
Improved designs

Hinge

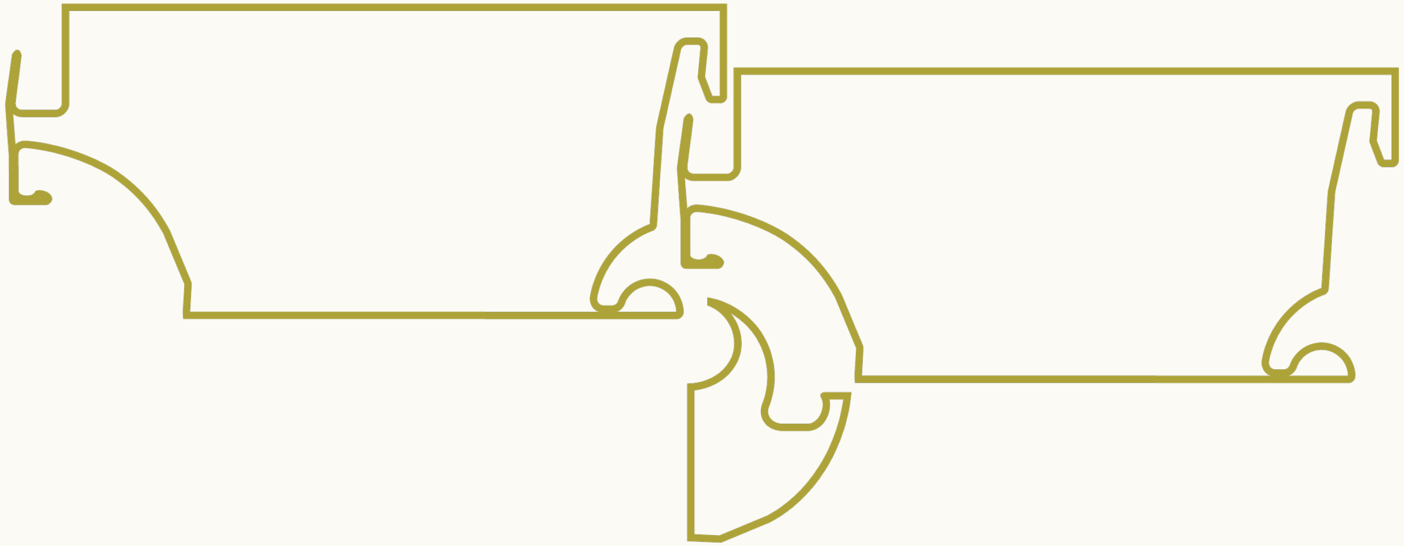
+ Ease of assembly and disassembly
+ Positive effect on appearance
+ Low energy needed for manufacturing
– Tight tolerances (locking element gets stuck)

Improved designs

Improved designs



Improved designs



Improved designs

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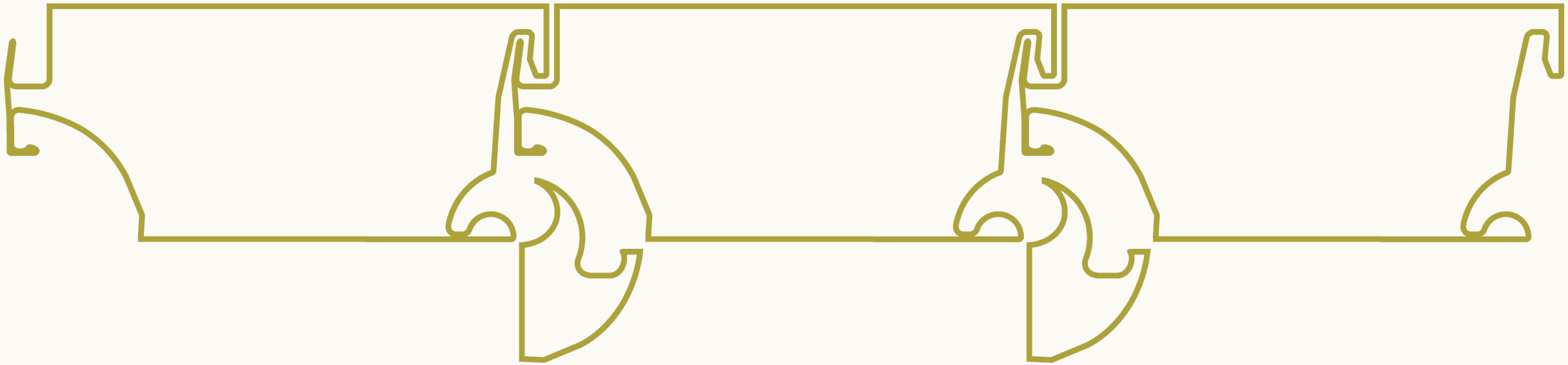

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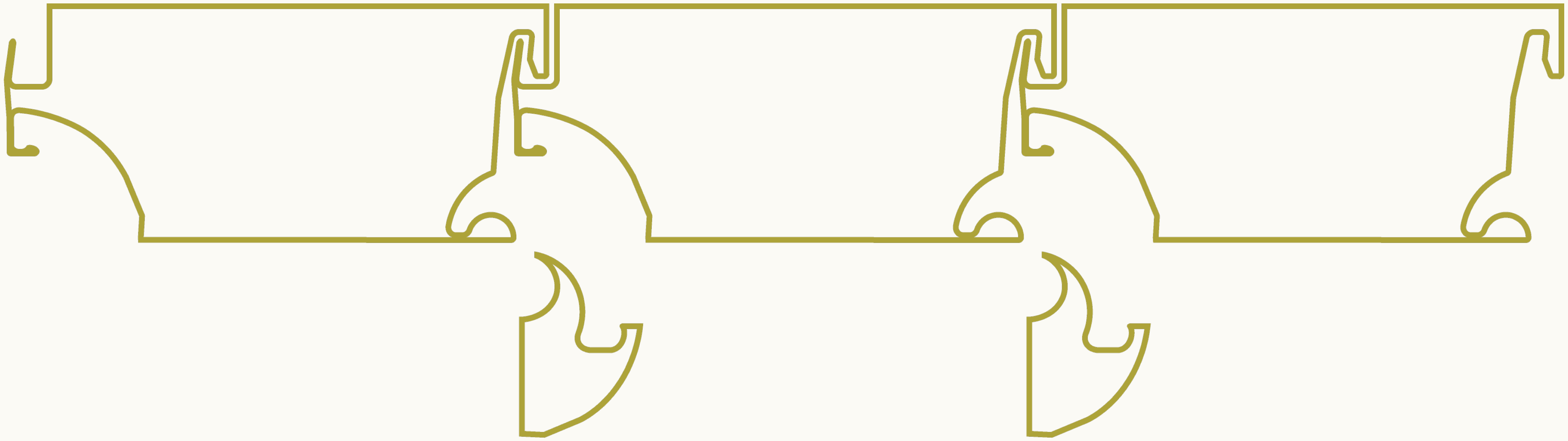
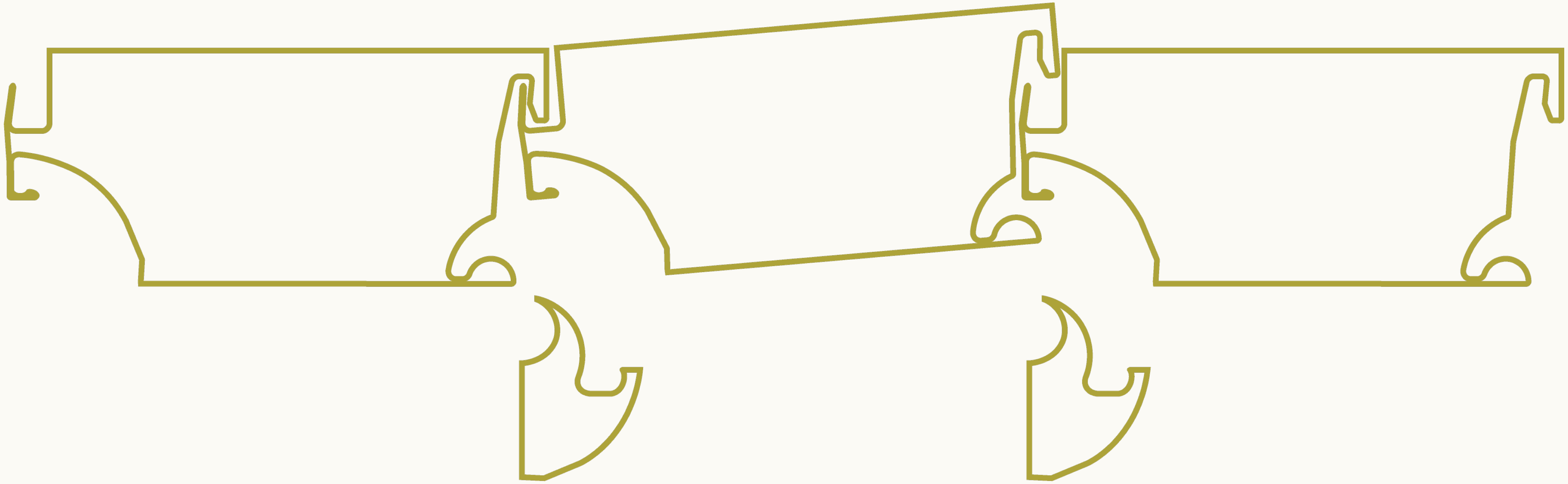
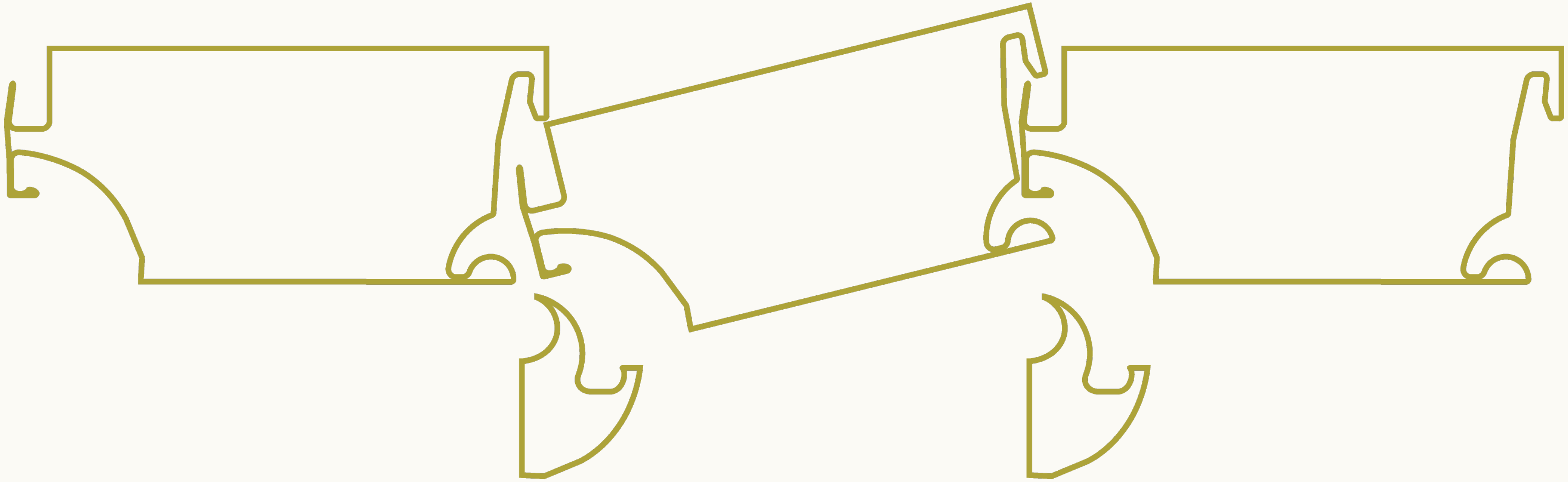


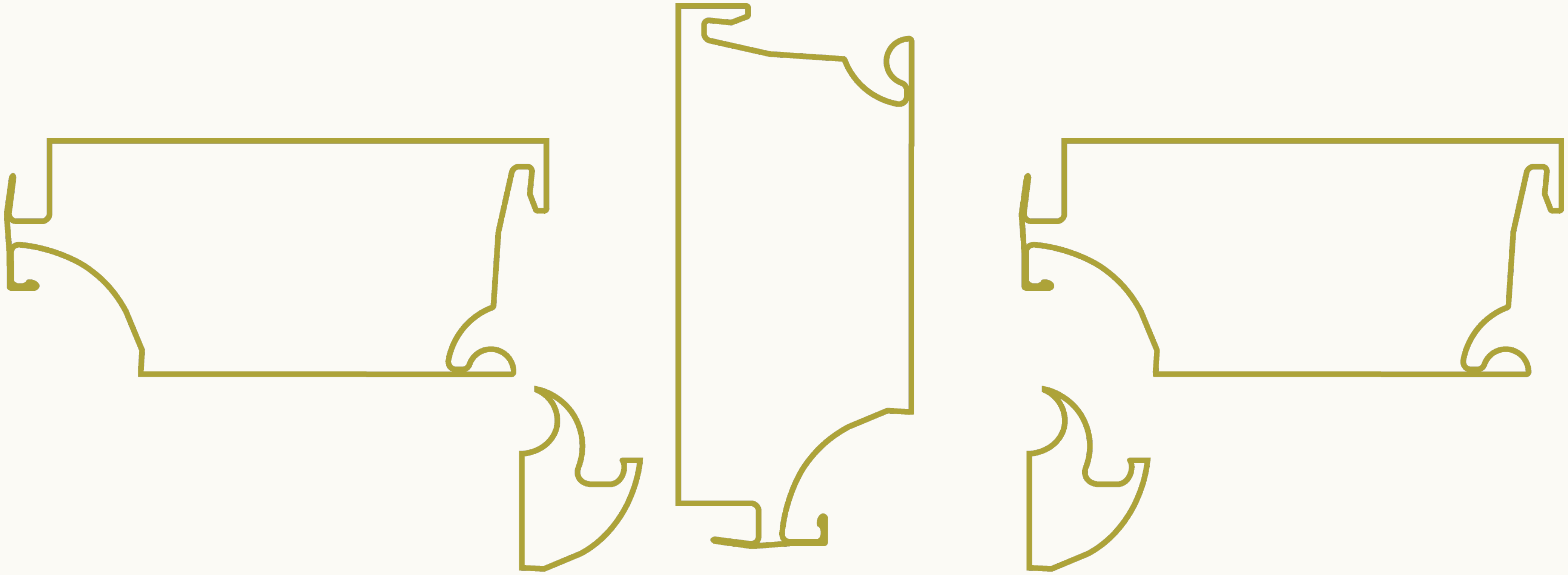
Improved designs



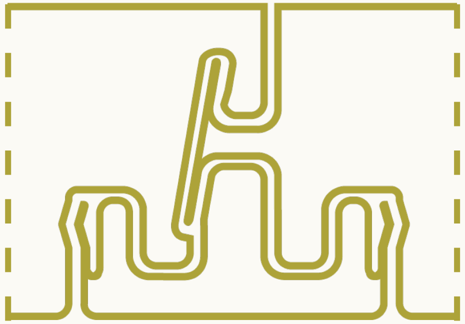
Improved designs



Improved designs



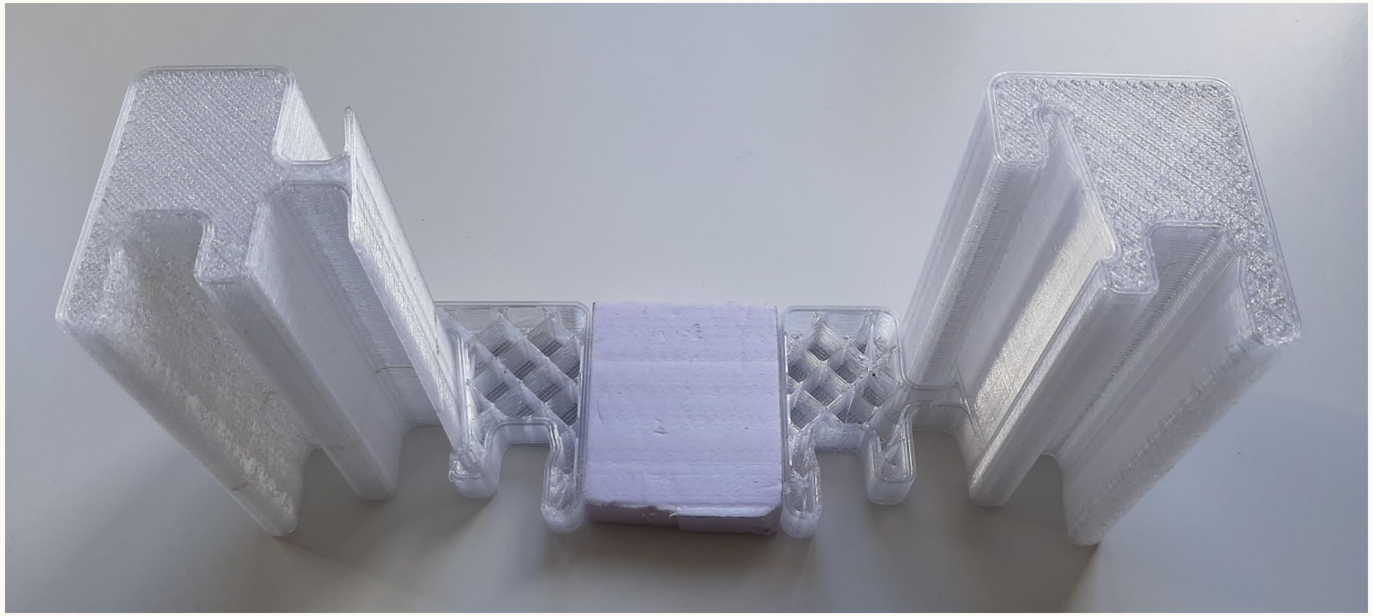
Improved designs

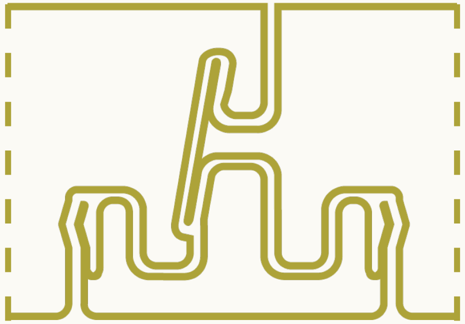


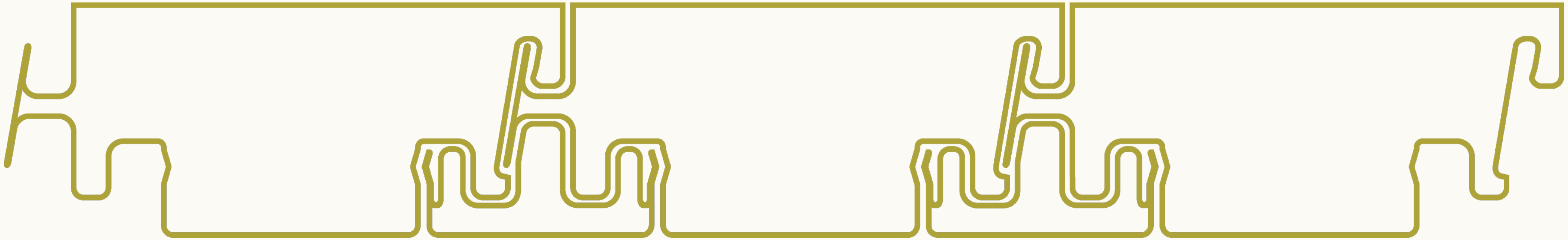
Snap Fit

- \+ High product reliability
- \+ Ease of assembly
- \+ Positive effect on appearance
- – Cannot disassemble
- – High energy for manufacturing

Improved designs







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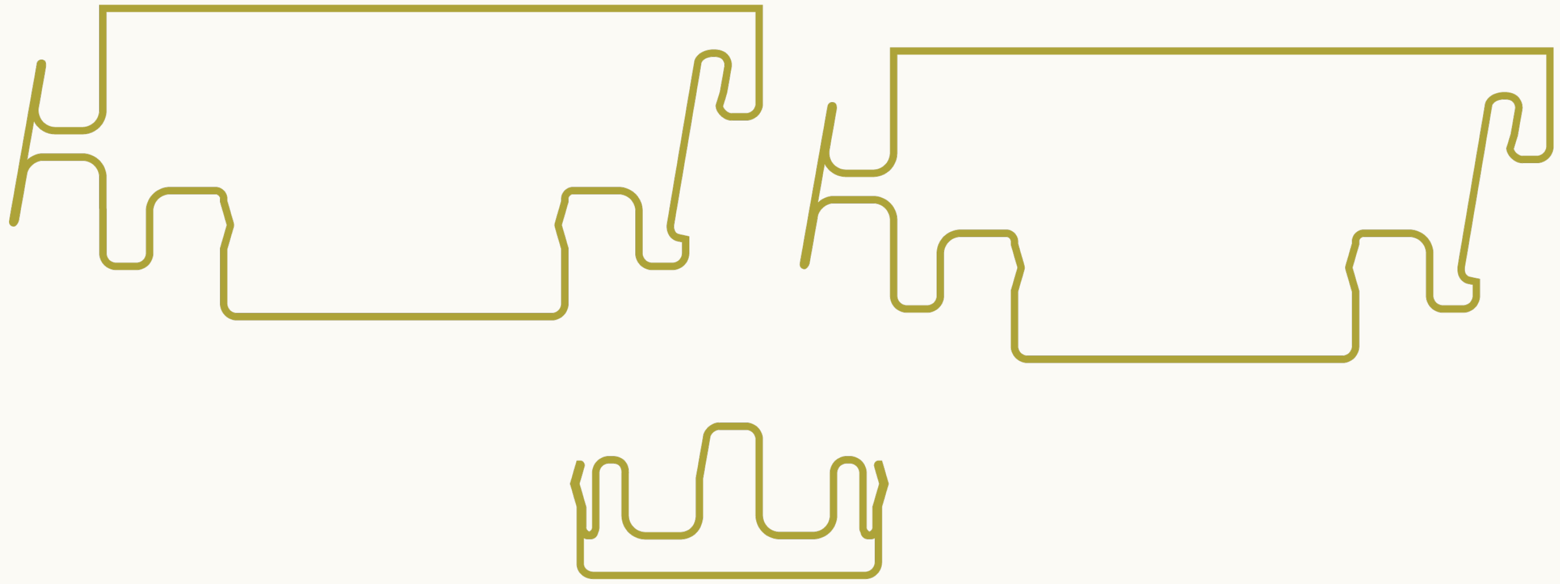

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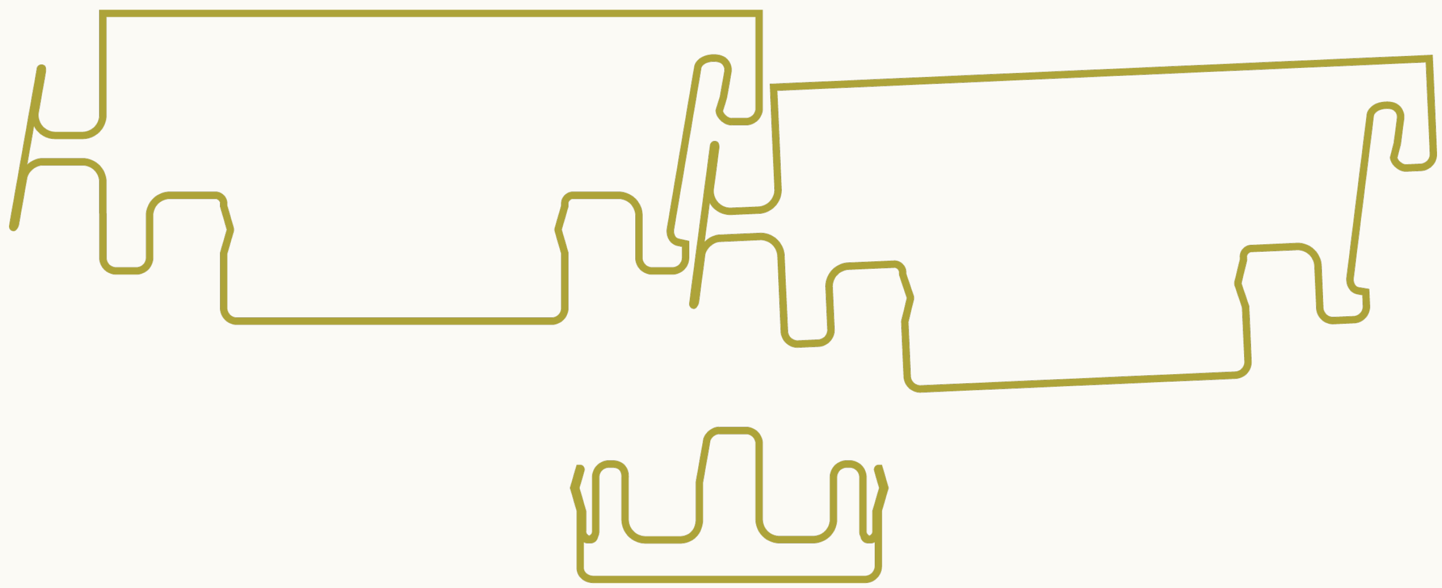

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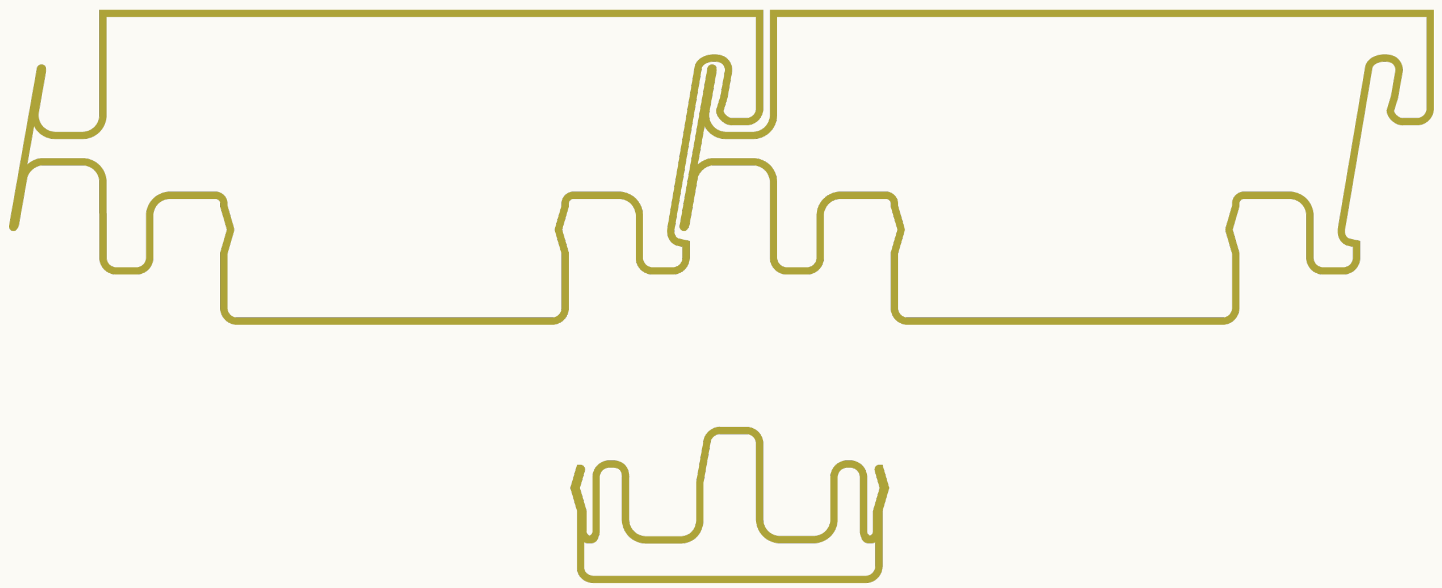

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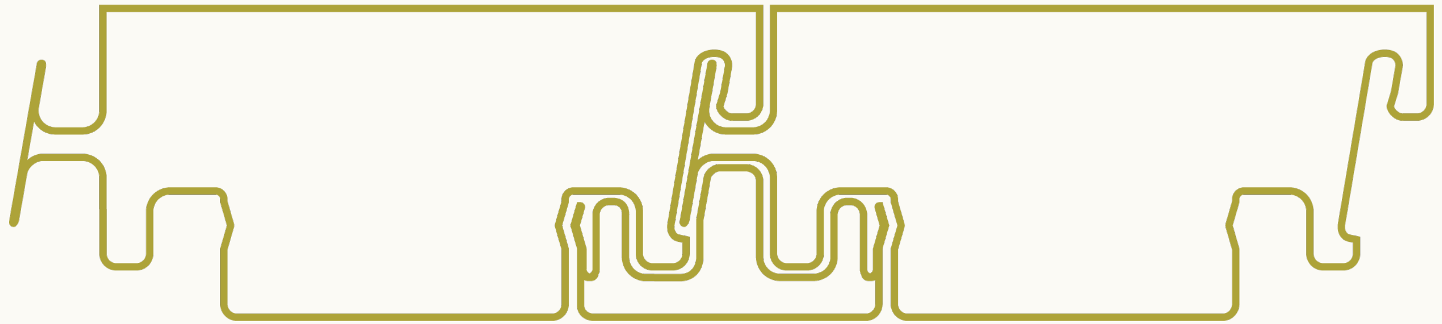

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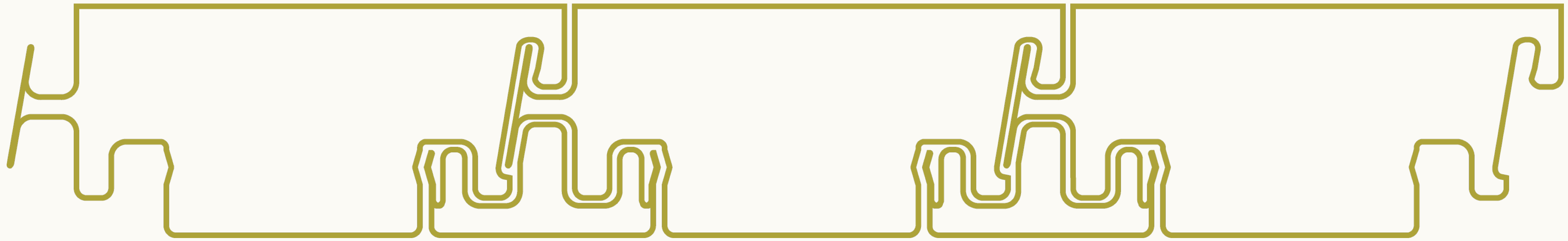

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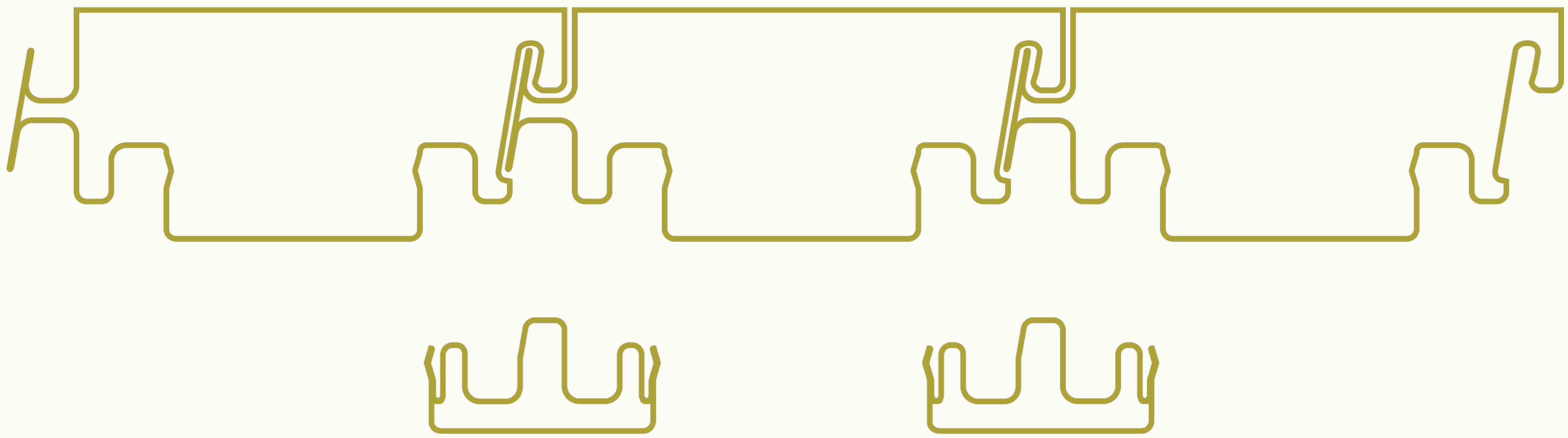

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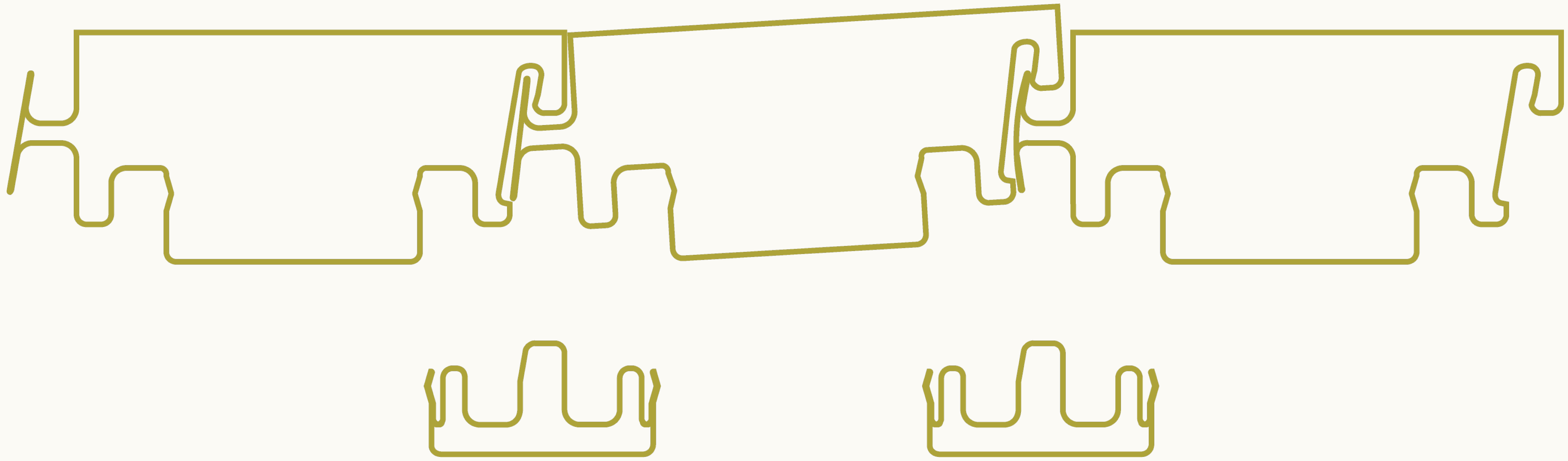
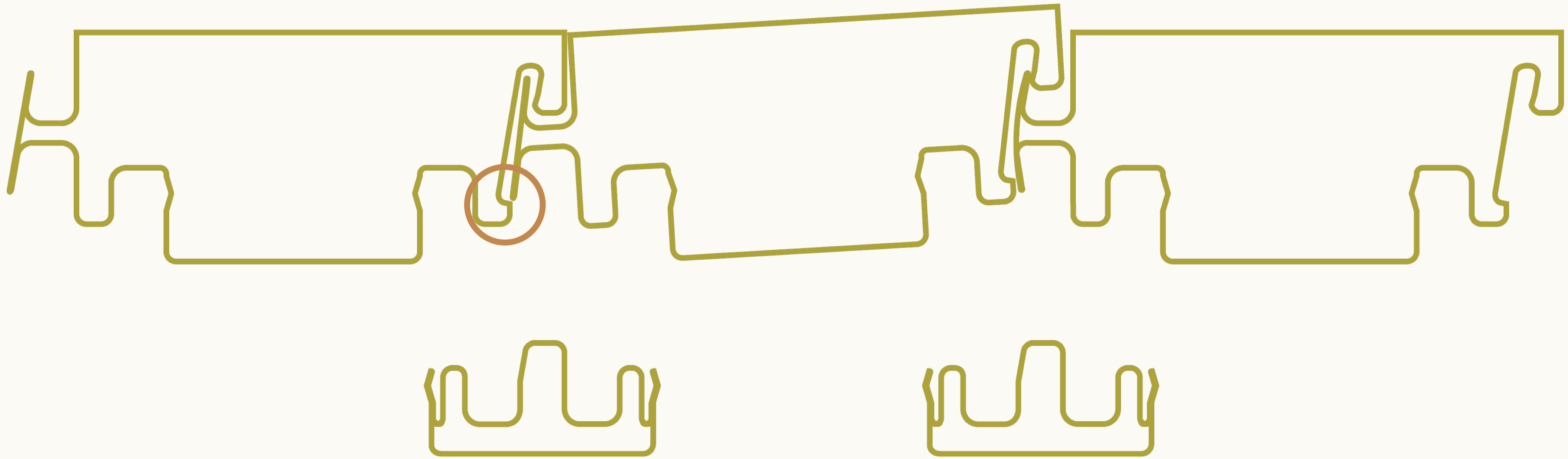
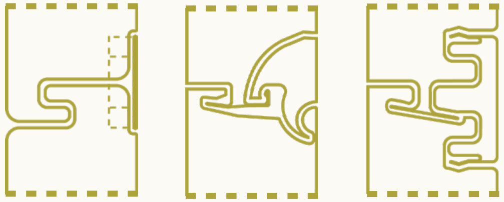


Improved designs



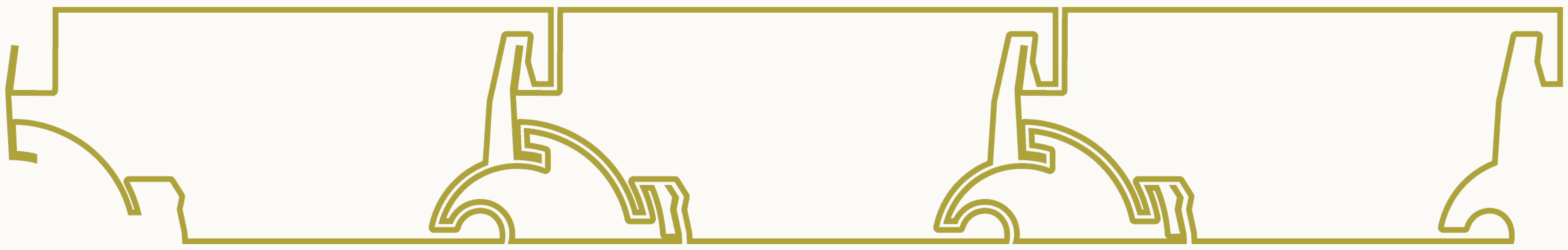
Improved designs - Evaluation



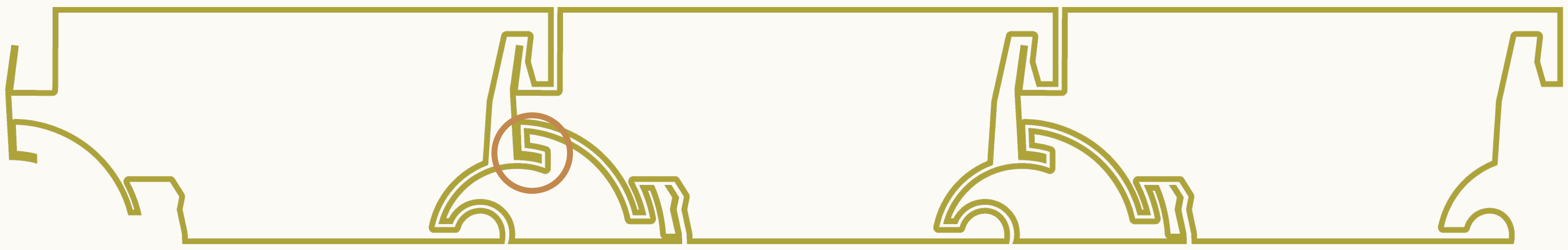
Category and Requirements	Preferred state	Category weight	Importance	Relative importance	Clips raw	Clips weighed	Hinge raw	Hinge weighed	Snap Fit raw	Snap Fit weighed
Manufacturing		**1**								
			19	*1,00*		3,00		2,21		1,21
Assembly concerns		**1**								
			16	*1,00*		2,06		2,69		2,63
In-use-period concerns		**2**								
			20	*1,00*		3,40		4,60		6,00
Disassembly concerns		**2**								
			19	*1,00*		2,53		3,05		2,84
Total					**48**	**10,99**	**53**	**12,55**	**48**	**12,68**

Improved designs

Final design – C-cure



Final design – C-cure



Final design – C-cure

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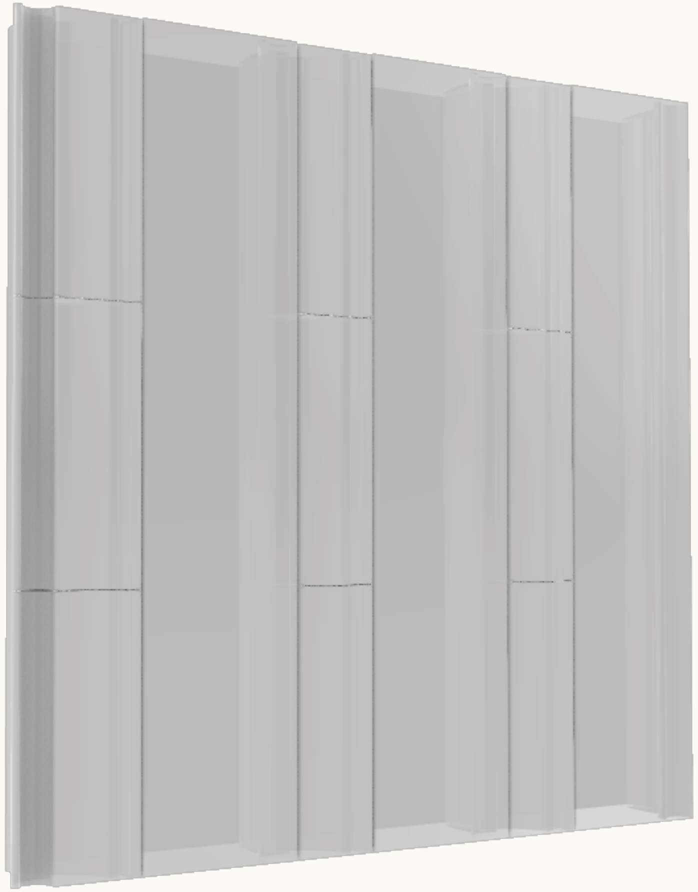
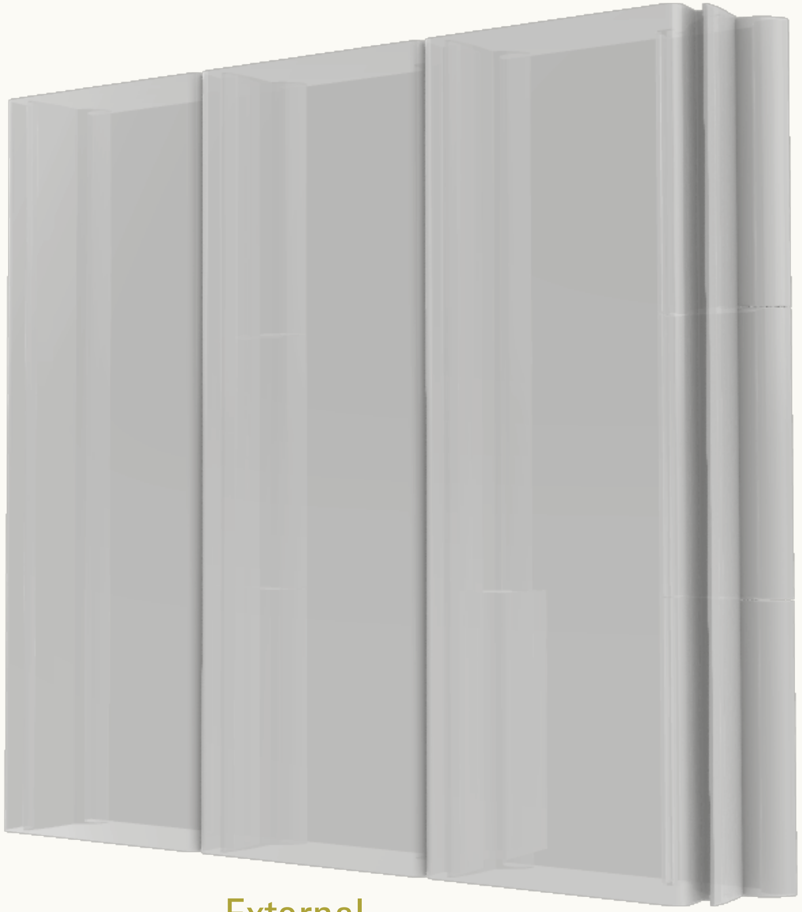
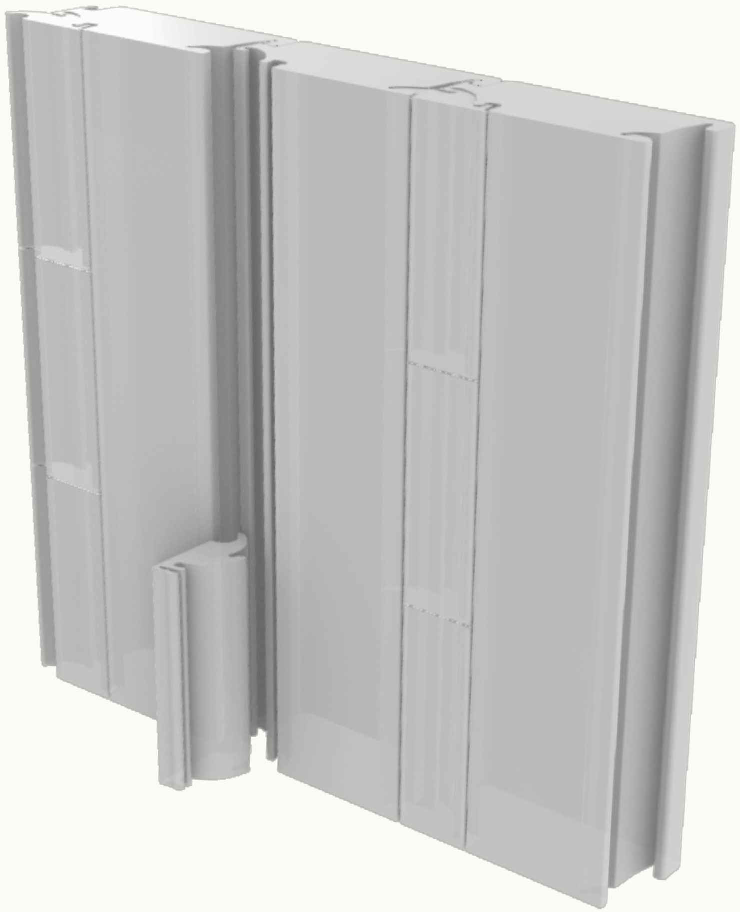


Internal

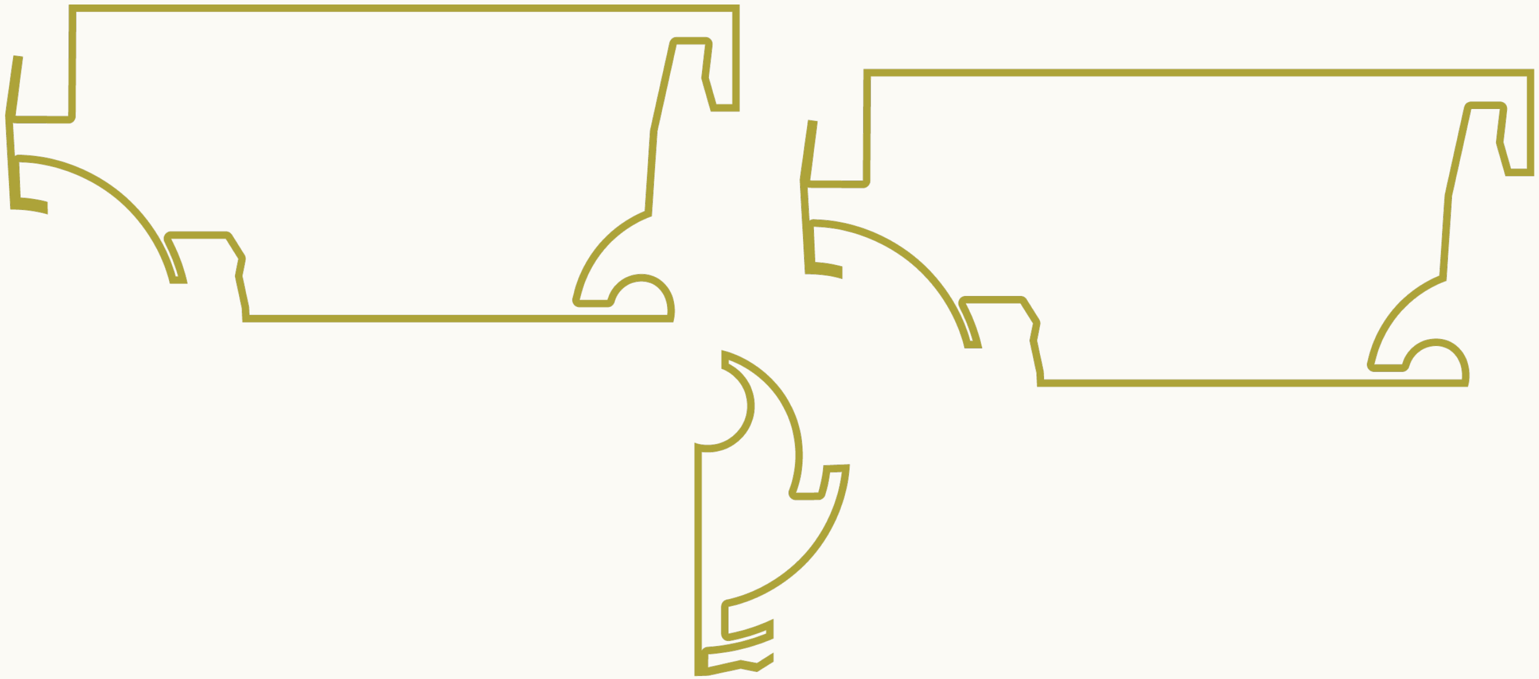


External

Final design – C-cure



Final design – C-cure



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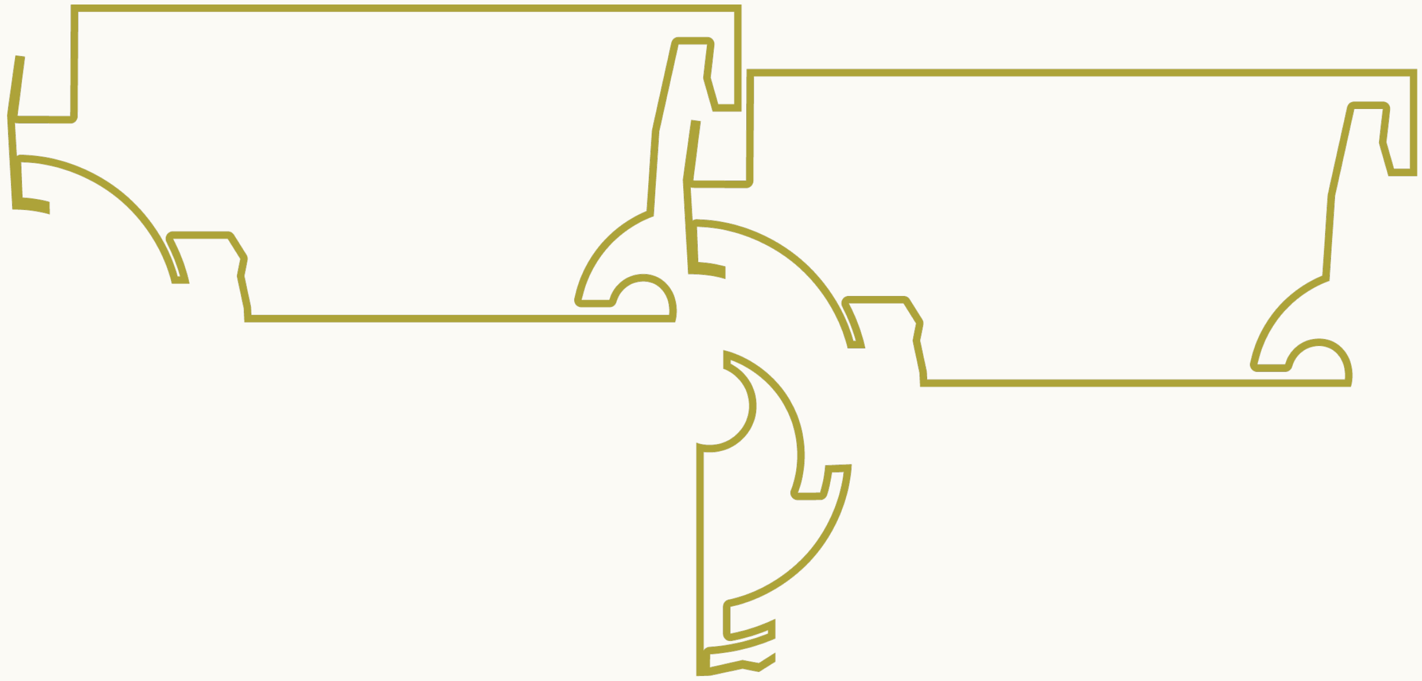

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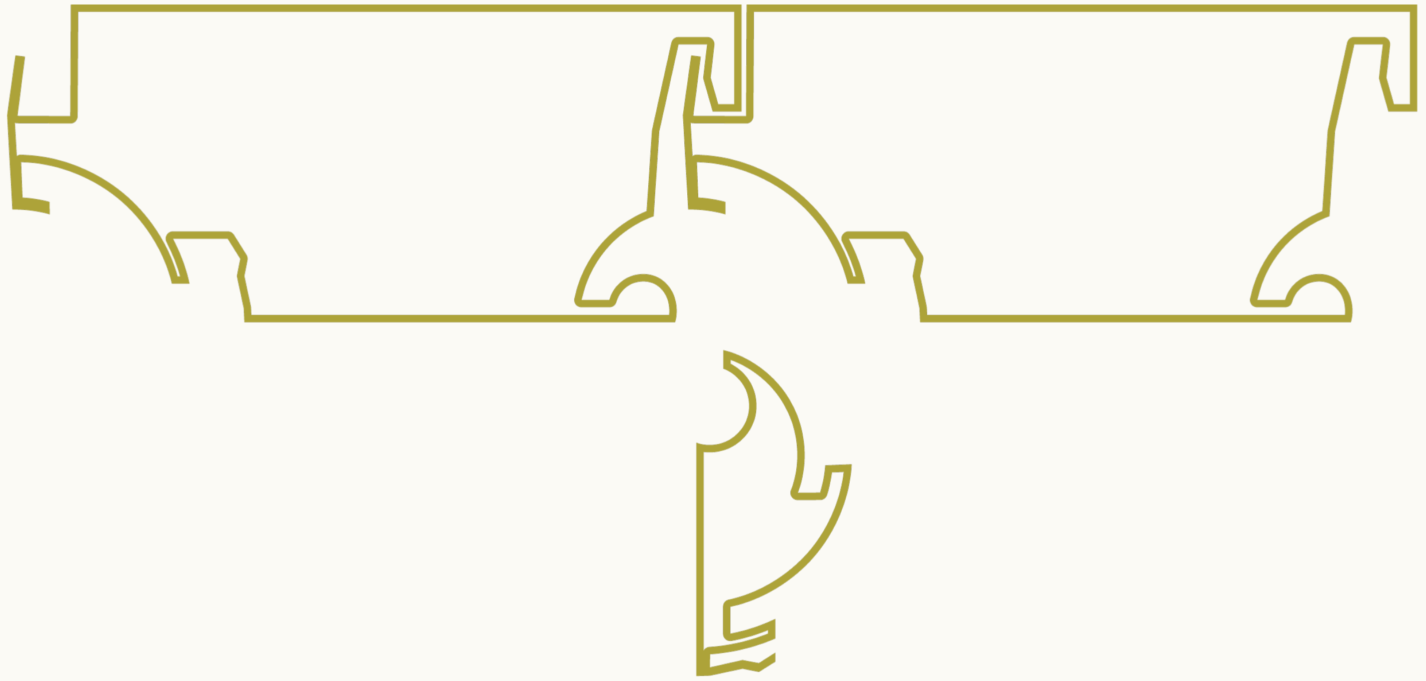

Final design – C-cure

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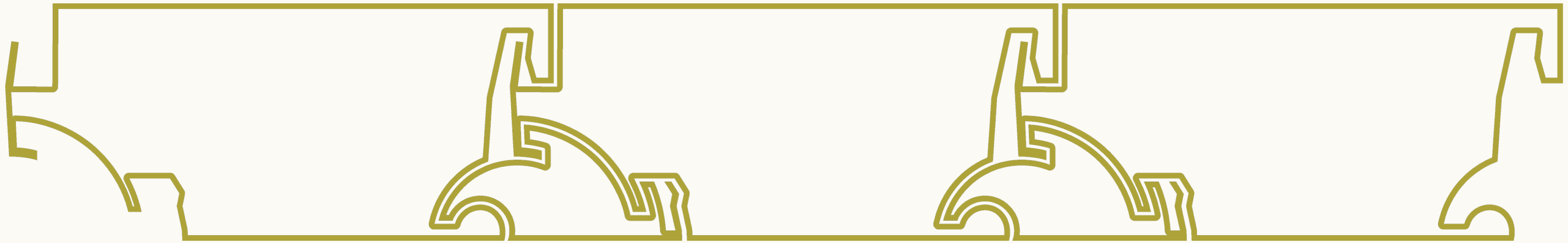

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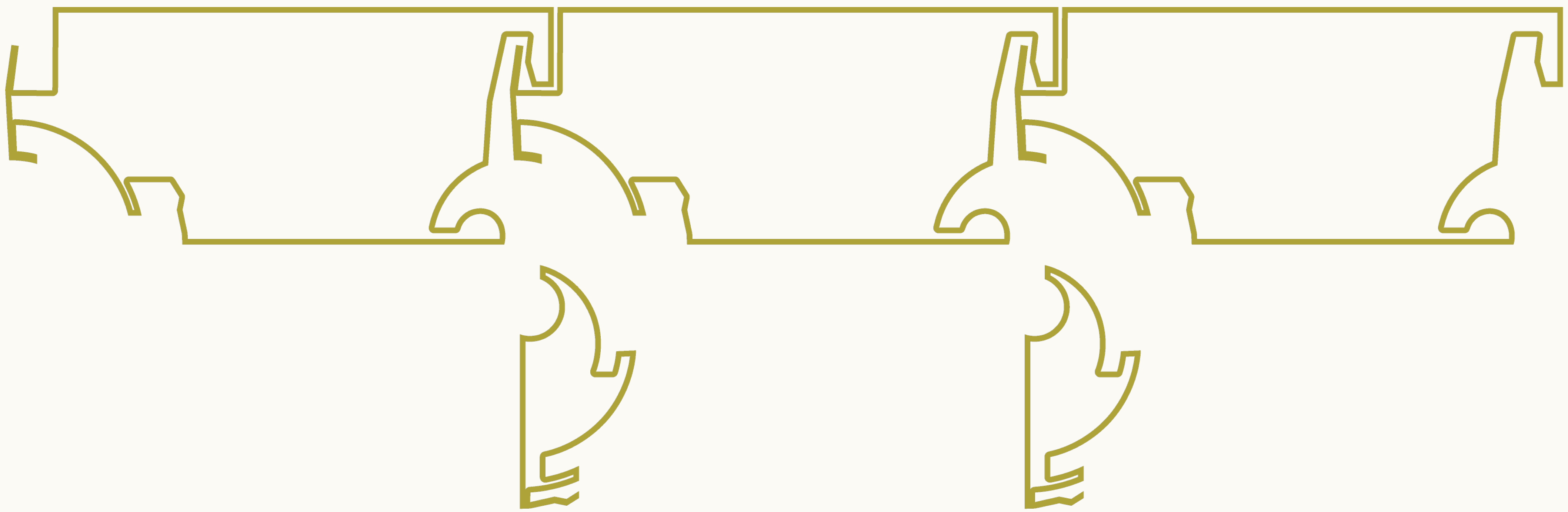
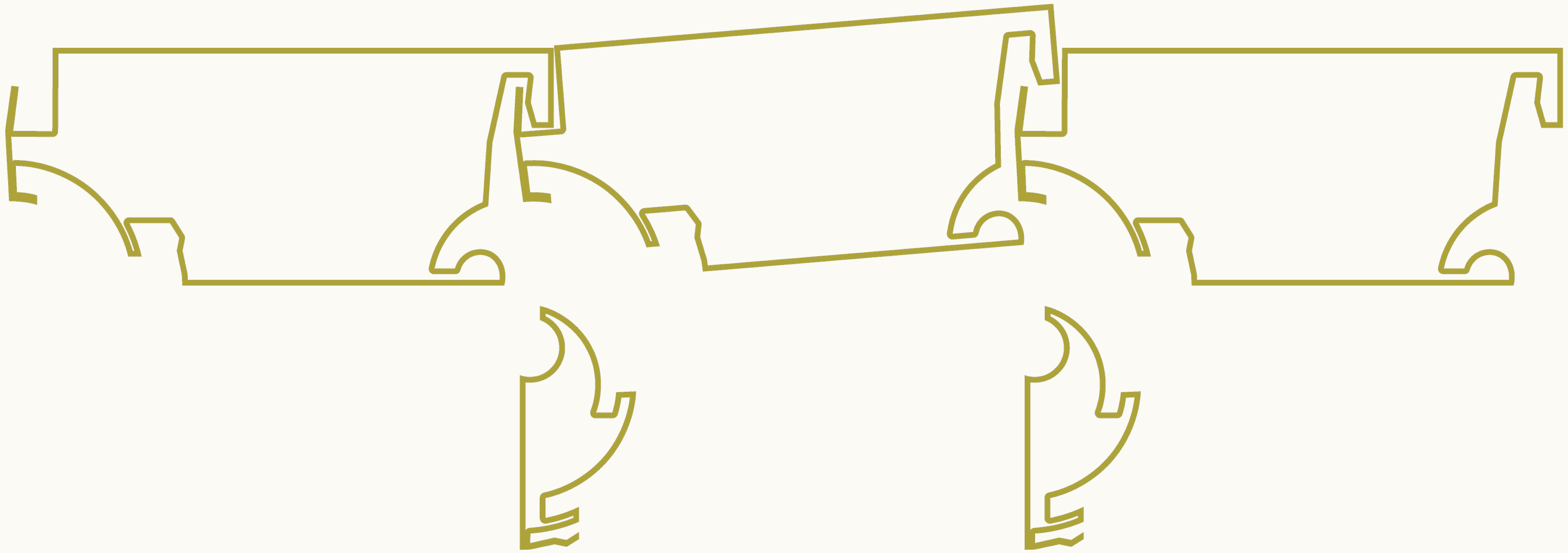
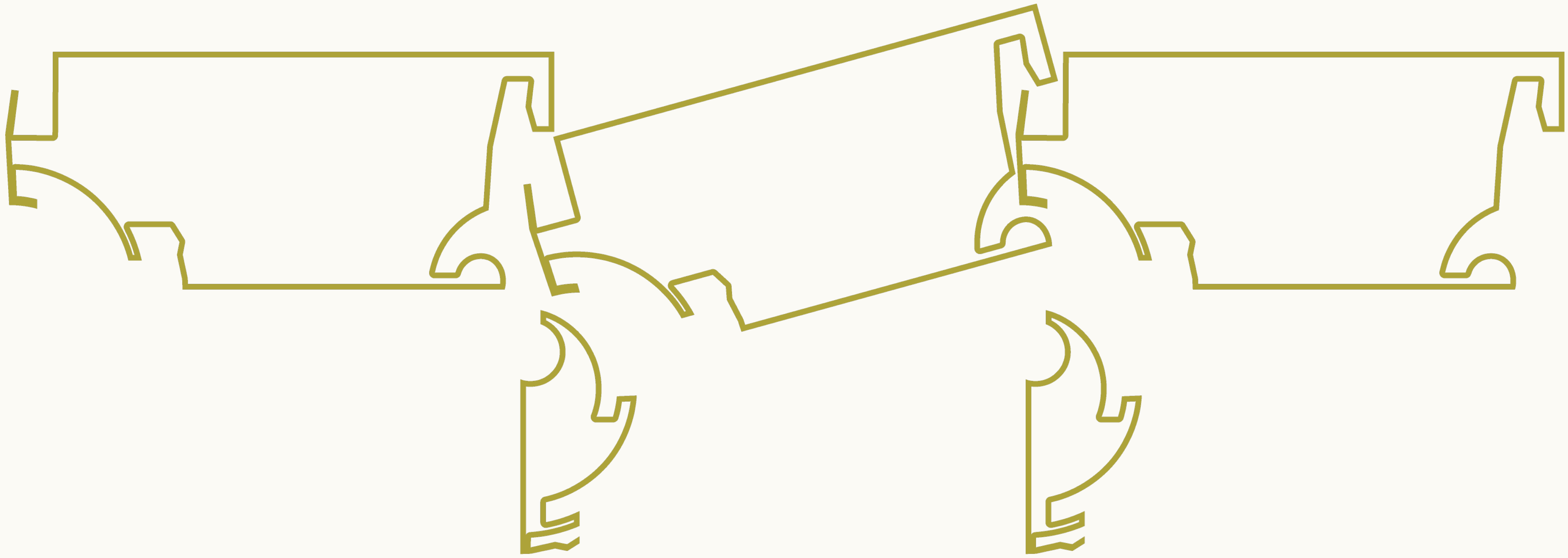


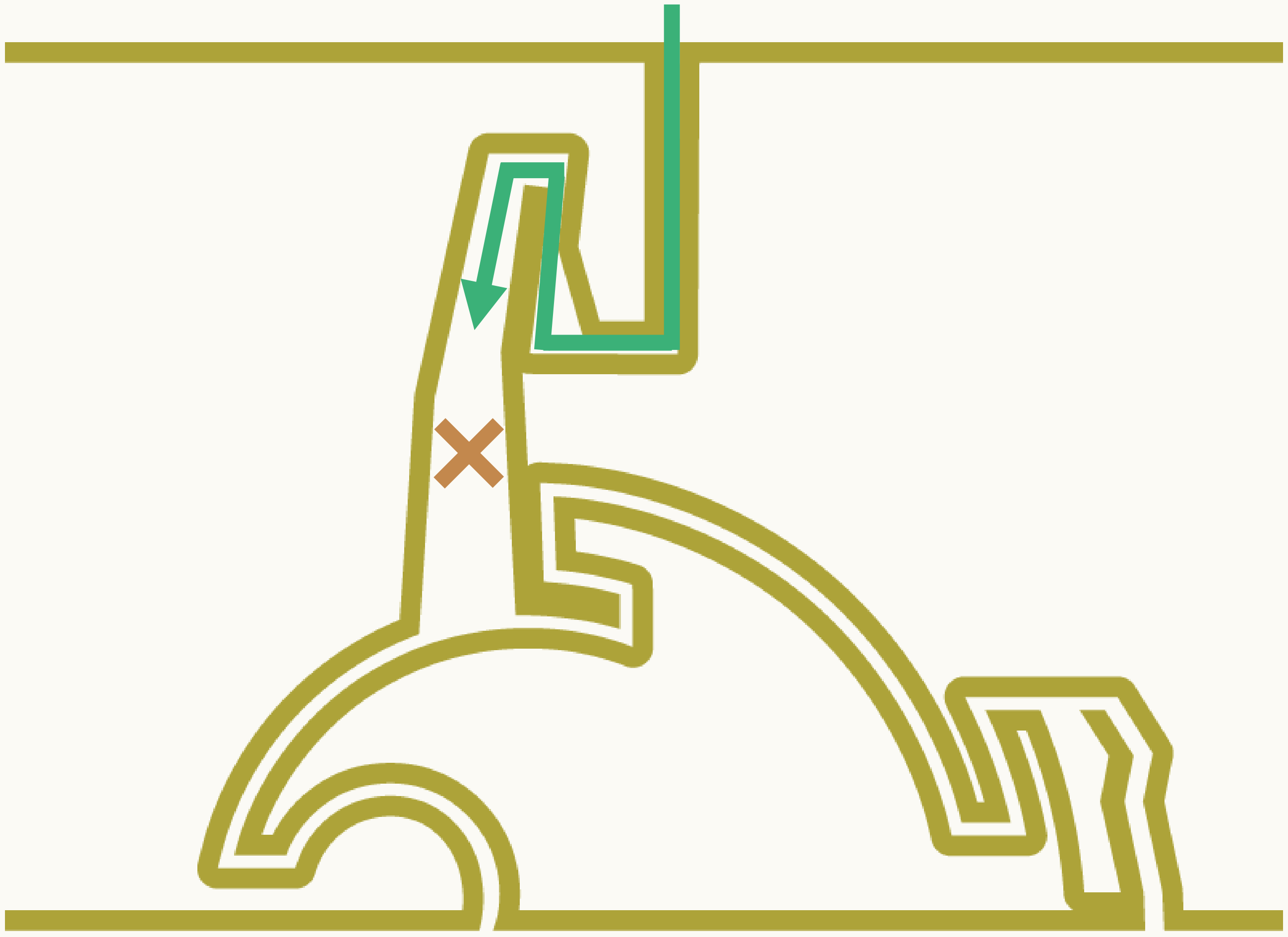
Final design – C-cure



Final design – C-cure



Final design – Watertightness



Conclusions

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- AM can be used to create Circular Building Products
- Spong3D has circular potential if optimized
- Through the requirements, a connector can be evaluated on circular potential
- C-cure meets all circurlar requirements set

Reccomendations

- Testing of strength, durability and watertightness
- Testing of rPET
- Different design scenarios
- 1:1 prototype (based on the Spong3D block)

Questions?