GREEN ROOF TILE

IMPROVING LOCAL BIODIVERSITY

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BUILDING TECHNOLOGY
30-06-2021


gobankingrates

financial times

Verdichten én vergroenen: 1 miljoen nieuwe woningen klimaatbestendig bouwen

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1 miljoen woningen nodig tot 2030

Volgens prognoses van ABF Research worden er in Nederland tot 2030 een miljoen woningen gevraagd. Hoeveel van deze nieuwbouwwoningen kunnen we bestaand gebied bouwen? Hoeveel transformatieruimte is er in de bestaa

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NIEUWS BOUWEN

Een miljoen woningen erbij in ruim tien jaar? Meer bouwen in groen en investeren in openbaar vervoer

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Opinie huisvesting

We moeten snel meer bouwen

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25 augustus 2018 09:48
Laatste update: 28 augustus 2018 09:20

133 NUjij-reacties

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'Bouwsector wil miljoen nieuwe woningen'

Door ANP PRODUCTIES
17 mei 2018 in FINANCIEEL

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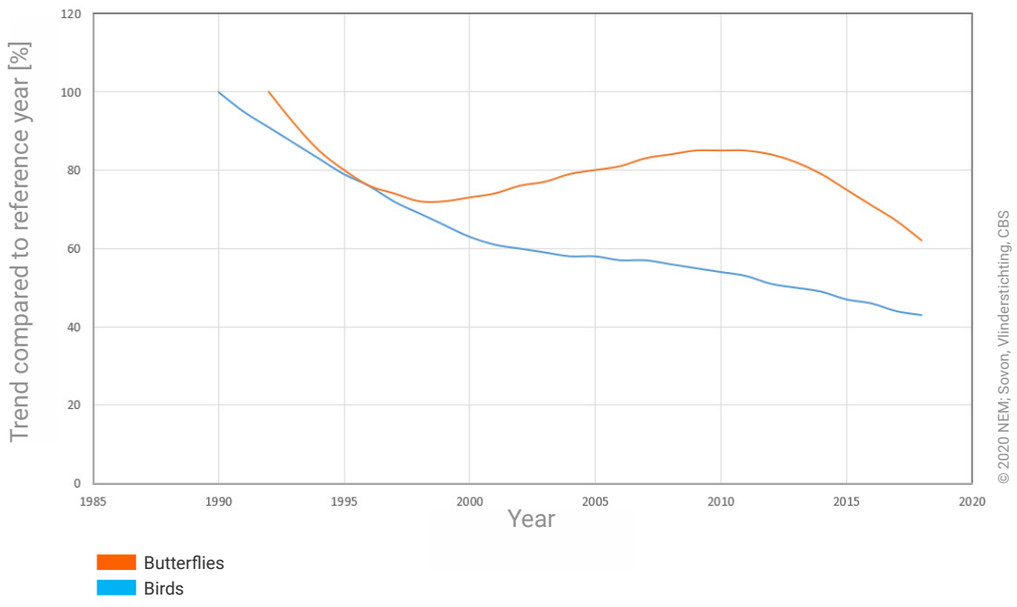
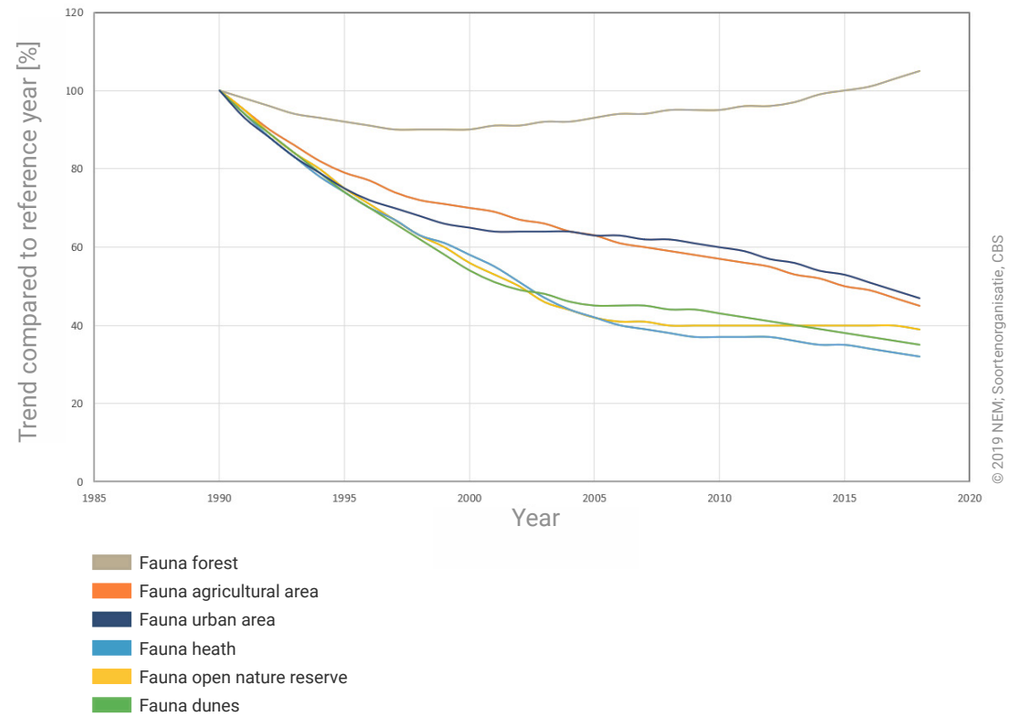
Trend butterflies and birds in urban areas



Trend fauna Netherlands

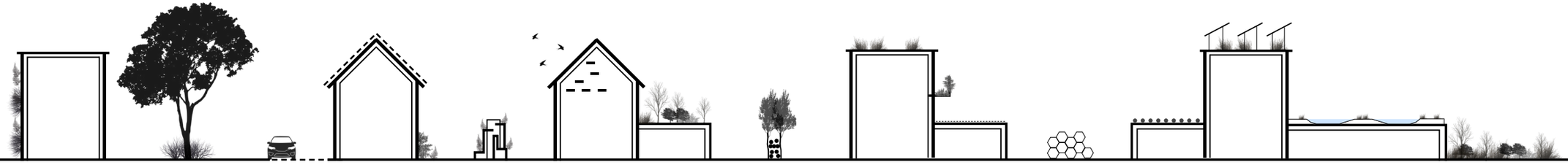


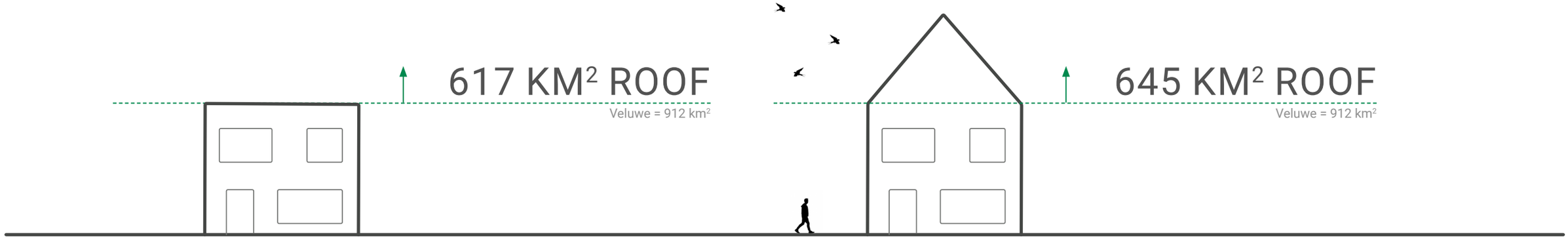
“**BIODIVERSITY** OF URBAN AREAS IS DECREASING AND NATURE IS REPLACED BY HOUSES.”

PROBLEM STATEMENT

RESEARCH

	Green facade	Flowery tree ground	Open pavement	Sedum roof tile	Facade garden	Wilderness wall	Breeding box bird	Breeding box bat	Intensive green roof	Branchesril	Green roof	Balcony garden	Sedum roof	Bee and insect hotel	Brown roof	PV panels and green roofs	Blue roof	Shrubbery	Butterfly and bee garden	Open sand
Plants	● ●	● ●	●	●	● ●	● ●			● ●	●	● ●	●	●		● ●	●	● ●	● ●	● ●	●
Insects	● ●	● ●	●	●	● ●	● ●			● ●	● ●	● ●	●	●	● ●	● ●	●	● ●	● ●	● ●	● ●
Birds	● ●	● ●		●	● ●	●	● ● ●		● ●	● ●	●	●	●	●	● ●	●	● ●	● ●	● ●	●
Bats								● ● ●	●		●			●	●		●			
Mammals		●			●	● ●				● ●								● ●	●	●
Area	● ●	●	● ●	● ●	●	●	●	●	● ●	●	● ●	●	● ●	●	● ●	●	● ●	● ●	● ●	●





- Intensive green roof
- Green roof
- Sedum roof
- PV panels and green roofs
- Brown roof
- Blue roof
- Polder roof

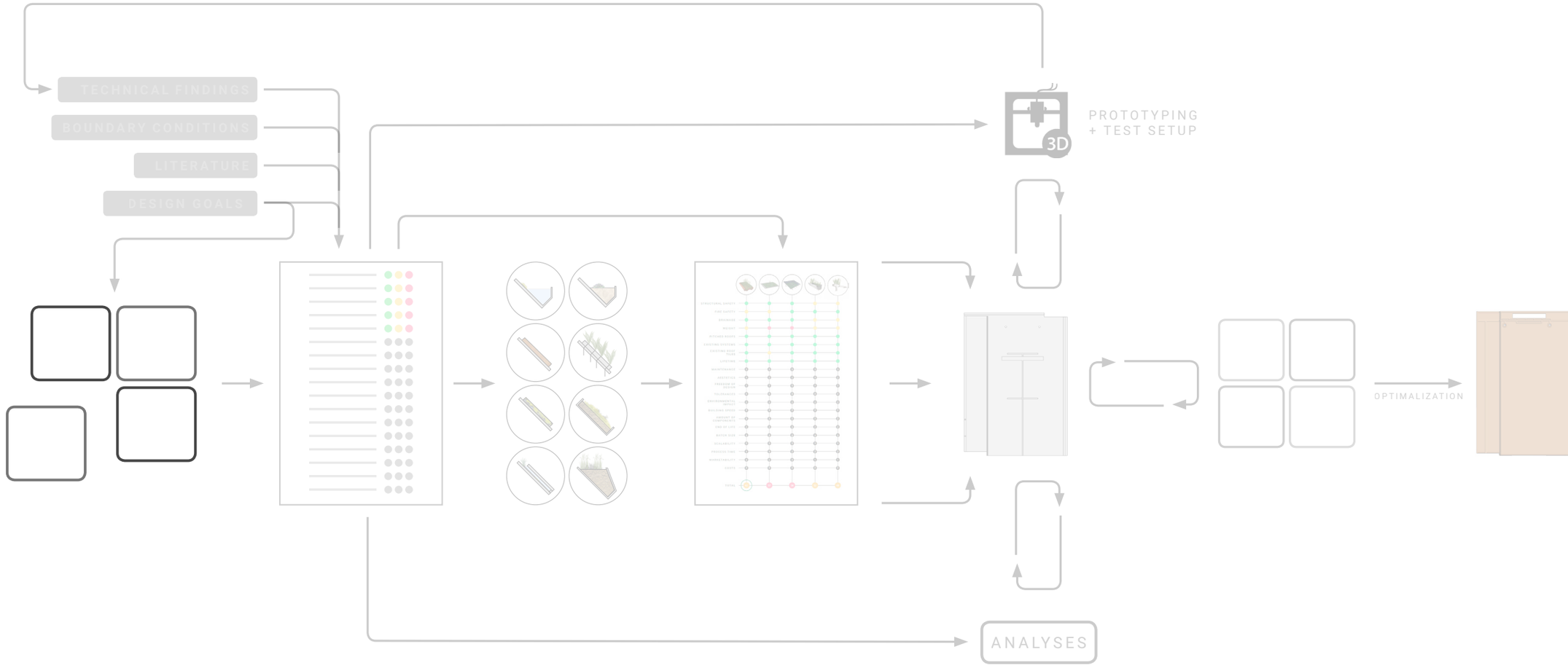
- Sedum roof
- Sedum roof tile

“HOW CAN A GREEN ROOF SYSTEM IMPROVE **BIODIVERSITY** OF PITCHED ROOFS IN DUTCH CITIES?”

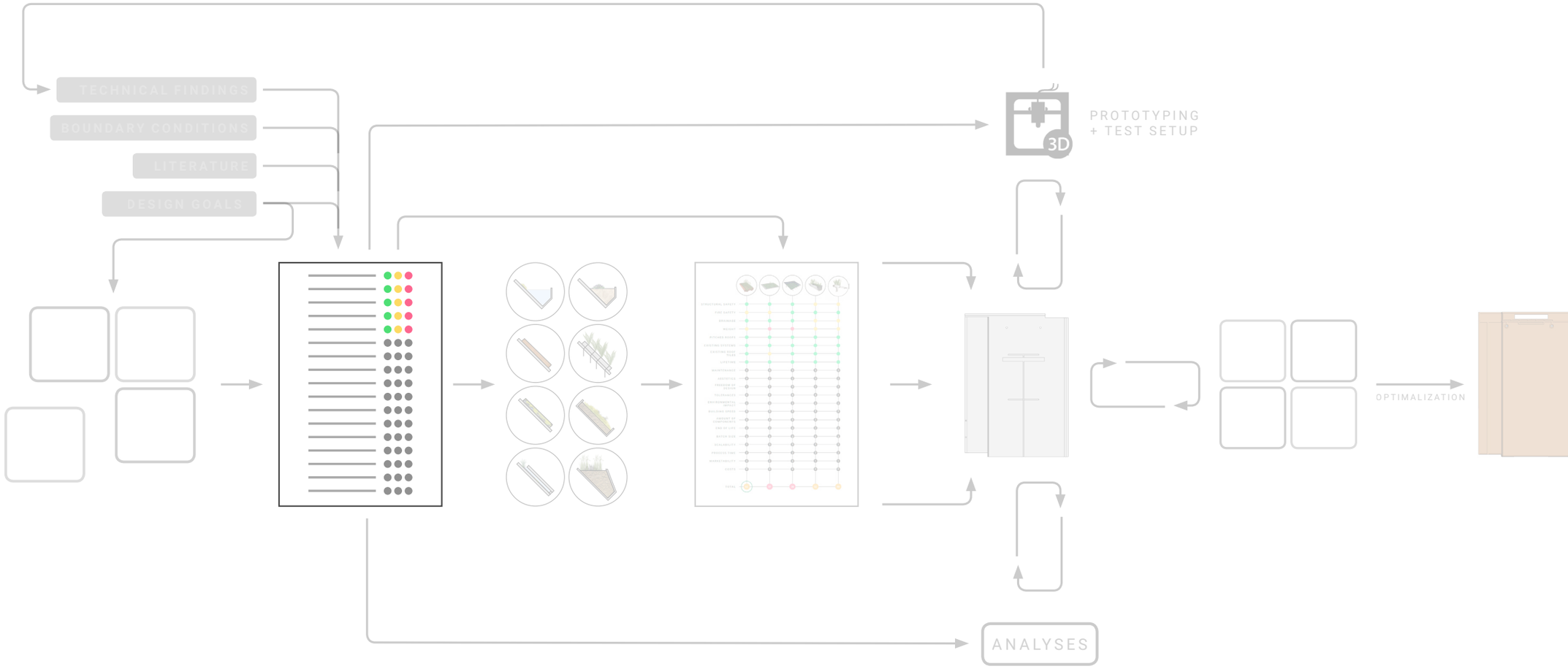
RESEARCH QUESTION

zinco-greenroof

CONCEPT DEVELOPMENT



A. DESIGN OBJECTIVES | B. CRITERIA | C. CONCEPTS | D. CONCEPT ANALYSES | E. DESIGN DEVELOPMENT | F. SUB-SOLUTIONS | G. FINAL DESIGN



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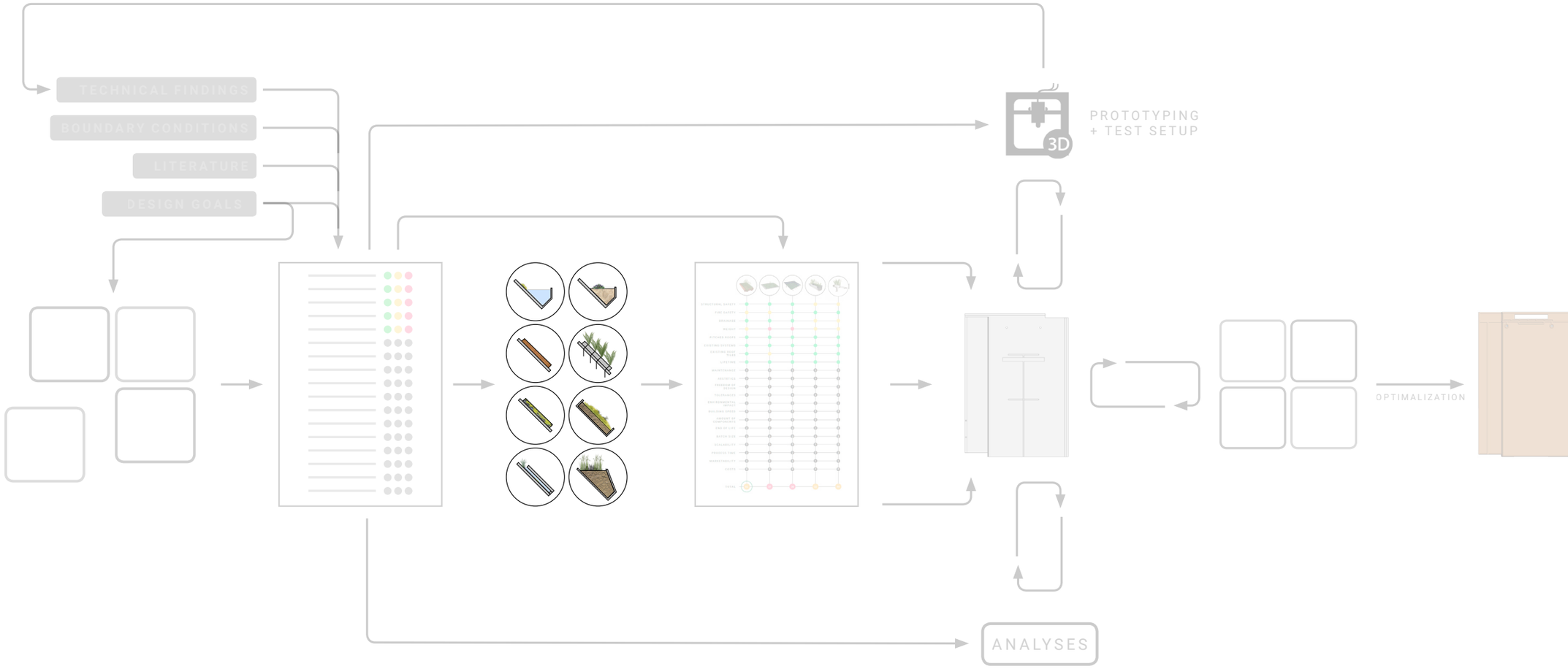

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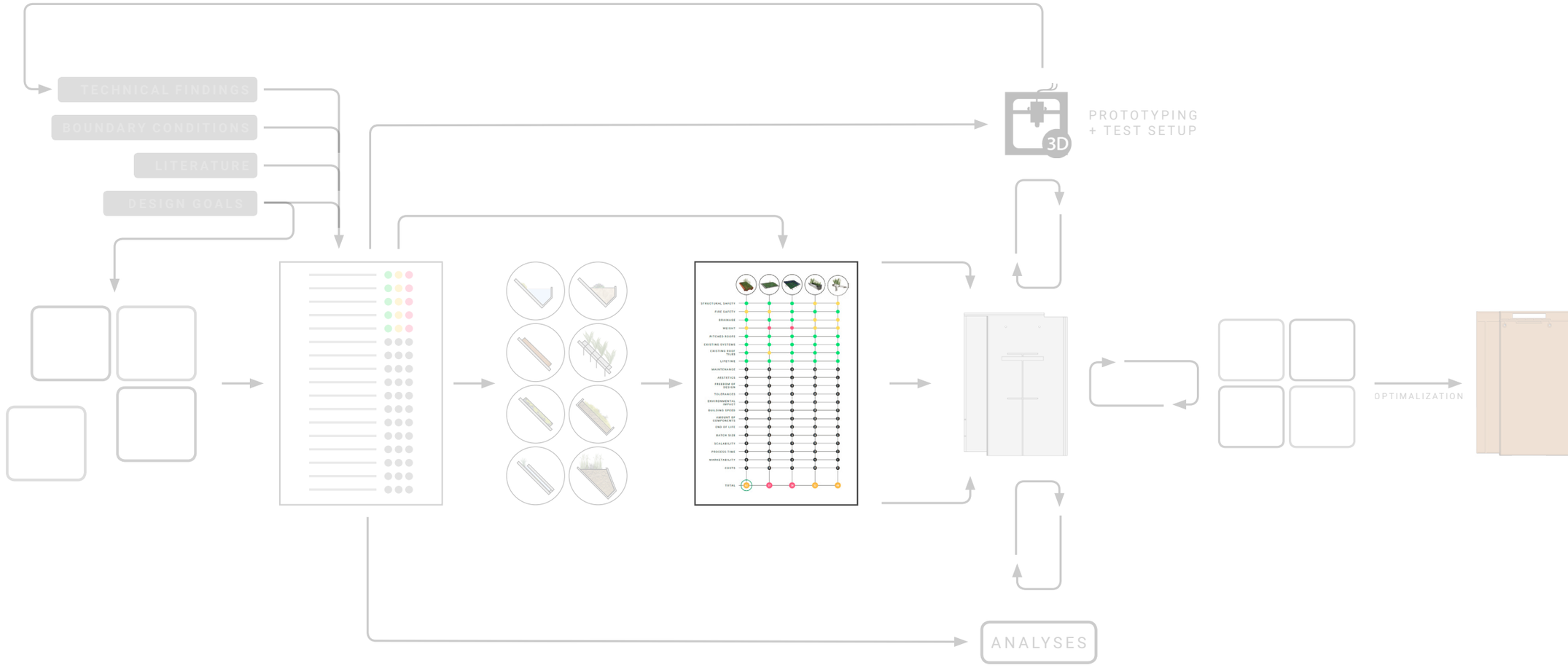

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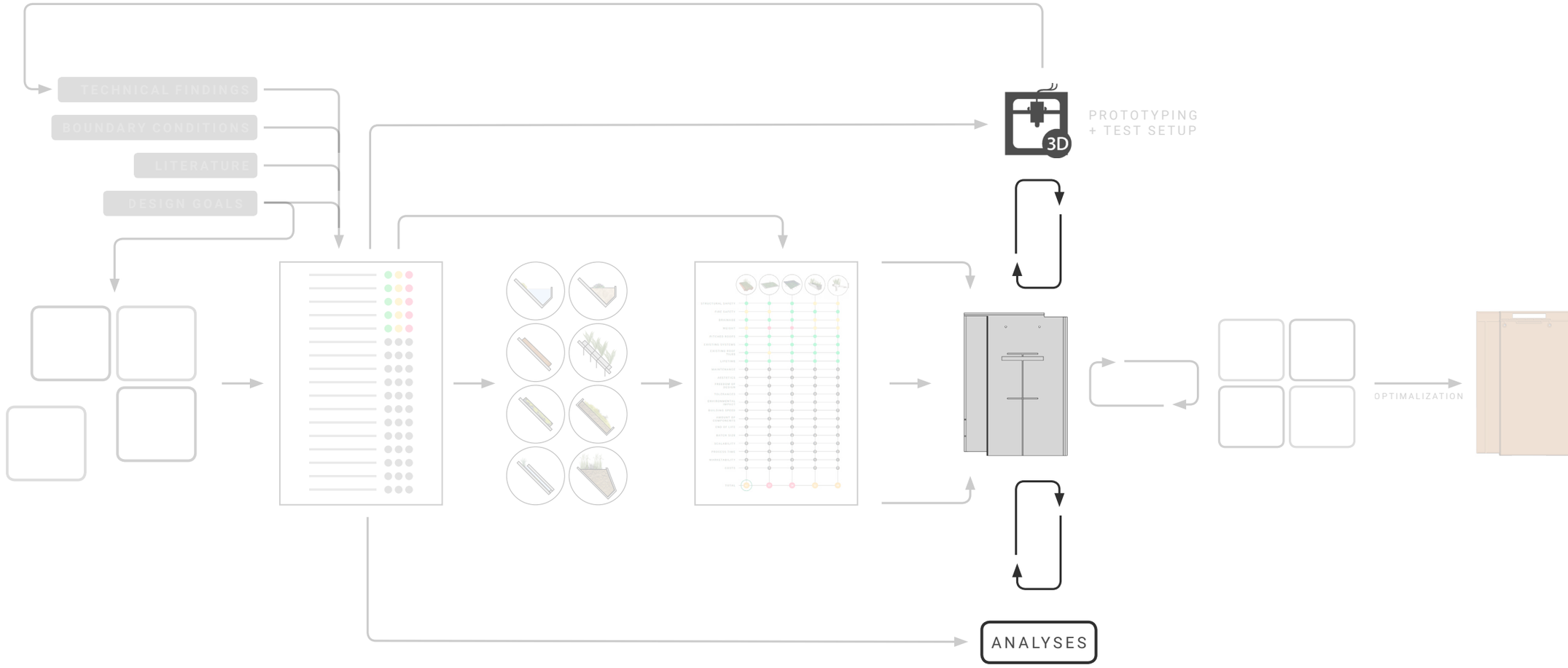

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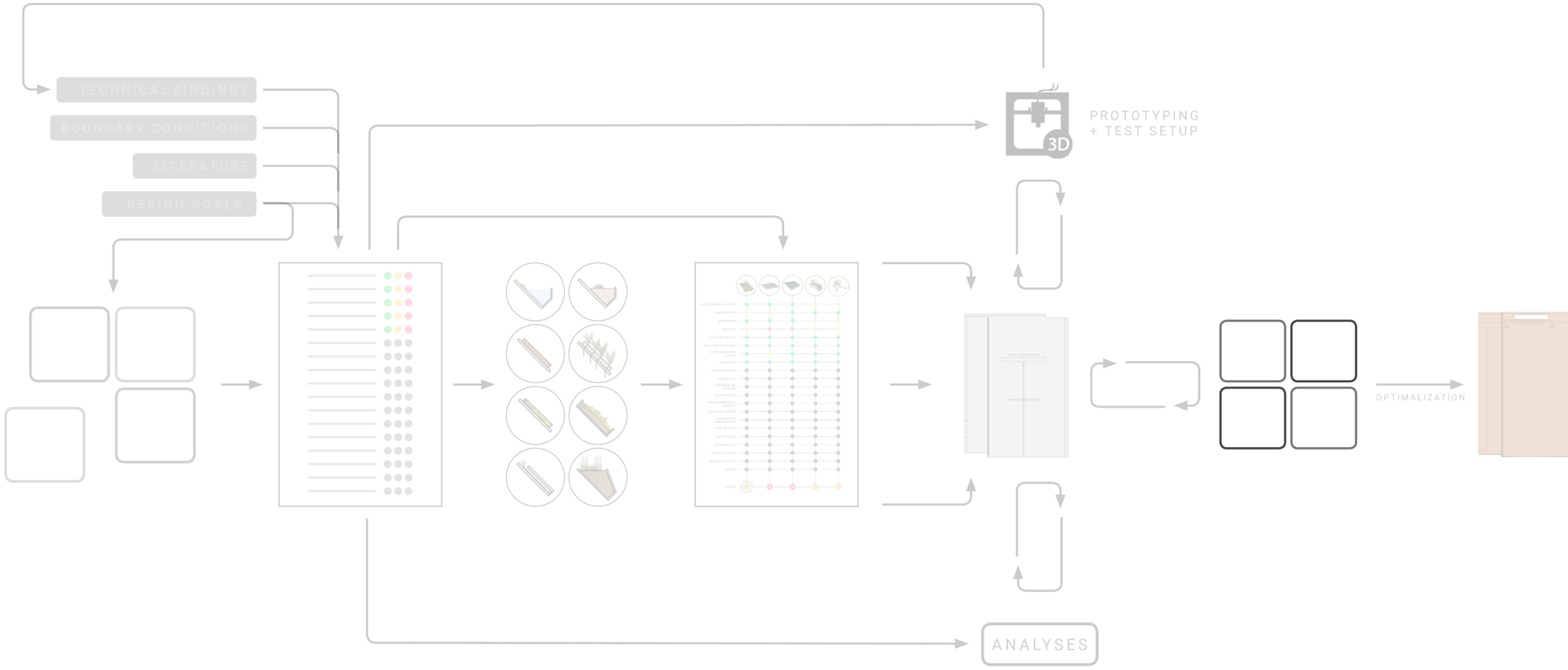

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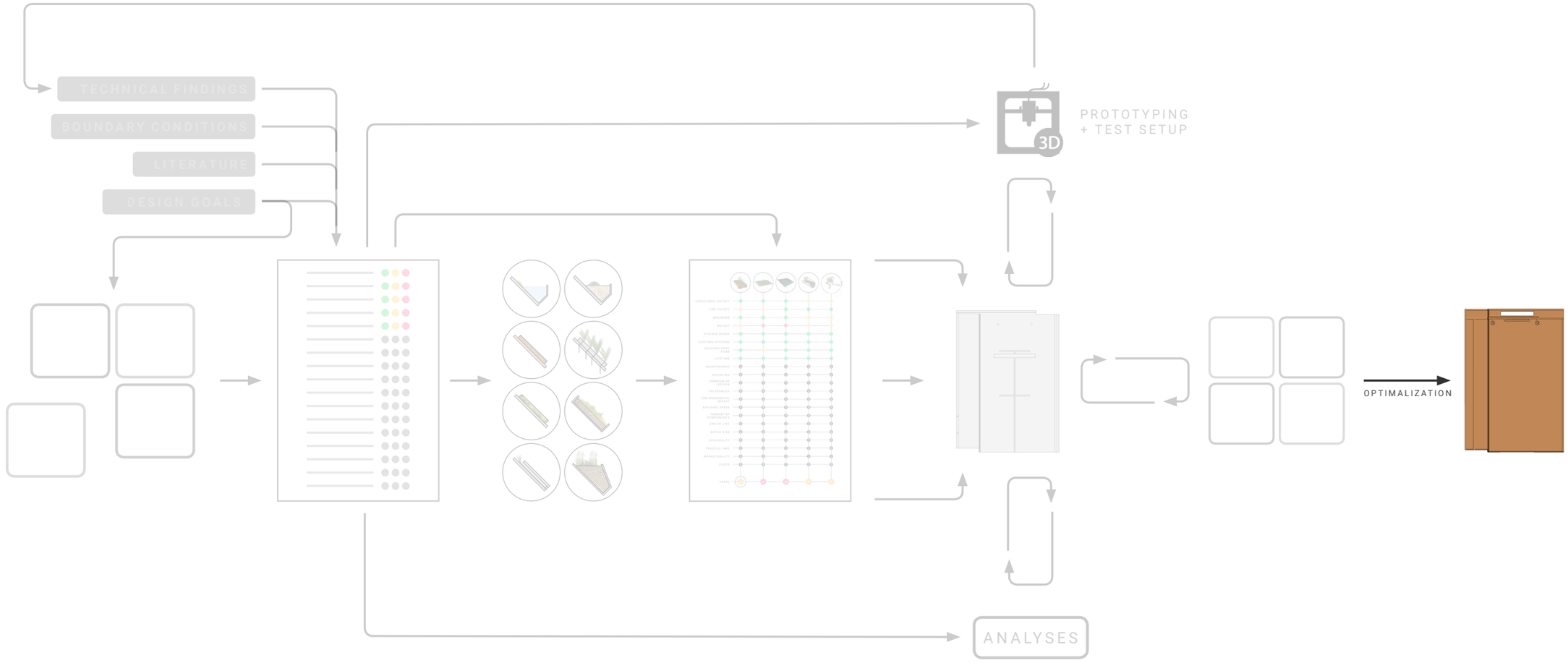

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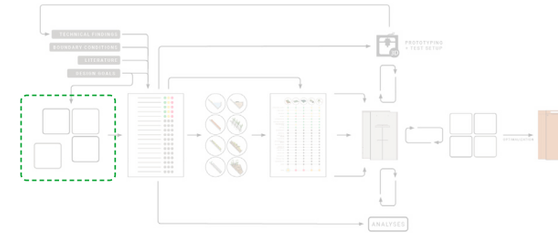
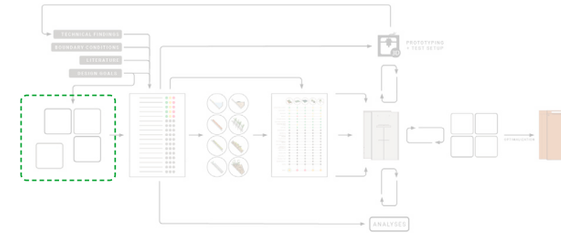
DESIGN OBJECTIVES



BIODIVERSITY

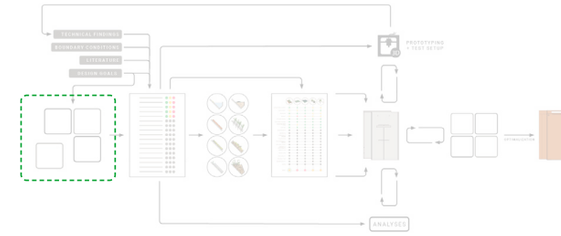
DESIGN OBJECTIVES

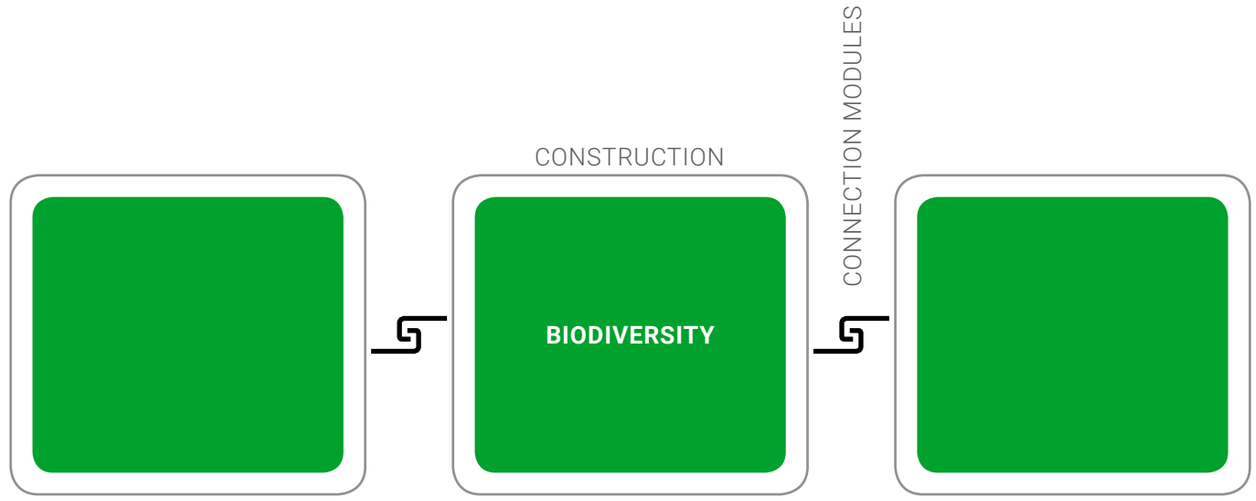


CONSTRUCTION

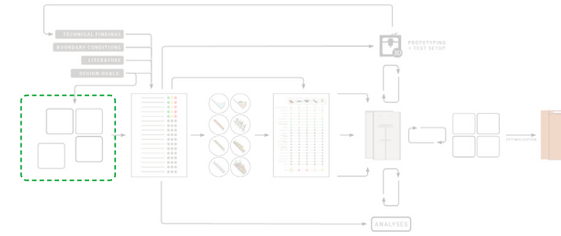
BIODIVERSITY

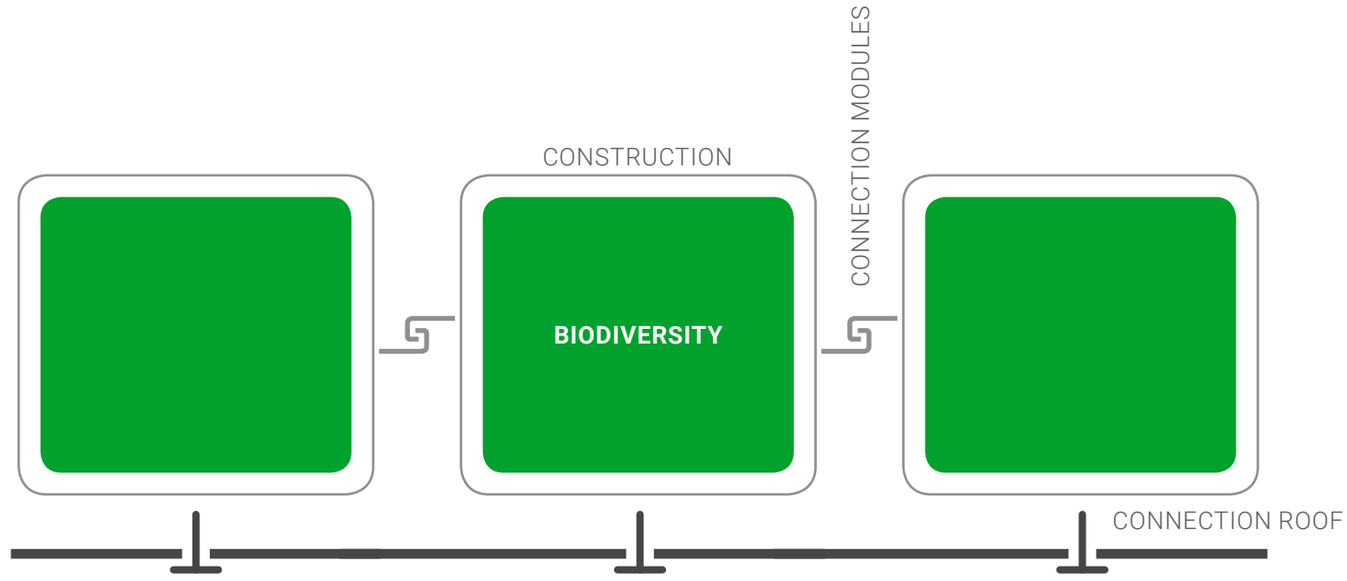
DESIGN OBJECTIVES





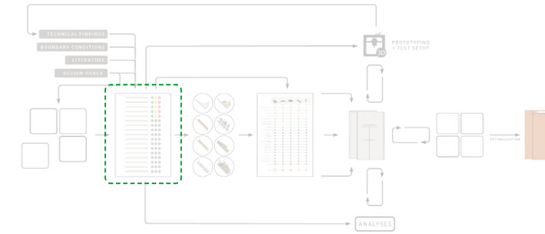
DESIGN OBJECTIVES



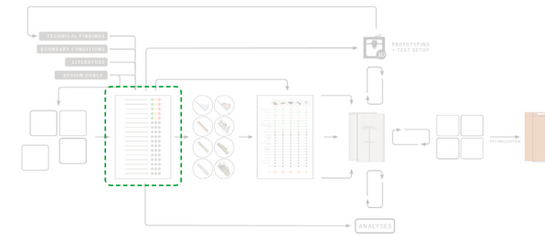


CRITERIA

BOUNDARY CONDITIONS	Structural safety	●●●	Needs to fulfill all national and international standards
	Fire safety	●●●	Needs to fulfill all national and international standards
	Drainage	●●●	Needs to fulfill all national and international standards
	Weight	●●●	Maximum weight is 10 kg
	Dimensions	●●●	Needs to fit on conventional roof structures
	Pitched roof	●●●	Needs to function on a pitched roof (20-60 degrees)
	Existing systems	●●●	Needs to work together with conventional roof structures
	Existing roof tiles	●●●	Needs to work together with conventional roof tiles
	Lifetime	●●●	Needs to function for at least 10 years
BIODIVERSITY	Gradient	●●●	Create gradients
	Diversity	●●●	Create diverse opportunities
	Opportunities	●●●	Create opportunities and let nature do most of the work
	Native Flora and Fauna	●●●	Focus on native Flora and Fauna
	Impact	●●●	Create maximum impact
USE	Adaptability	●●	Can product adapt in case of changes
	Maintenance	●●	Minimize necessity of maintenance
DESIGN QUALITY	Aesthetics	●●●	The look and feel of product
	Freedom of design	●	Can design adapt for future needs?
	Tolerance	●	Minimize strict tolerances
	Cooling effect	●●	Optimize cooling effect of product
	Water storage	●●	Optimize water storage of product
	Acoustics	●	Optimize damping effect of product
	Air filtration	●	Optimize air filtration of product
MATERIAL	Environmental impact	●●	Minimize environmental impact
ASSEMBLY	Building speed	●	Minimize building time
	Number of components	●	Minimize number of components
	Replacing module	●●	Is it possible to repace a individual module?
	End of life	●●	What happens at end of product life?
PRODUCTION	Batch size	●	Is a big batch size possible?
	Scalability	●●	Is it possible to scale up production?
	Process time	●●	Minimize production time
COSTS	Overall costs	●●	Aim for economical feasible product
	Marketability	●●	Aim for saleable product

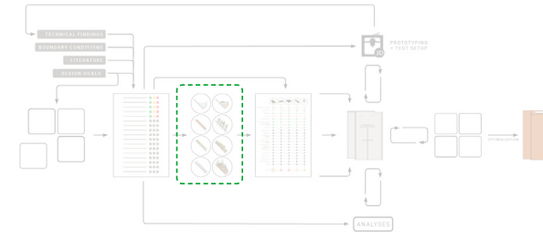


CRITERIA



TOPIC	CRITERION	WEIGHT	EXPLANATION
DESIGN QUALITY	Aesthetics	●●●	The look and feel of product
	Freedom of design	●	Can design adapt for future needs?
	Tolerance	●	Minimize strict tolerances
	Cooling effect	●●	Optimize cooling effect of product
	Water storage	●●	Optimize water storage of product
	Acoustics	●	Optimize damping effect of product
	Air filtration	●	Optimize air filtration of product

CONCEPTS



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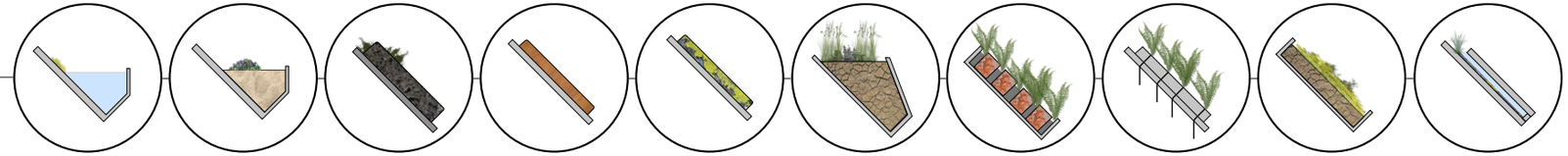

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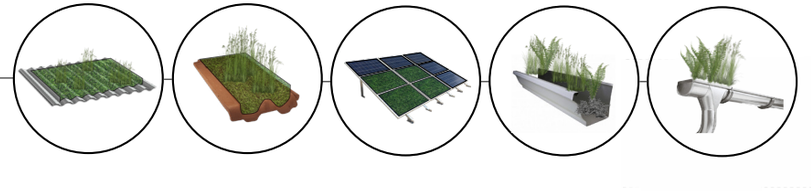

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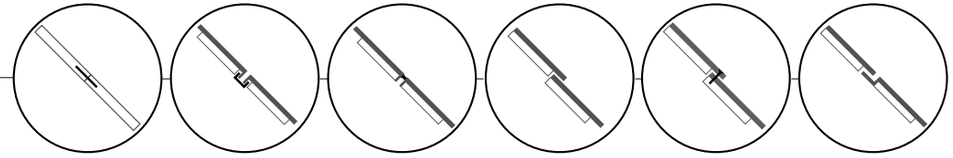
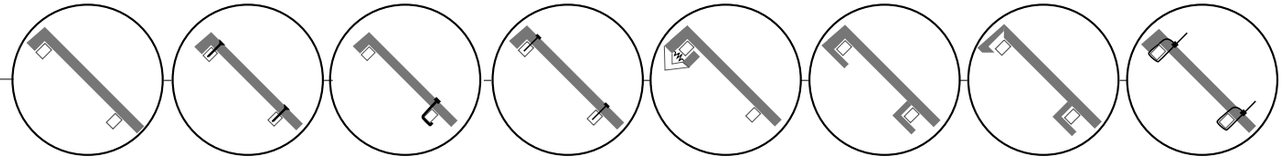
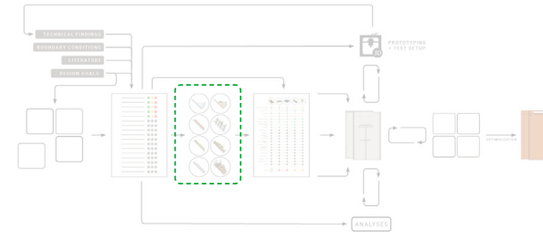


RS



CONCEPTS



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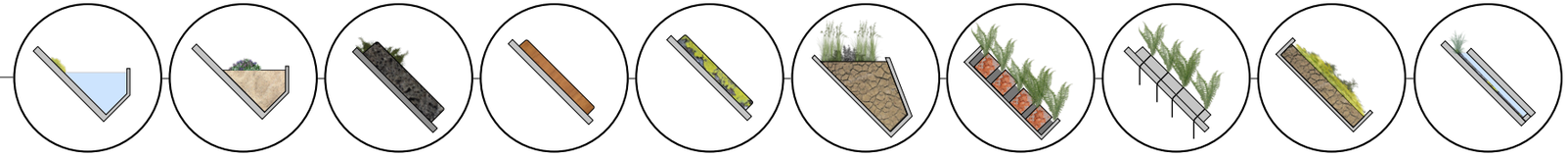

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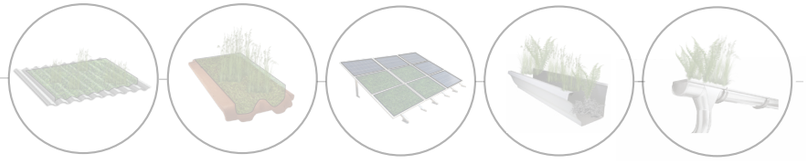

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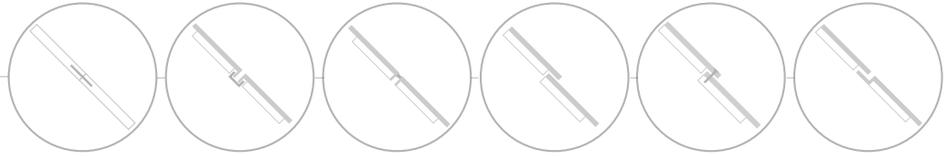

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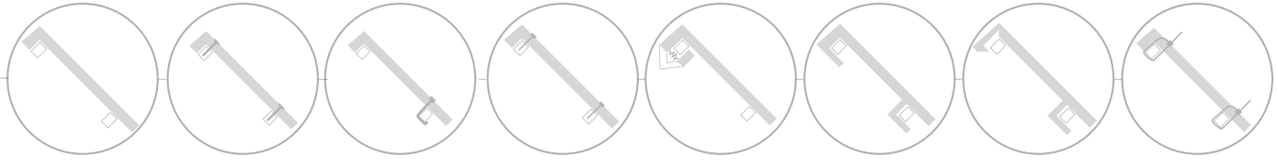
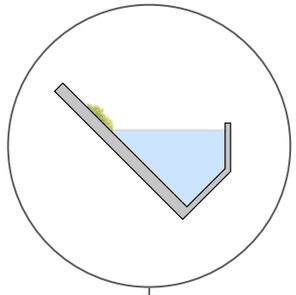
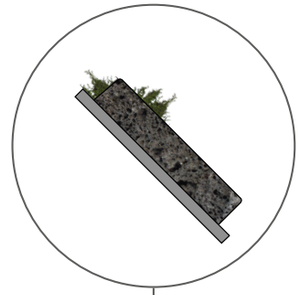




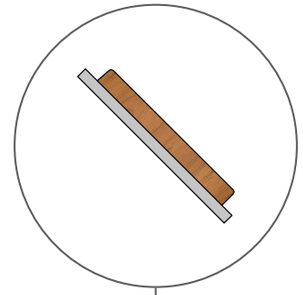
WATER BOWL

- Creates a variety of life
- Will dry out during a hot summer
- Mosquitos close to people



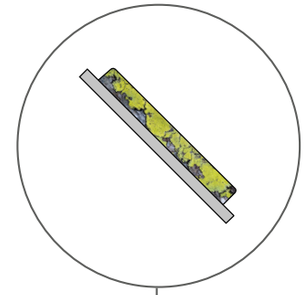
POROUS STONE

- Creates opportunities
- Creates a chaotic roof
- Will insects and plants move to a roof?



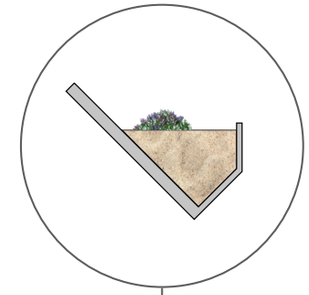
WOOD

- Creates diverse life on a roof
- How does a wooden roof look like after a few years?



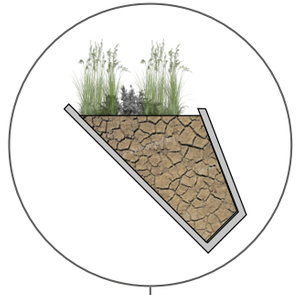
LICHENS STONE

- Creates a colourful roof in patterns
- Creates a basis for other species to grow



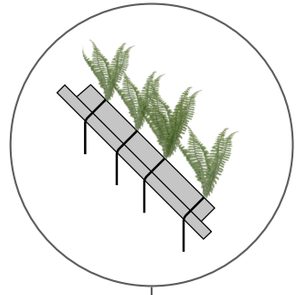
SAND BOWL

- Provides opportunities for nature
- Will insects and plants move to a roof?
- Will wind blow sand away?



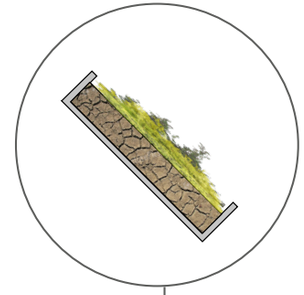
HERBS ROOF

- Significant impact on biodiversity
- Cools and filters air
- Can roof structures hold enough substrate?



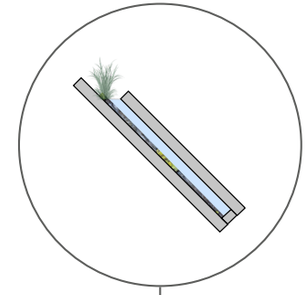
CAVITY

- Making use of other aspects of a roof
- Difficult solution and unknown if it works



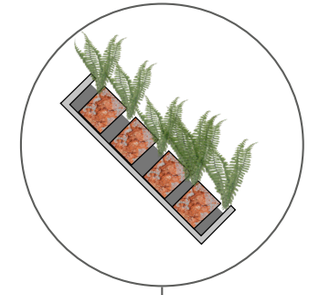
SEDUM ROOF

- Survives extreme conditions
- Green roof with low weight
- Sedum has low biodiversity impact



ENVELOPE

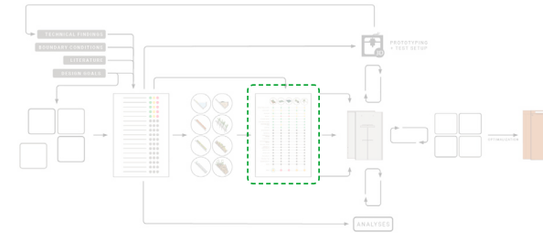
- Improving biodiversity while looks of a roof remain
- Will insects and plants move to a roof?
- Will the envelope not become too hot/dry during summer?

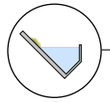
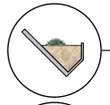


WALL PLANTS

- Creating opportunities for wall plants
- How to stay humid and what is total weight?
- Only suitable for roof orientated north

CONCEPT ANALYSIS



	FIRE SAFETY	WEIGHT	PITCHED ROOFS	DIMENSIONS	LIFETIME	GRADIENTS	DIVERSITY	OPPORTUNITIES	NATIVE FLORA AND FAUNA	IMPACT	ENVIRONEMTAL IMAPCT	END OF LIFE	BATCH SIZE	SCALABILITY	PROCESS TIME	ADAPTABILITY	MAINTENANCE	AESTETICS	FREEDOM OF DESIGN	COOLING EFFECT	WATER STORAGE	ACOUSTICS	AIR FILTRATION	MARKETABILITY	COSTS	TOTAL
						2	2	2	3	1	2	2	3	3	3	1	3	2	2	2	2	1	1	2	2	85
						2	2	3	3	1	2	2	3	3	3	1	3	2	2	2	2	1	1	2	2	88
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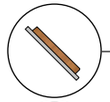
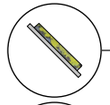
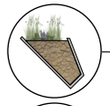
						2	2	3	3	2	3	2	3	3	3	1	3	2	3	2	2	1	1	2	3	98
						2	2	2	3	2	2	1	3	3	3	2	3	3	2	1	2	1	2	2	3	94
						3	3	2	2	3	2	2	3	3	1	3	2	3	2	3	3	3	3	3	2	107
						2	3	2	2	2	2	1	2	3	1	2	2	2	1	2	2	2	3	2	2	85
						2	3	2	2	2	2	2	2	2	1	2	2	2	1	2	2	2	3	2	1	85
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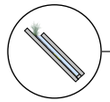
						3	3	3	3	2	2	1	3	3	3	1	3	2	2	1	2	1	2	2	3	98

CREATES GRADIENTS

ADAPTABLE

DIVERSE

SIGNIFICANT IMPACT

COOLING EFFECT

WATER STORAGE

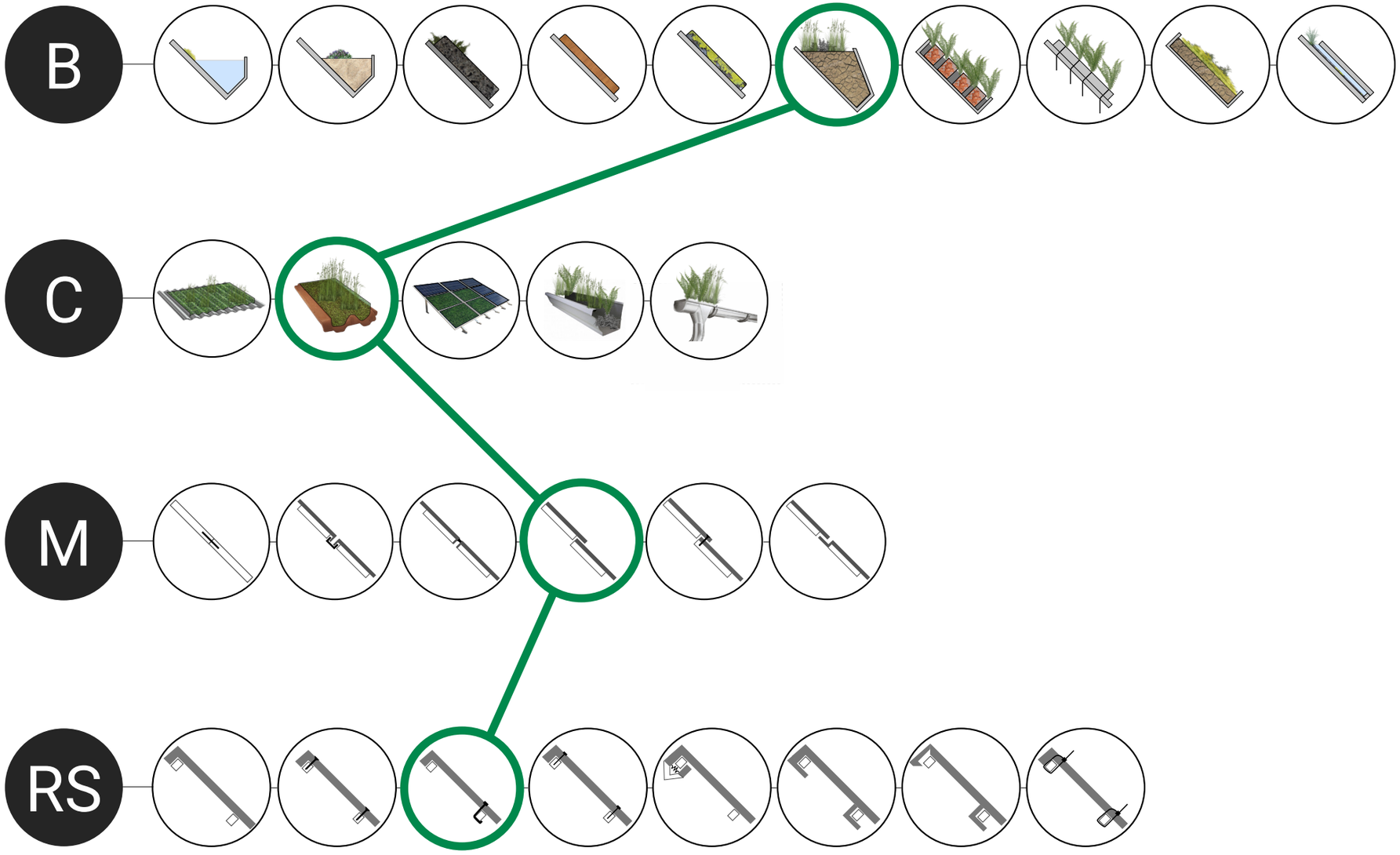
ACOUSTICS

AIR FILTRATION

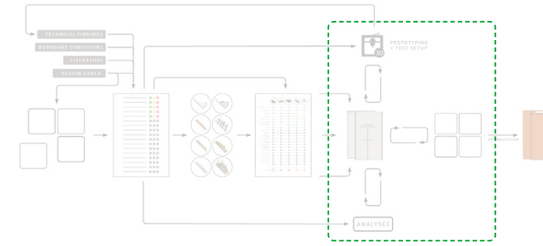
AESTETHICS

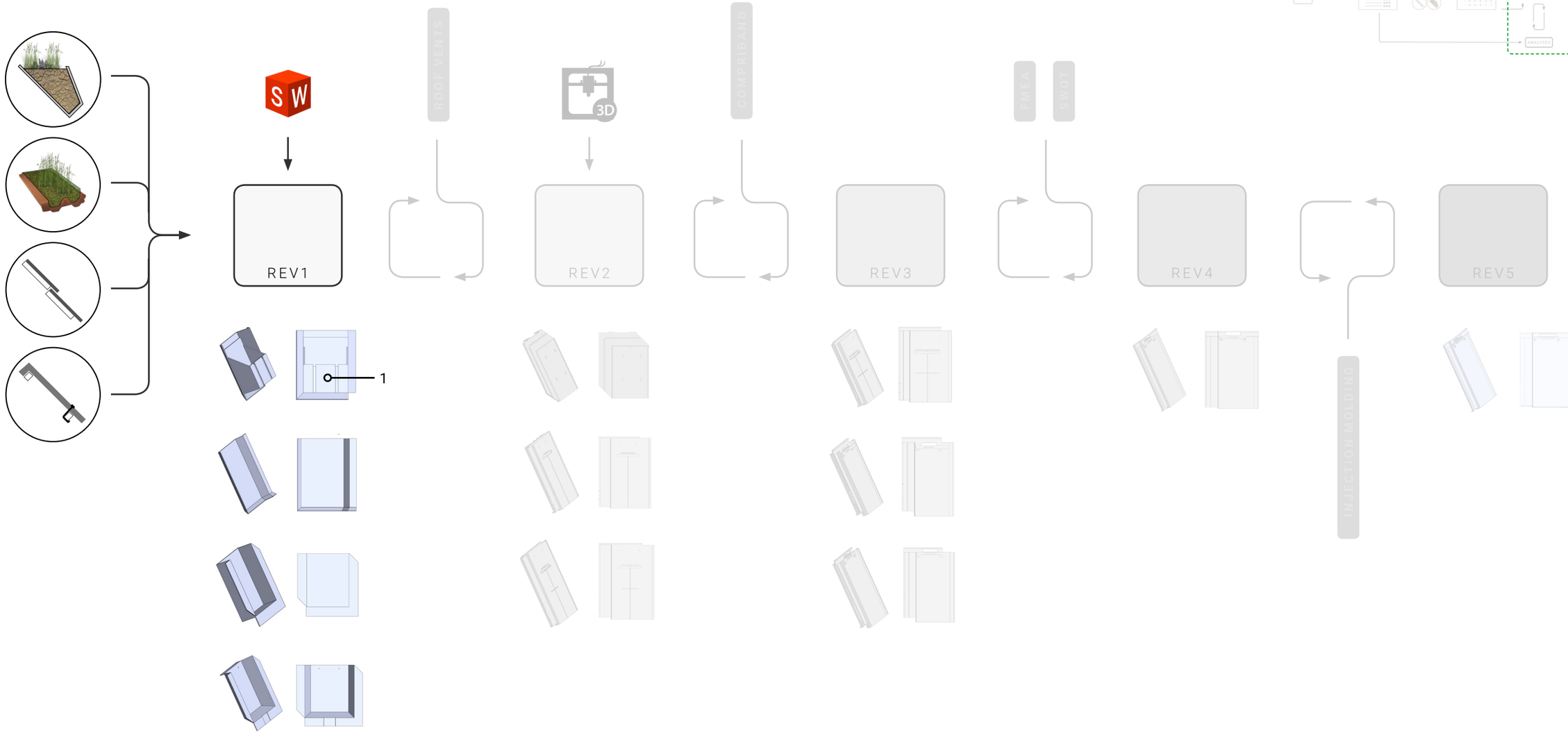
MARKETABILITY

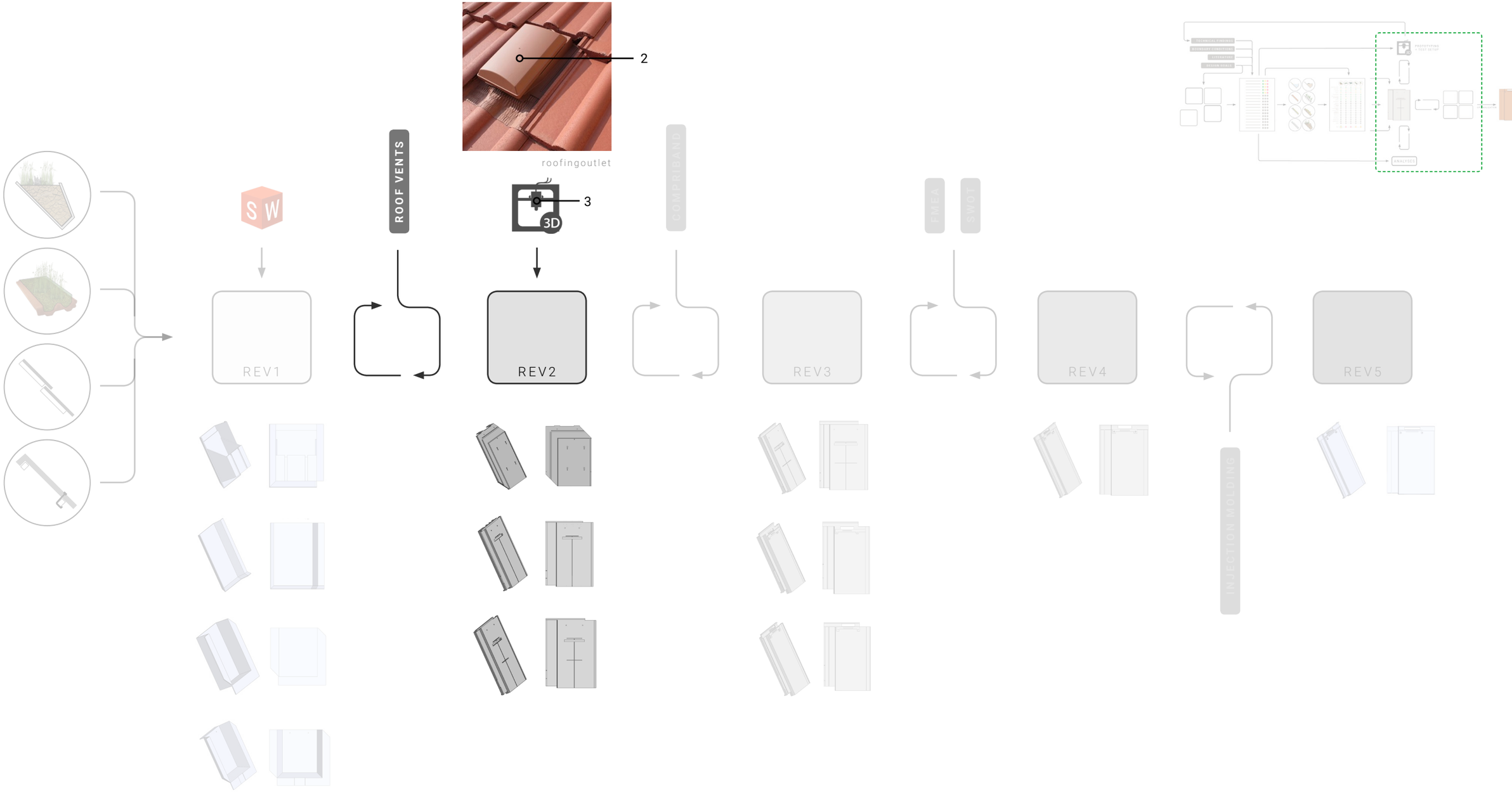
CONCEPT ANALYSIS

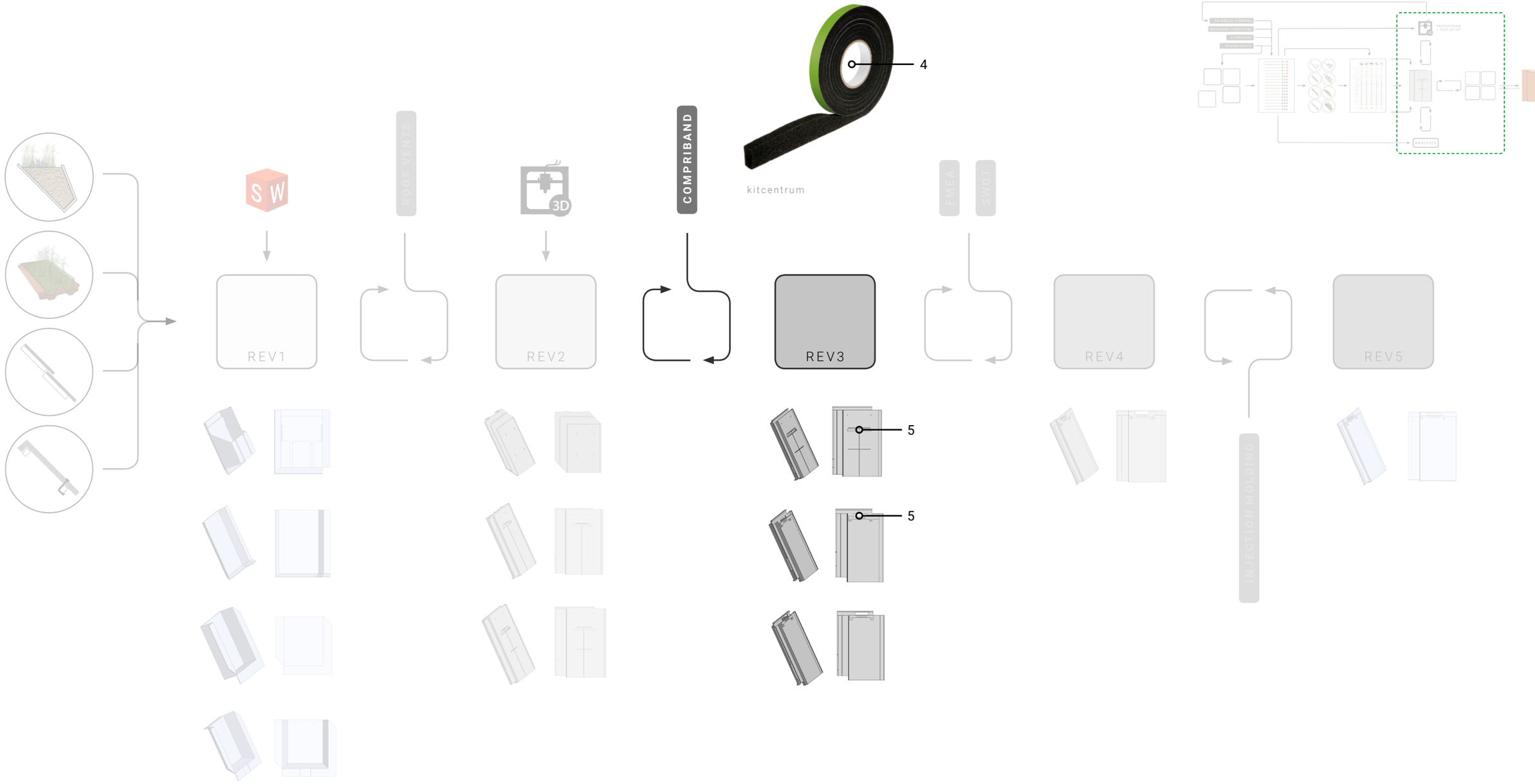


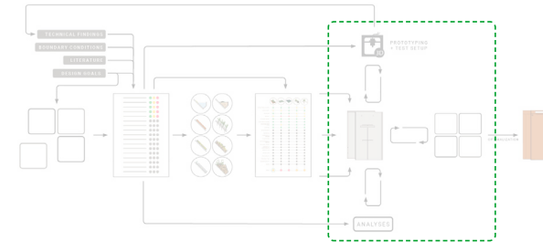
DESIGN DEVELOPMENT

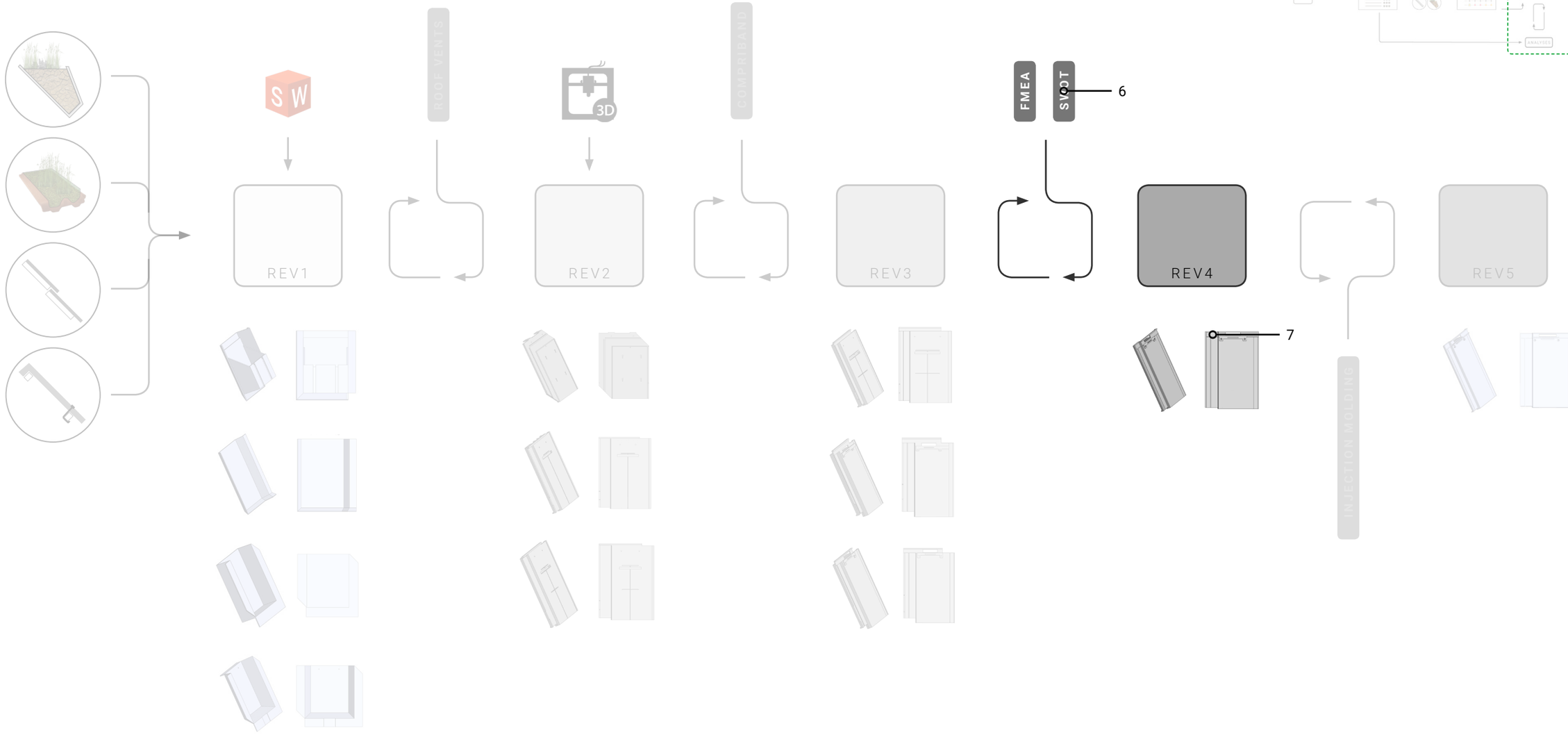


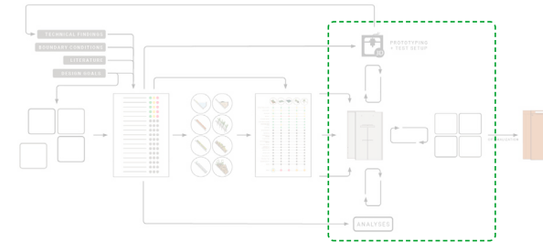

SW
REV1
1
ROOF VENTS
3D
REV2
COMPRIBAND
REV3
FMEA
SWOT
REV4
INJECTION MOLDING
REV5

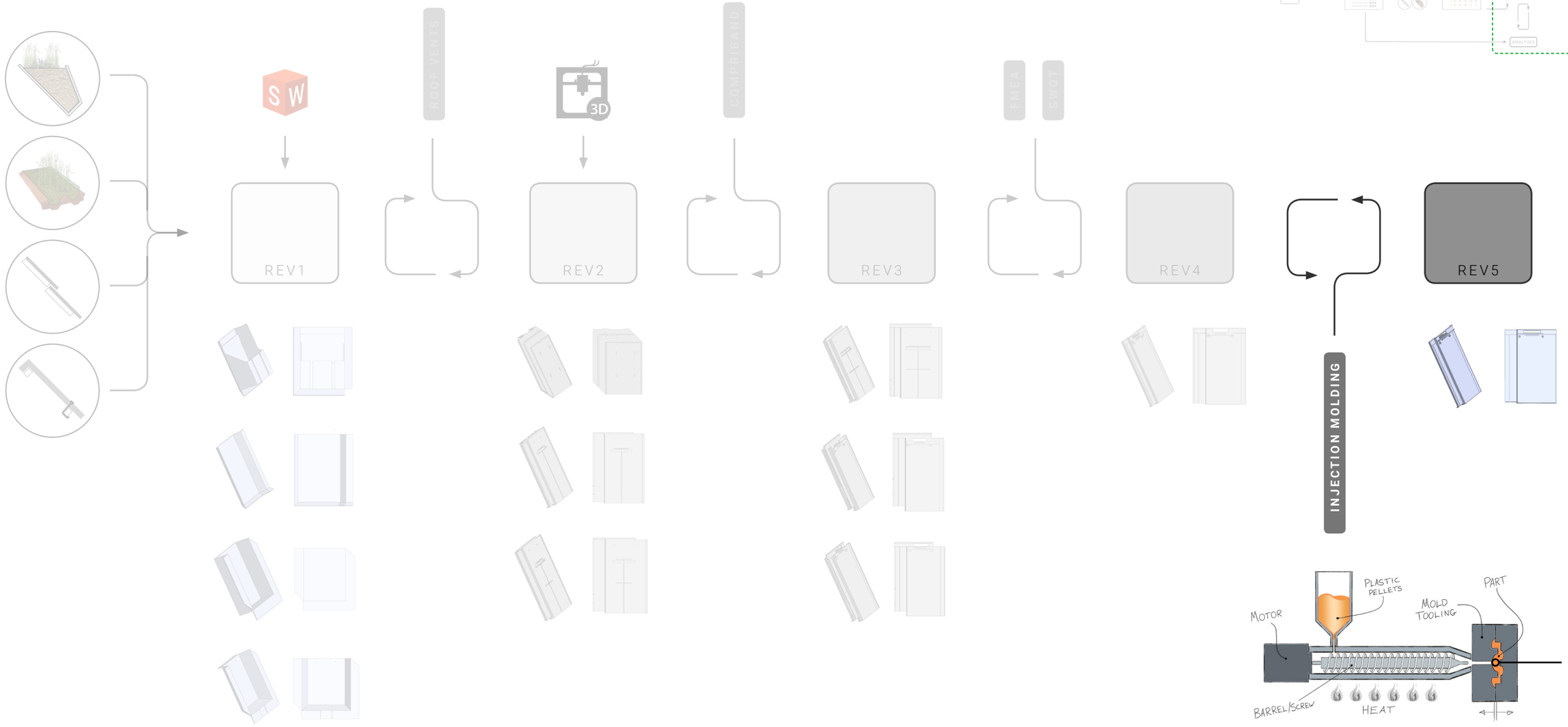

2
roofingoutlet
3
3D
SW
ROOF VENTS
COMPRIBAND
FMEA
SWOT
REV1
REV2
REV3
REV4
REV5
INJECTION MOLDING


SW
ROOF VENTS
3D
COMPRIBAND
kitcentrum
4
FMEA
SWOT
REV1
REV2
REV3
REV4
REV5
5
5
INJECTION MOLDING




SW
ROOF VENTS
3D
COMPRIBAND
FMEA
SWOT
6
REV1
REV2
REV3
REV4
REV5
7
INJECTION MOLDING

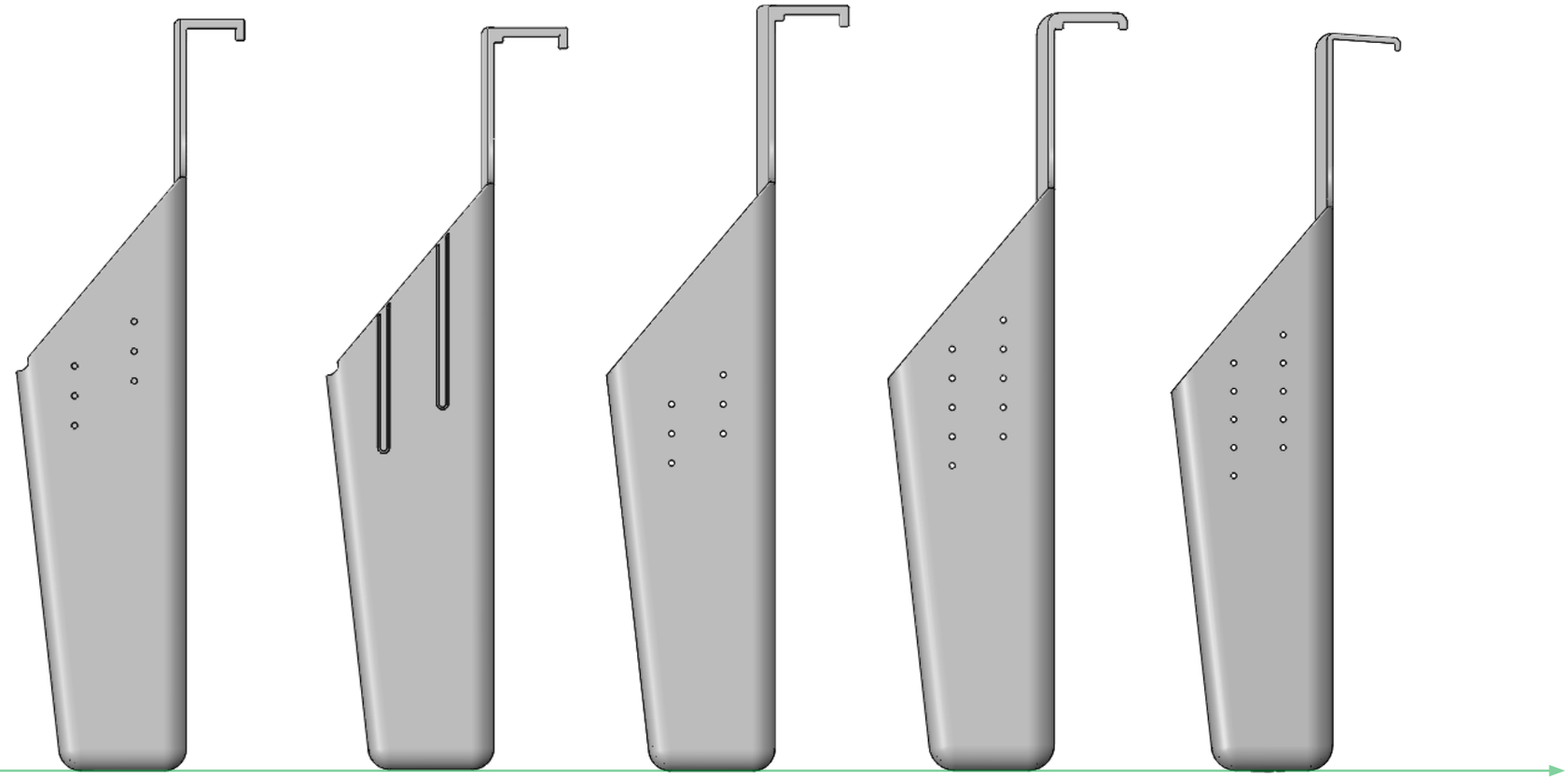



SW
ROOF VENTS
3D
COMPRIBAND
FMEA
SWOT
REV1
REV2
REV3
REV4
REV5
INJECTION MOLDING

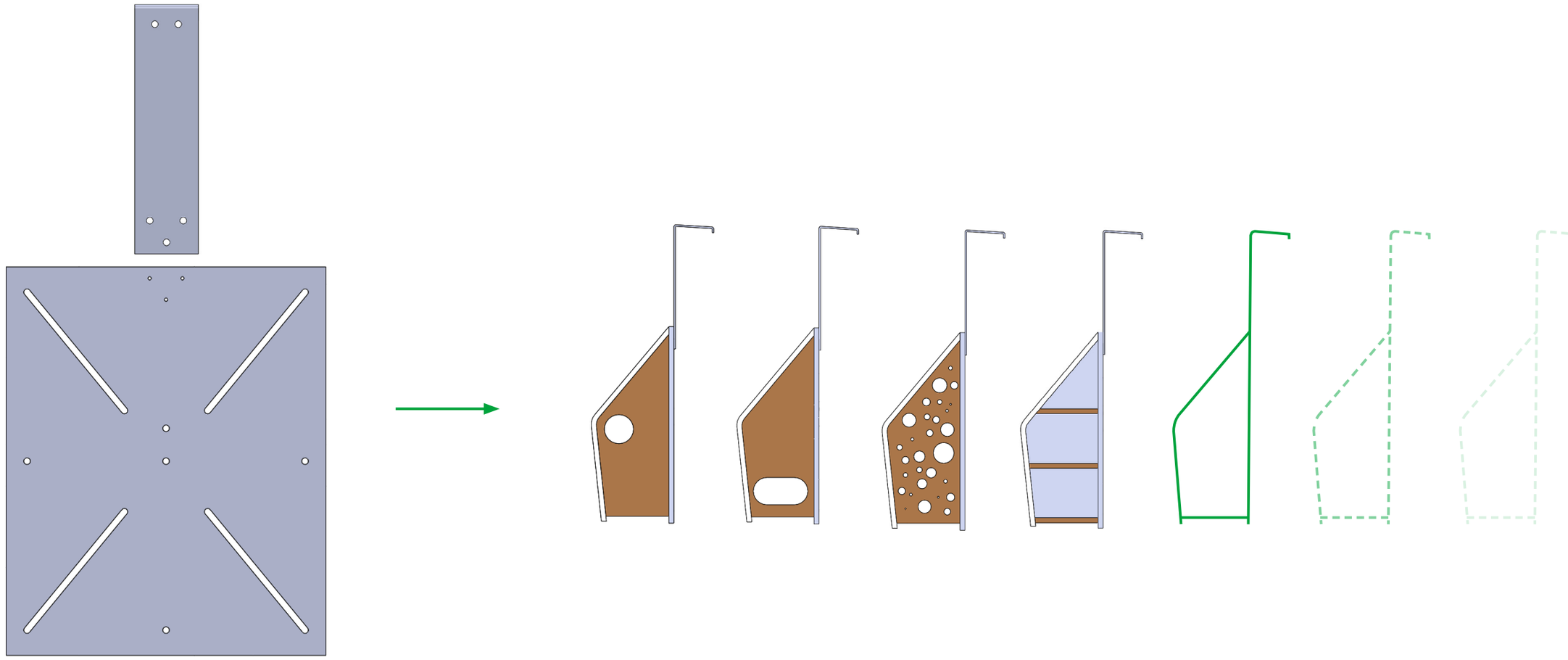
PLASTIC PELLETS
PART
MOLD TOOLING
MOTOR
8
BARREL/SCREW
HEAT


2
HDPE
GRT
337/04
2
HDPE
GRT
337/04
2
HDPE
GRT
337/04

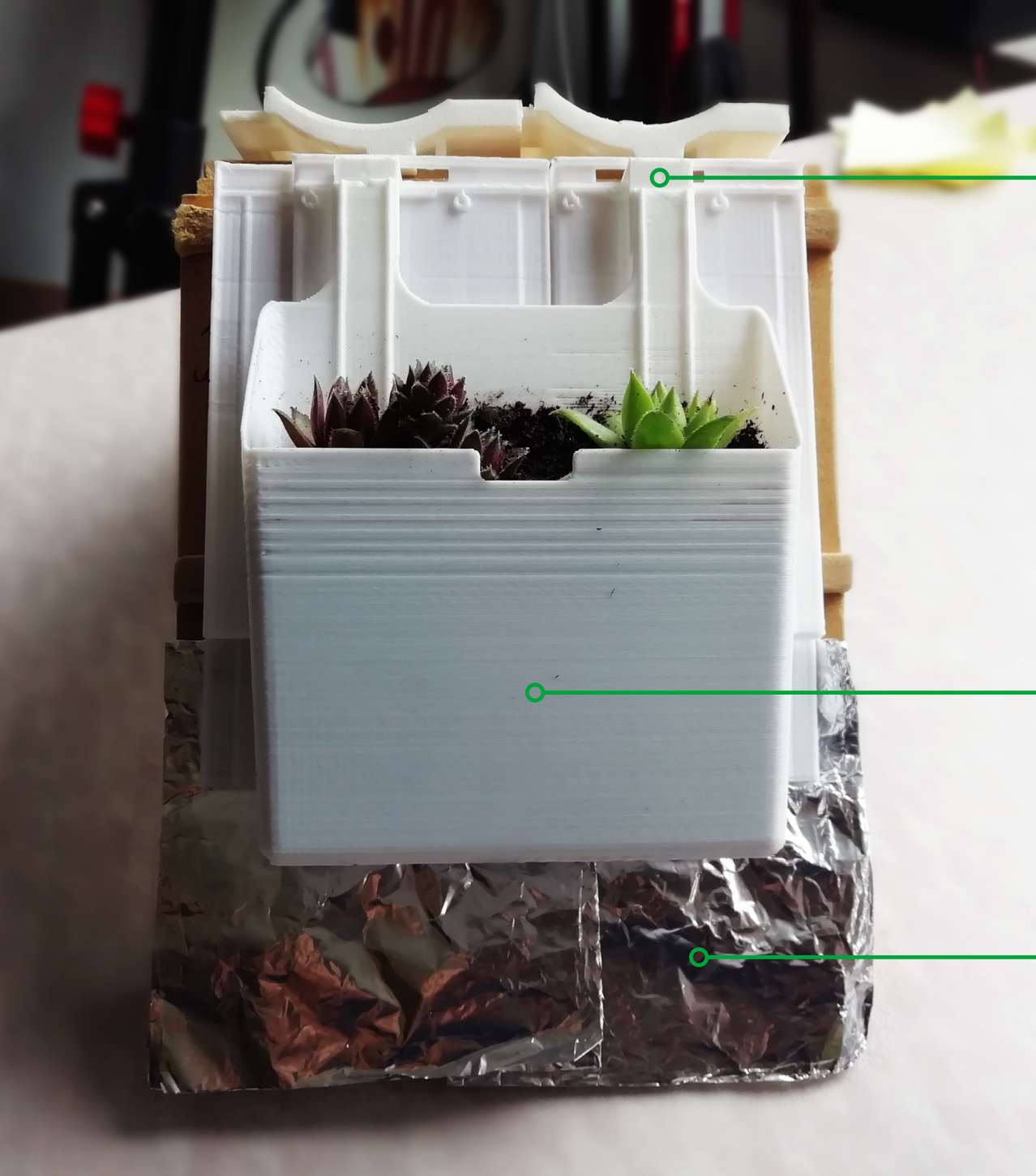
PLANTER

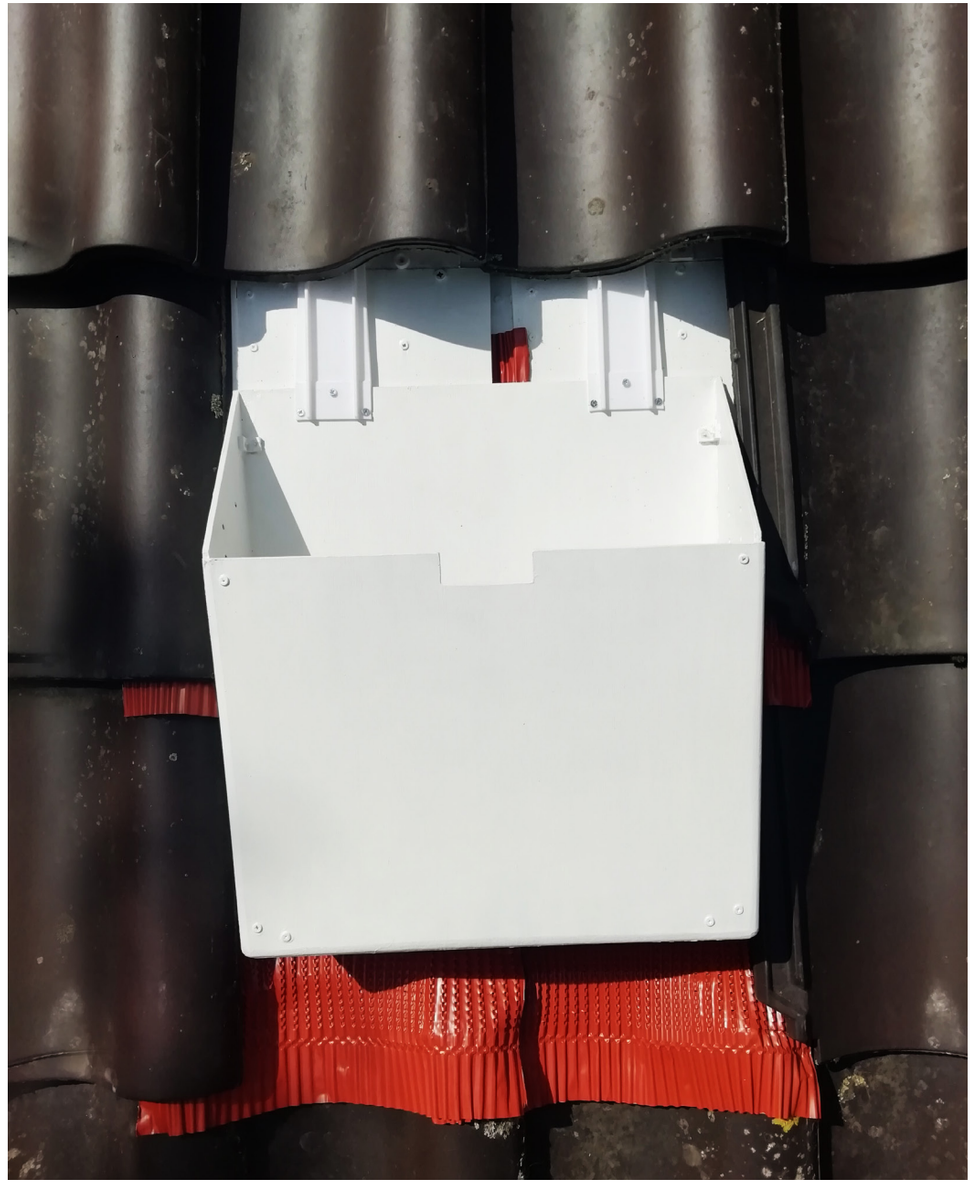


BASEPLATE

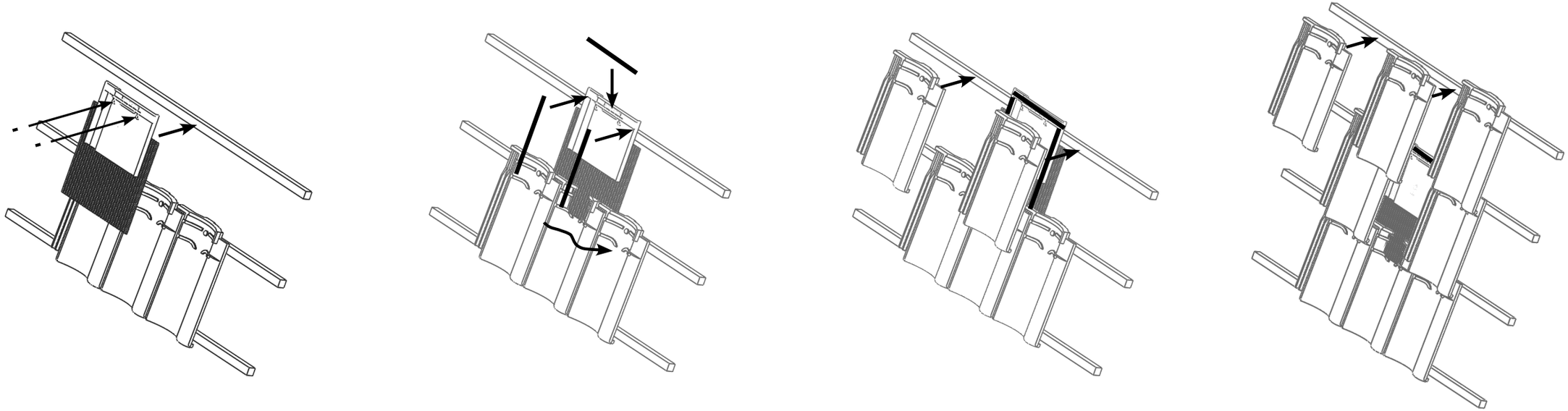


FINAL DESIGN

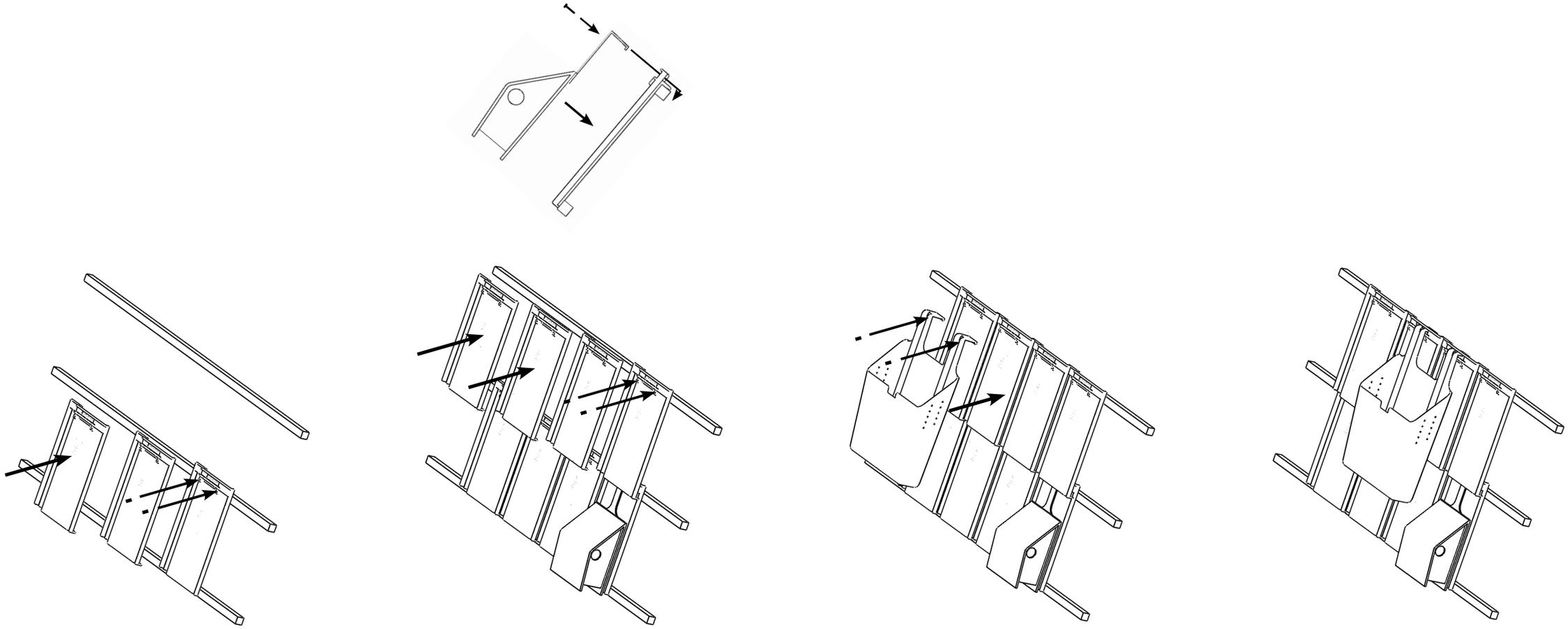

2.
1.
3.



ASSEMBLY SEQUENCE



ASSEMBLY SEQUENCE



IMPLEMENTATION

ROOF TILE	€19.95
SIDEPLATE	€19.95
PLANTER	€29.95
BREEDING BOX	€24.95
INSECT HOTEL	€24.95

IMPLEMENTATION

ROOF TILE — €19.95

23.95

SIDEPLATE — €19.95

PLANTER — €29.95

BREEDING BOX — €24.95

24.95

INSECT HOTEL — €24.95

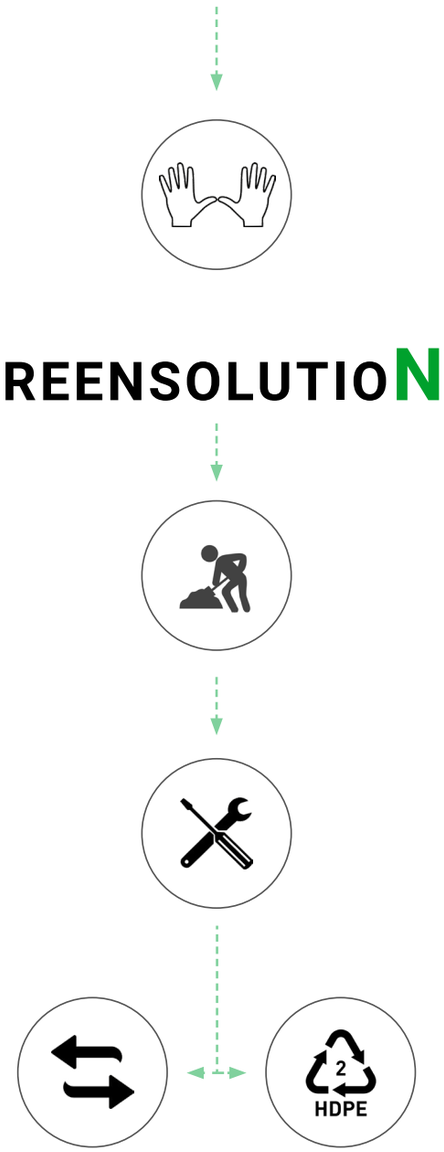
23.99

debouwmarktshop, Faunaprojecten, Intratuin

CUSTOMER

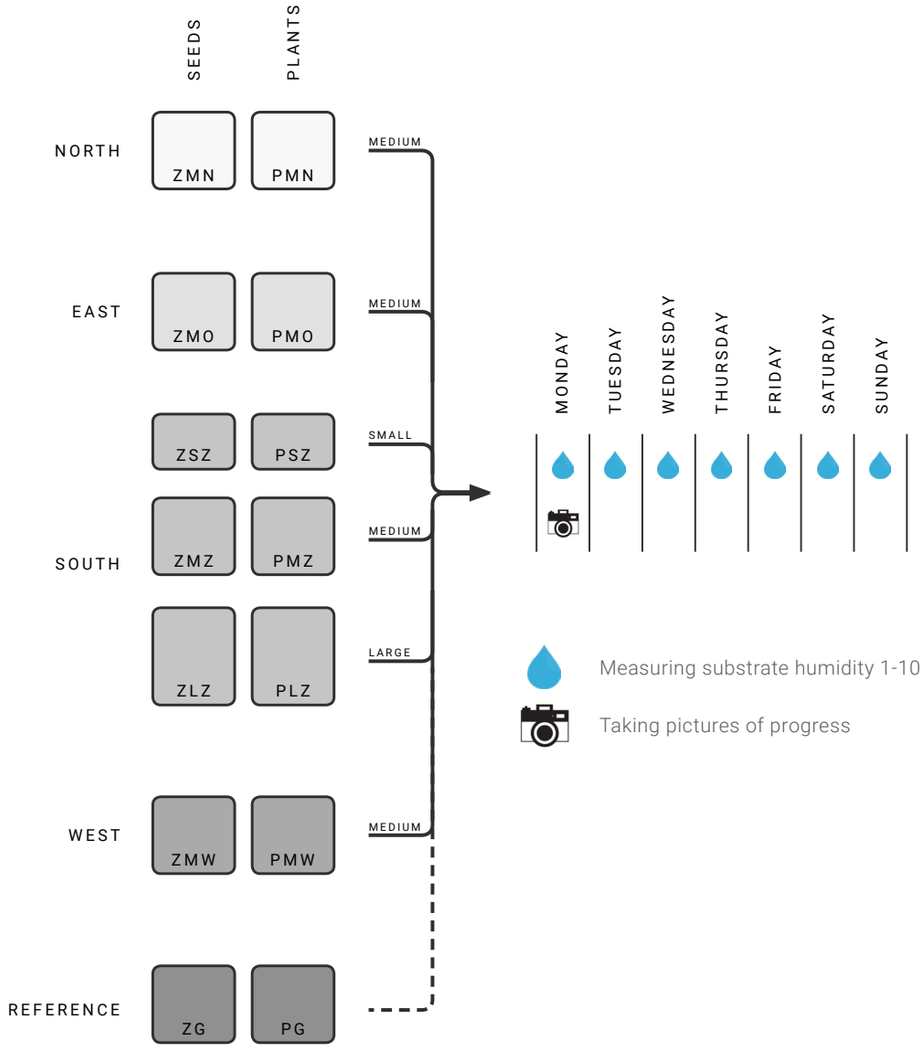
CUSTOMER

GREENSOLUTION™



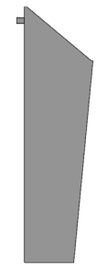
TEST SETUP

TEST SETUP

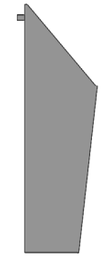


Measuring substrate humidity 1-10

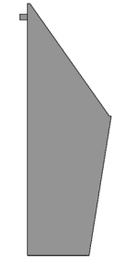
Taking pictures of progress



Small
4.47 dm2 | 9.4 dm3
1:2.1

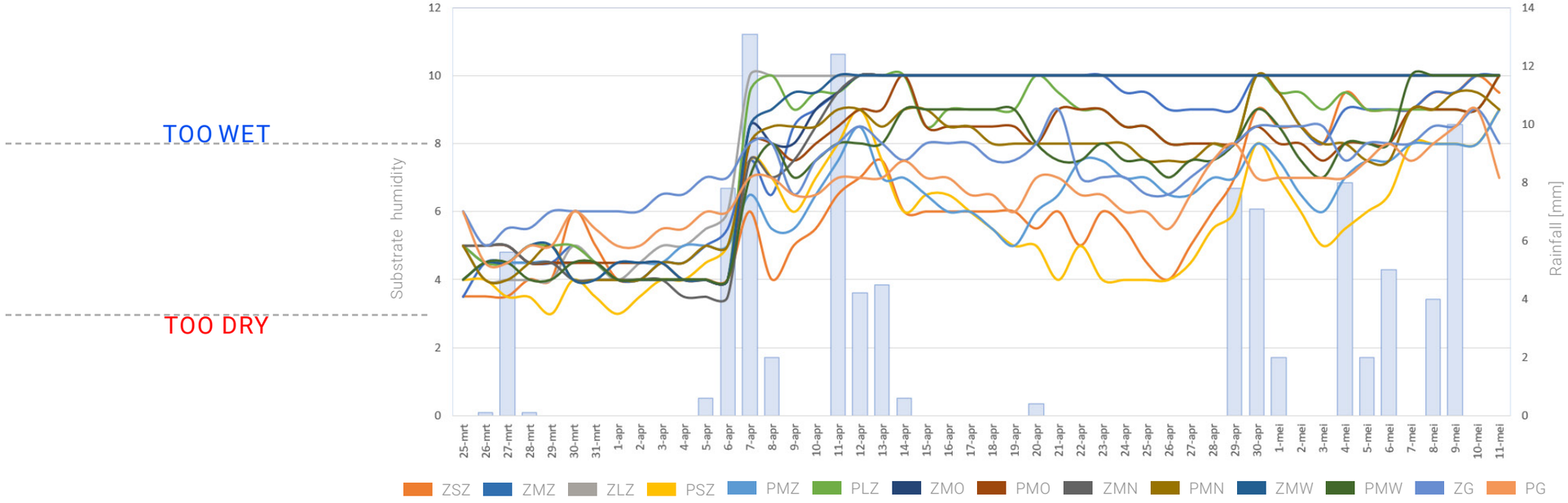


Medium
5.85 dm2 | 9.4 dm3
1:1.6

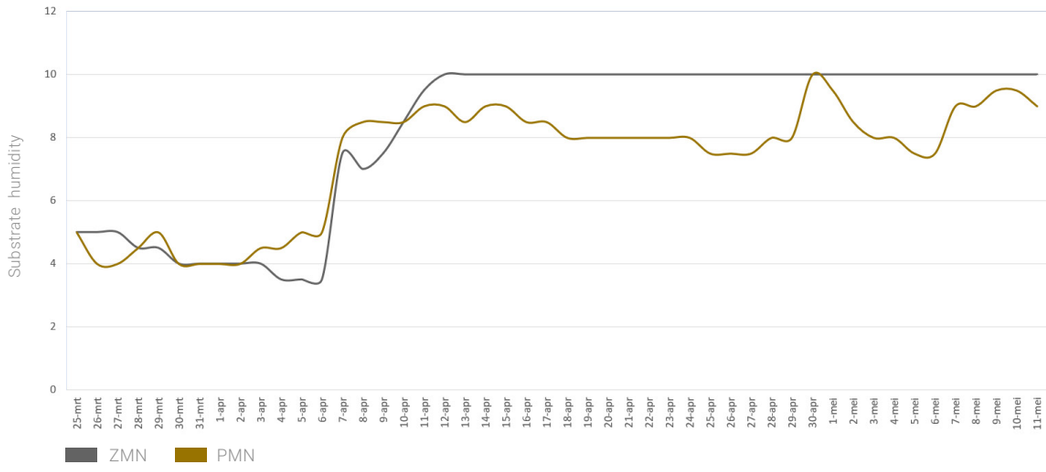


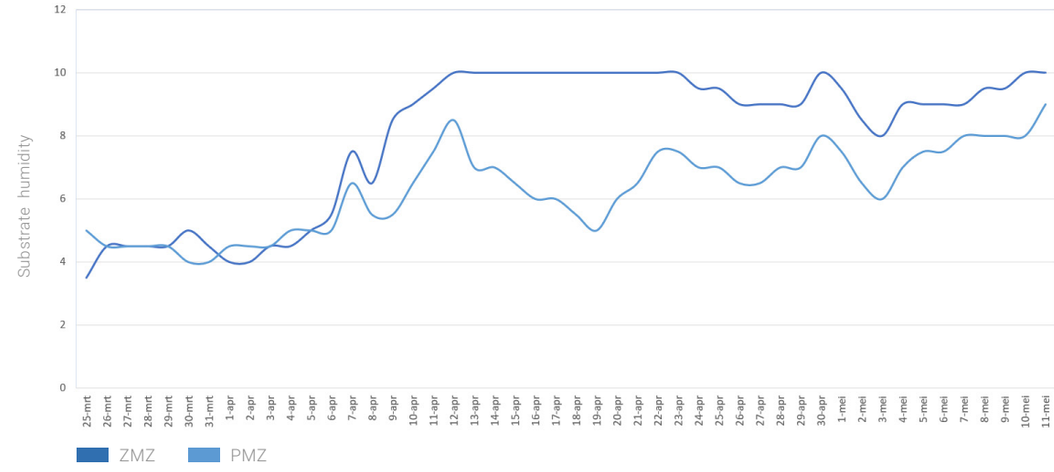
Large
7.47 dm2 | 9.4 dm3
1:1.3

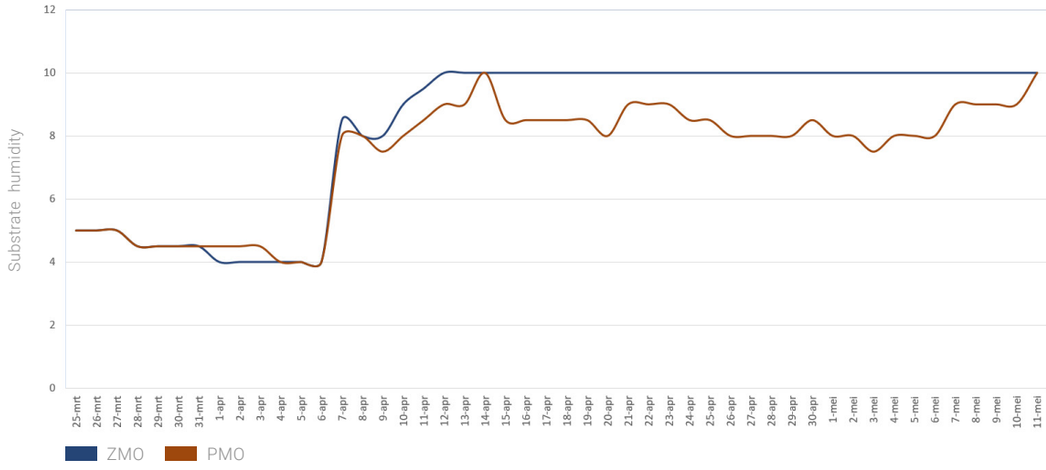
RESULTS

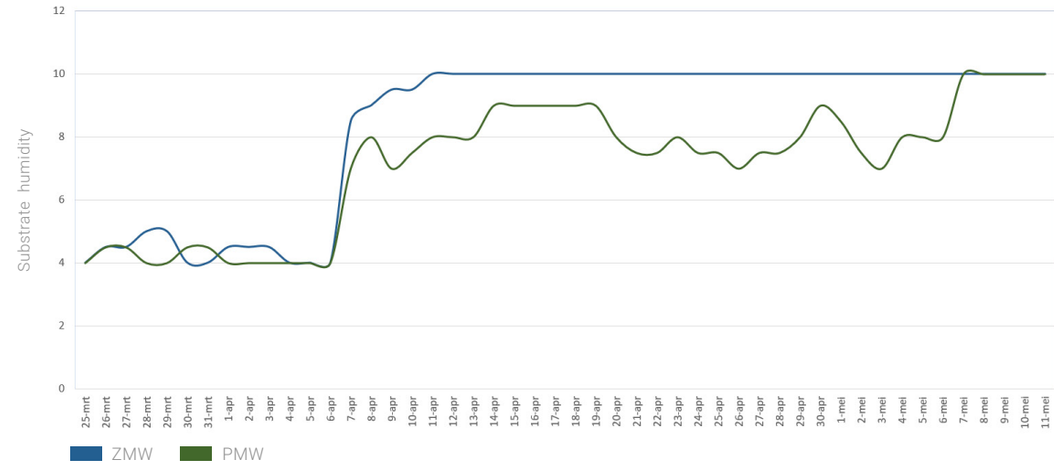

TOO WET
TOO DRY
Substrate humidity
Rainfall [mm]
0
2
4
6
8
10
12
14
25-mrt
26-mrt
27-mrt
28-mrt
29-mrt
30-mrt
31-mrt
1-apr
2-apr
3-apr
4-apr
5-apr
6-apr
7-apr
8-apr
9-apr
10-apr
11-apr
12-apr
13-apr
14-apr
15-apr
16-apr
17-apr
18-apr
19-apr
20-apr
21-apr
22-apr
23-apr
24-apr
25-apr
26-apr
27-apr
28-apr
29-apr
30-apr
1-mei
2-mei
3-mei
4-mei
5-mei
6-mei
7-mei
8-mei
9-mei
10-mei
11-mei
ZSZ
ZMZ
ZLZ
PSZ
PMZ
PLZ
ZMO
PMO
ZMN
PMN
ZMW
PMW
ZG
PG

ORIENTATION

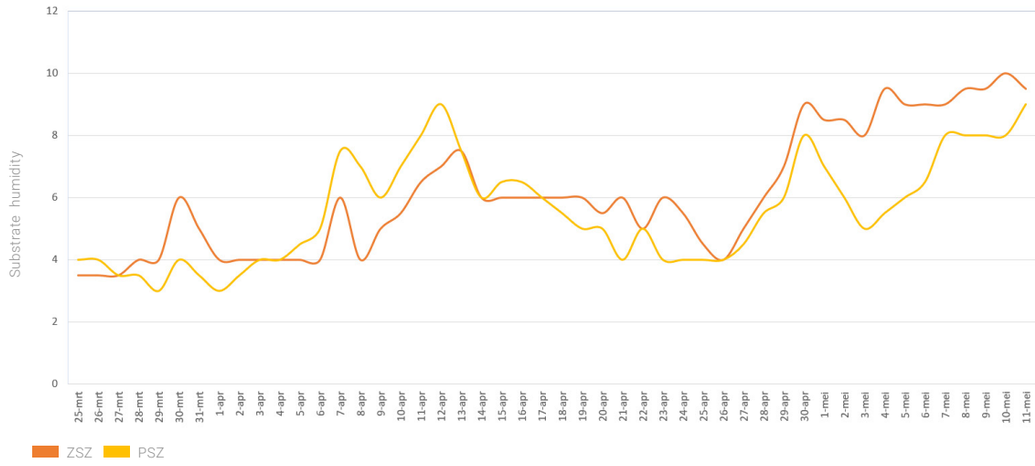


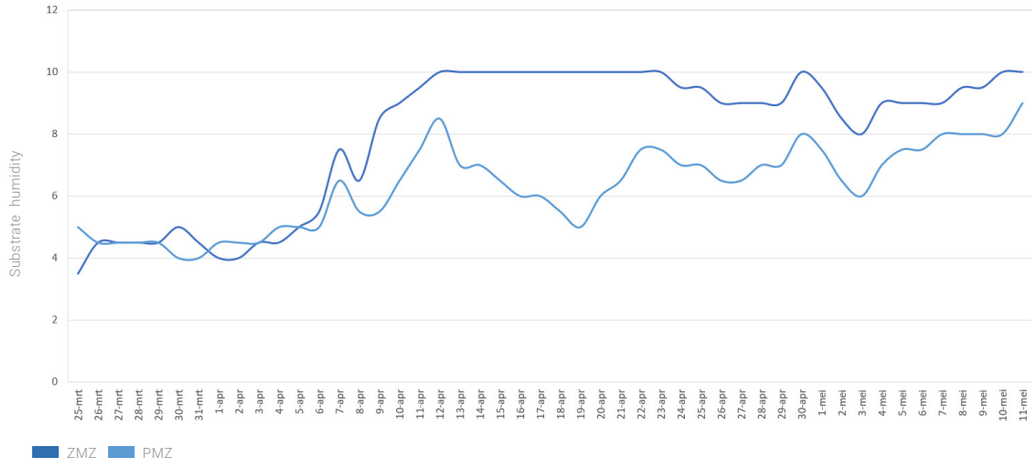


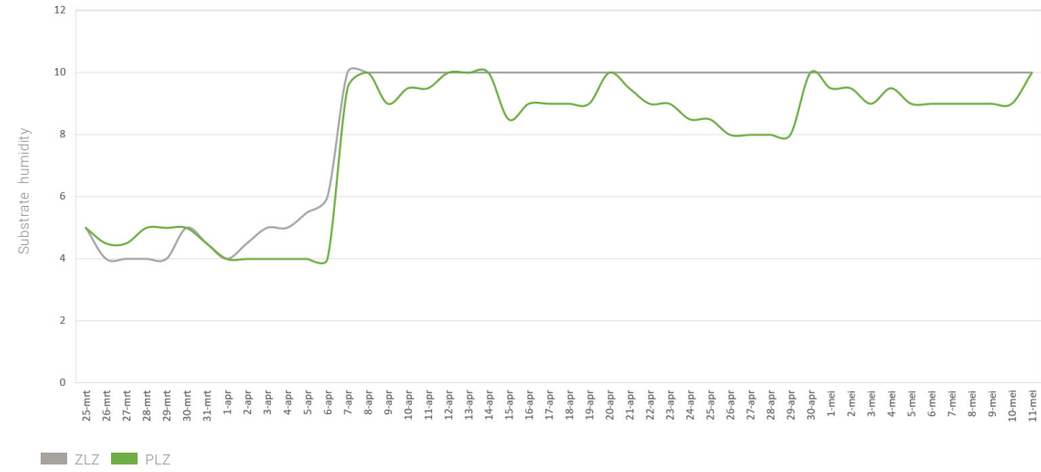


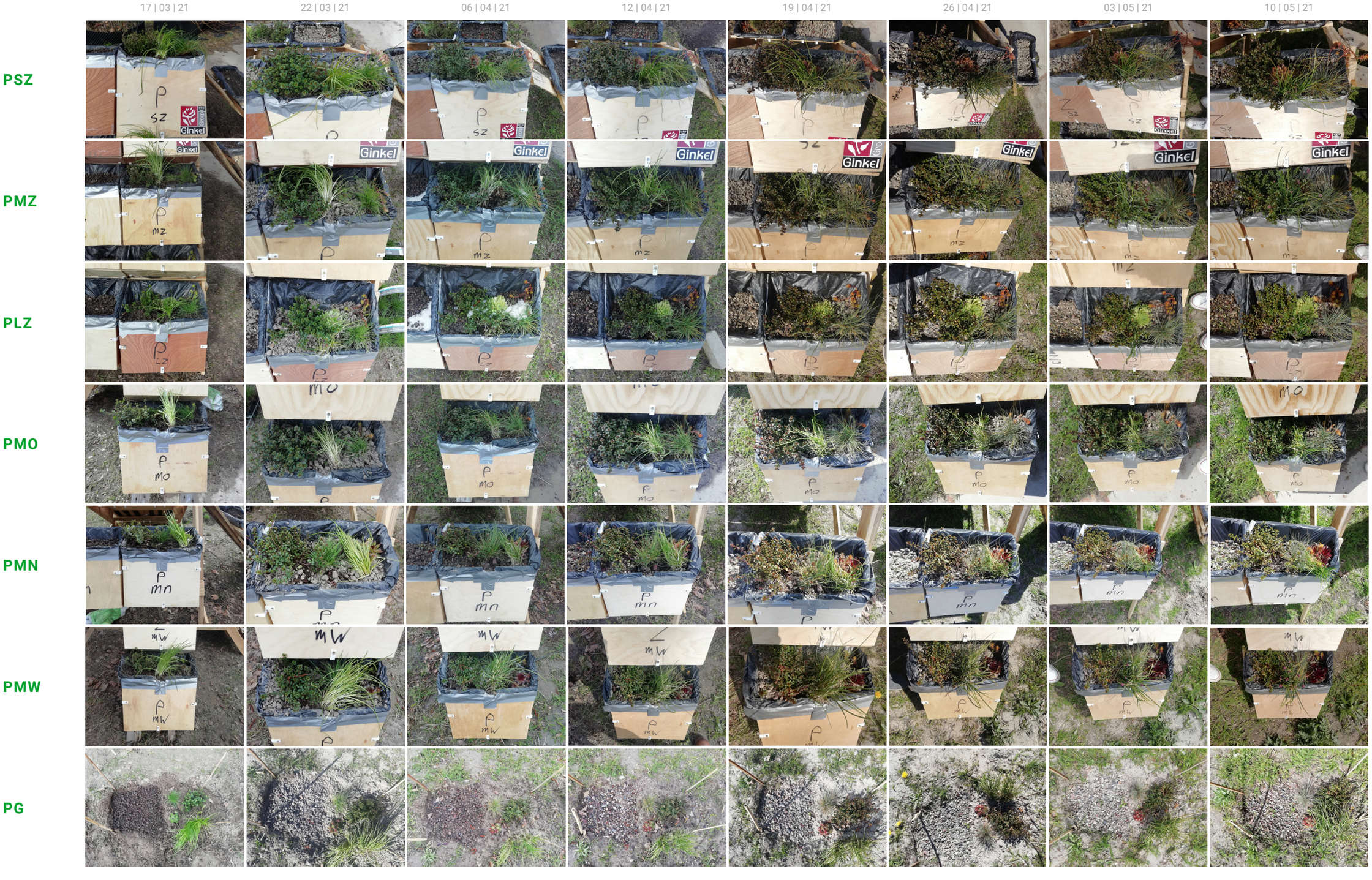


VOLUME/SURFACE RATIO








17 | 03 | 21
22 | 03 | 21
06 | 04 | 21
12 | 04 | 21
19 | 04 | 21
26 | 04 | 21
03 | 05 | 21
10 | 05 | 21
PSZ
PMZ
PLZ
PMO
PMN
PMW
PG

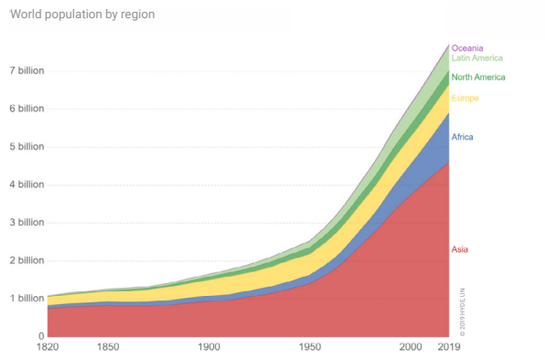

Ginkel

DRY

WET

SHADOW

CONCLUSION



1 miljoen woningen nodig tot 2030

Volgens prognoses van ABF Research worden er in Nederland tot 2030 een miljoen woningen gevraagd. Hoeveel van deze nieuwbouwwoningen kunnen we redelijkerwijs in bestaand gebied bouwen? Hoeveel transformatieruimte is er in de bestaande stad?

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Verdichten én vergroenen: 1 miljoen nieuwe woningen klimaatbestendig bouwen

Gepubliceerd 30 juli 2019

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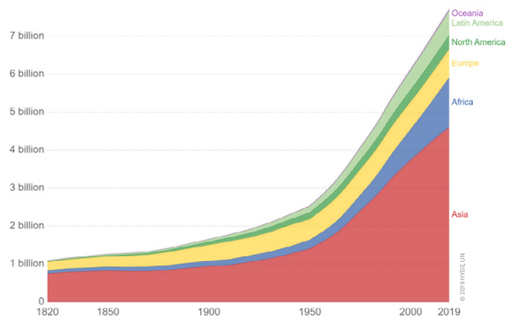
World population by region



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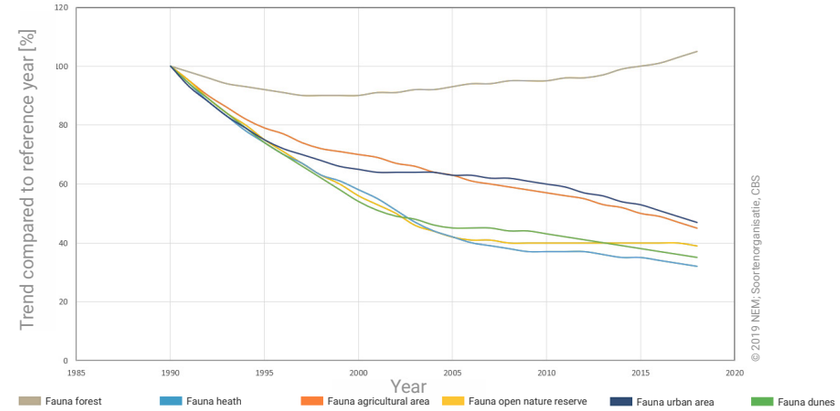
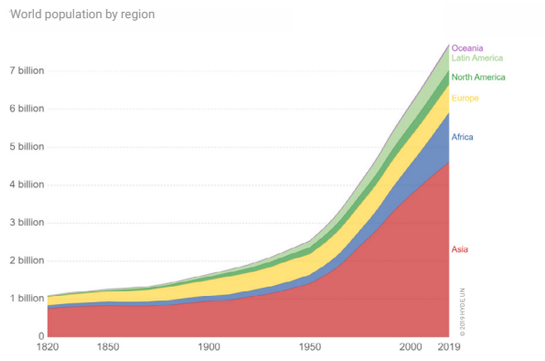
Trend fauna Netherlands





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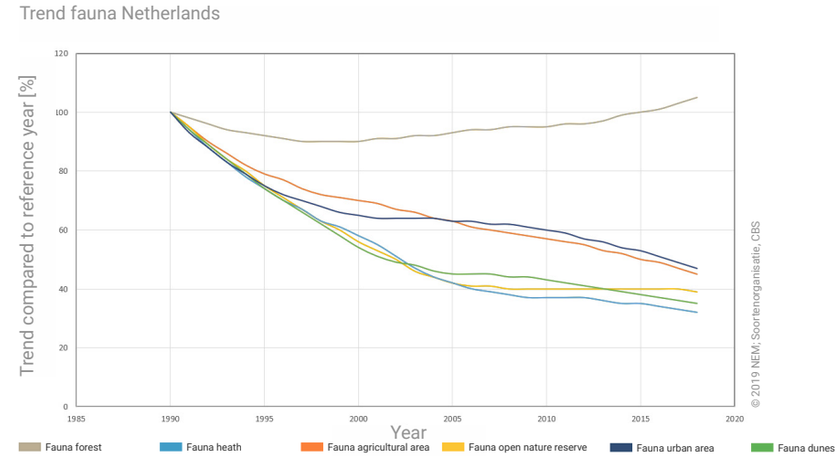

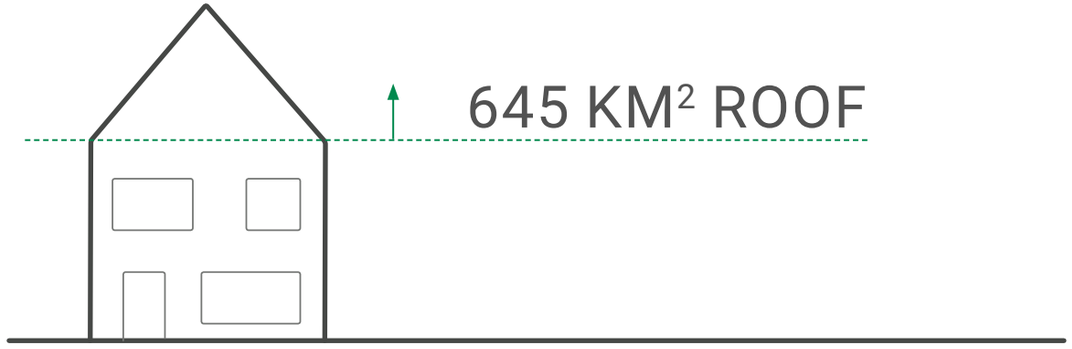

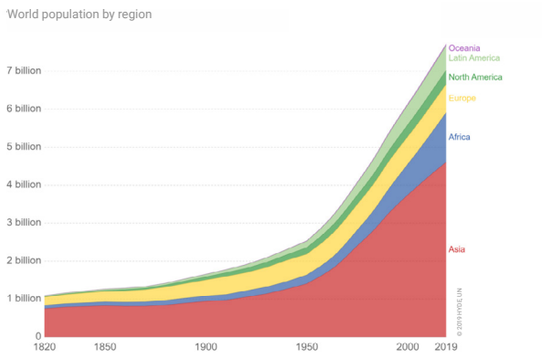

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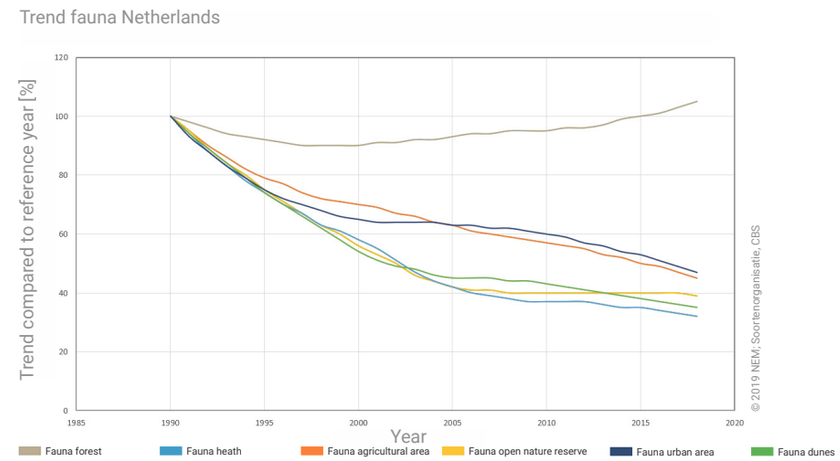
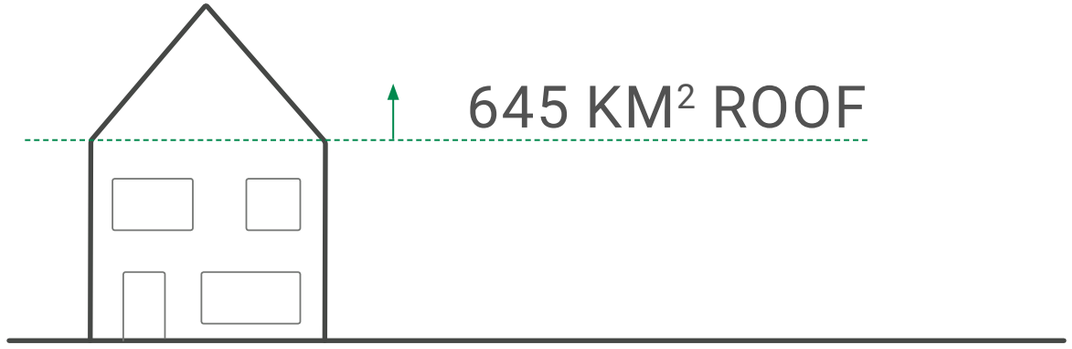
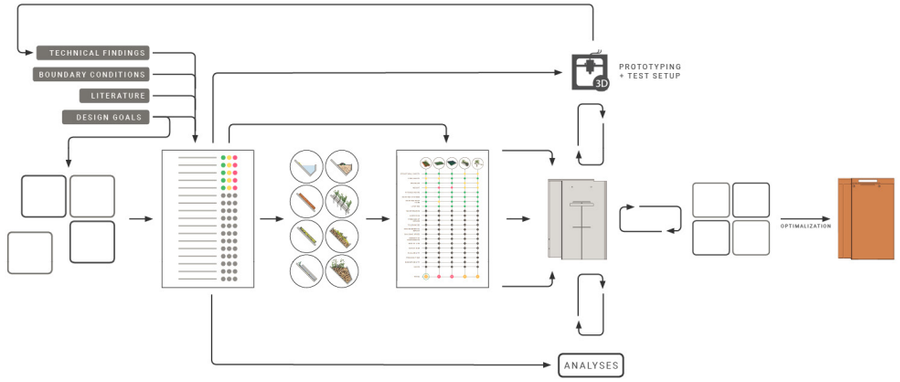
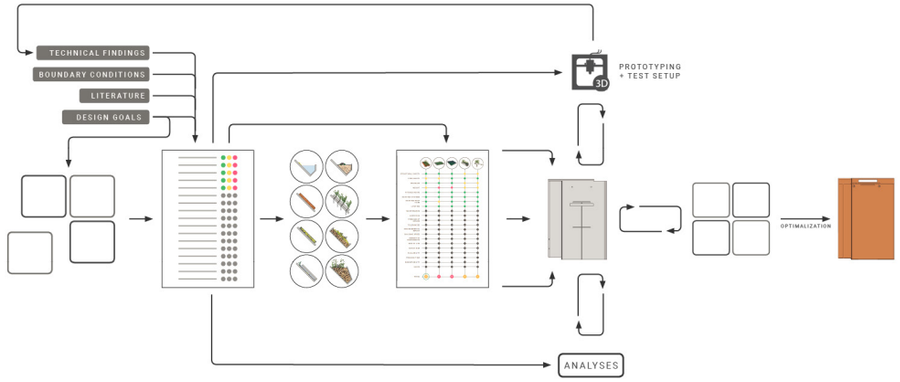




“HOW CAN A GREEN ROOF SYSTEM IMPROVE **BIODIVERSITY** OF PITCHED ROOFS IN DUTCH CITIES?”


TECHNICAL FINDINGS
BOUNDARY CONDITIONS
LITERATURE
DESIGN GOALS
3D
PROTOTYPING
+ TEST SETUP
OPTIMALIZATION
ANALYSES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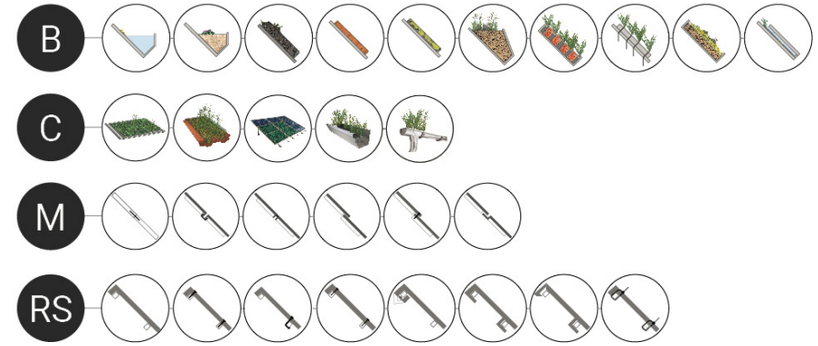
B
C
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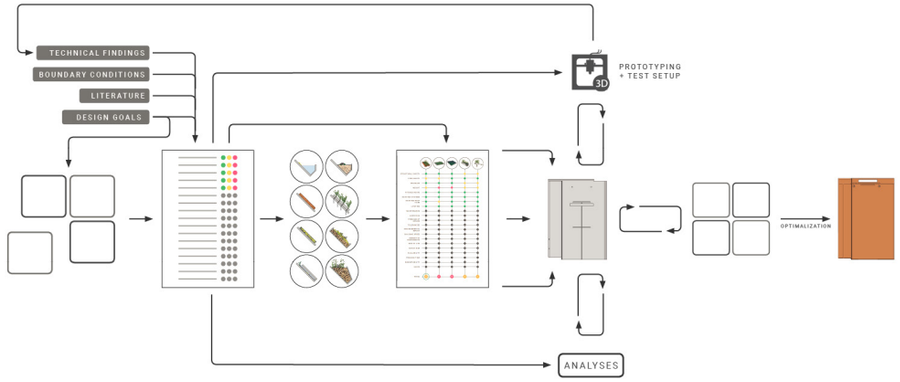
RS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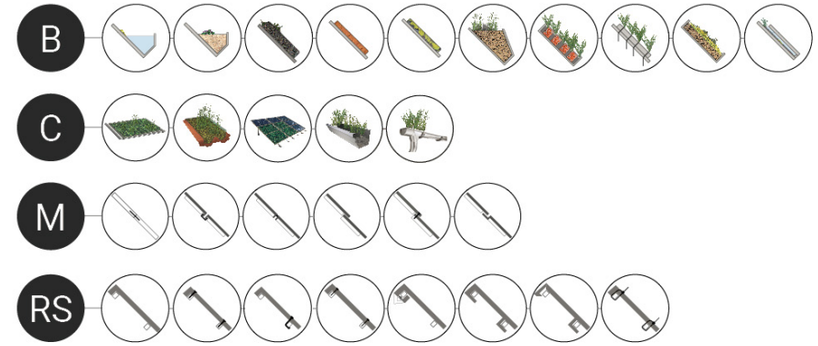
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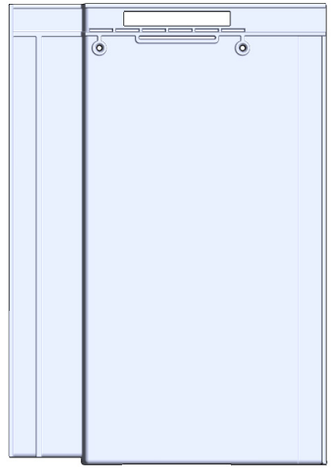

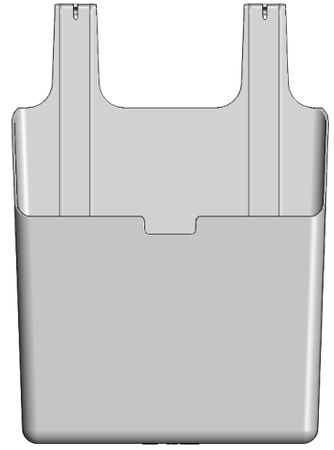

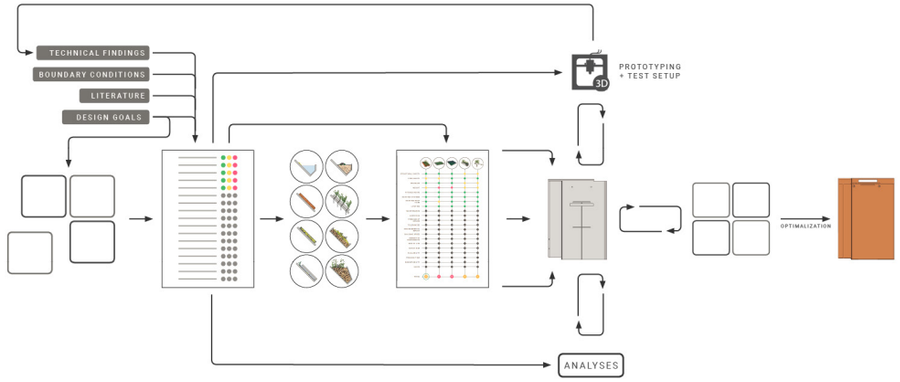
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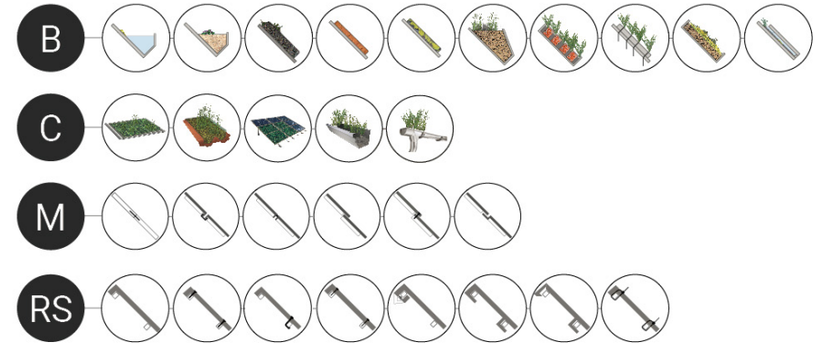
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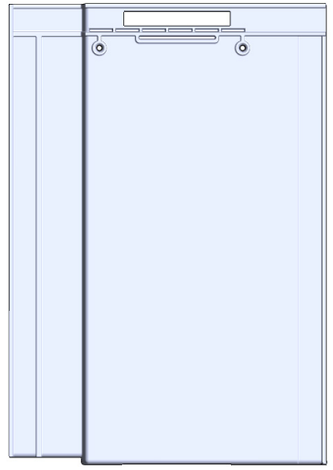
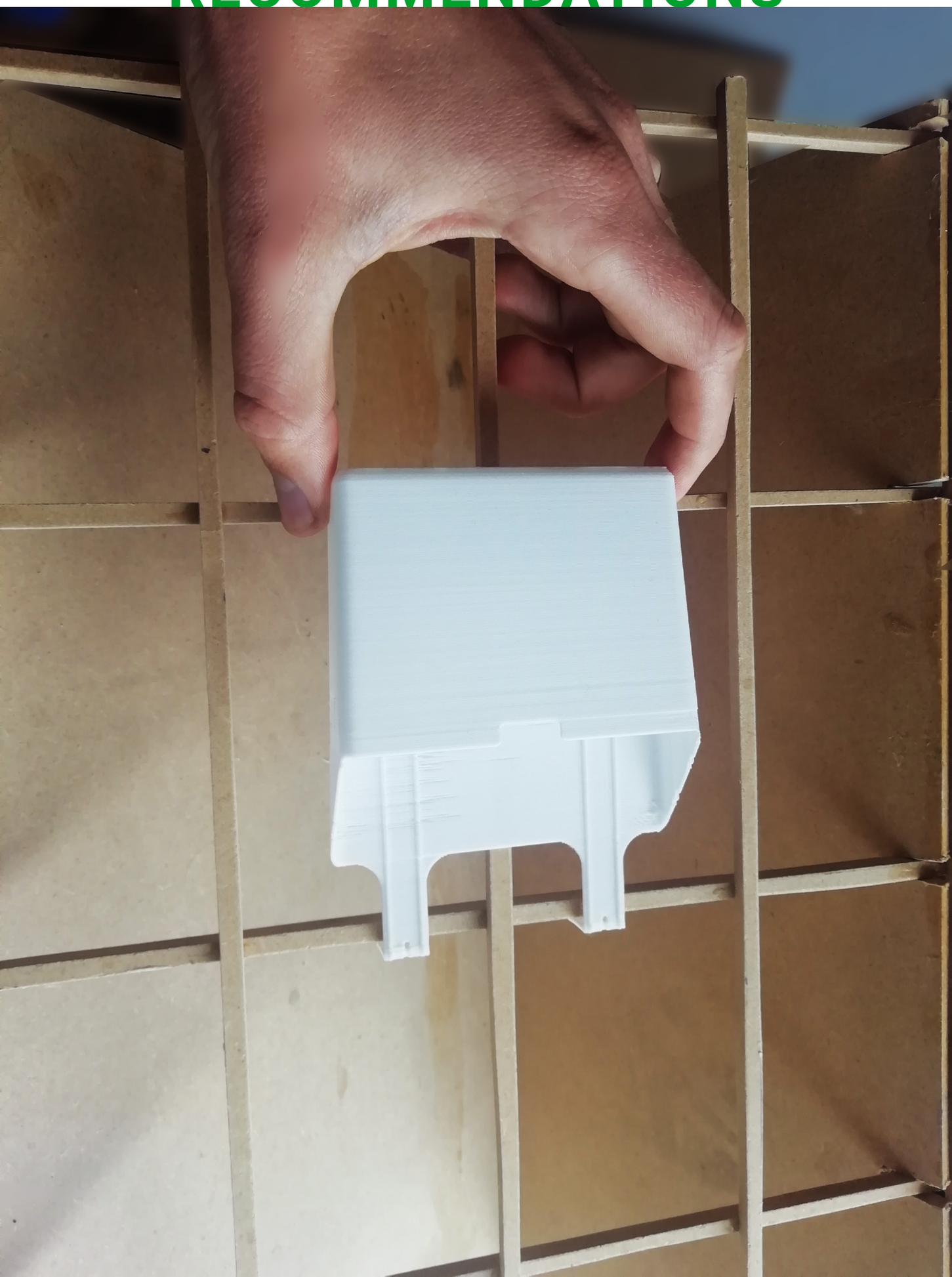
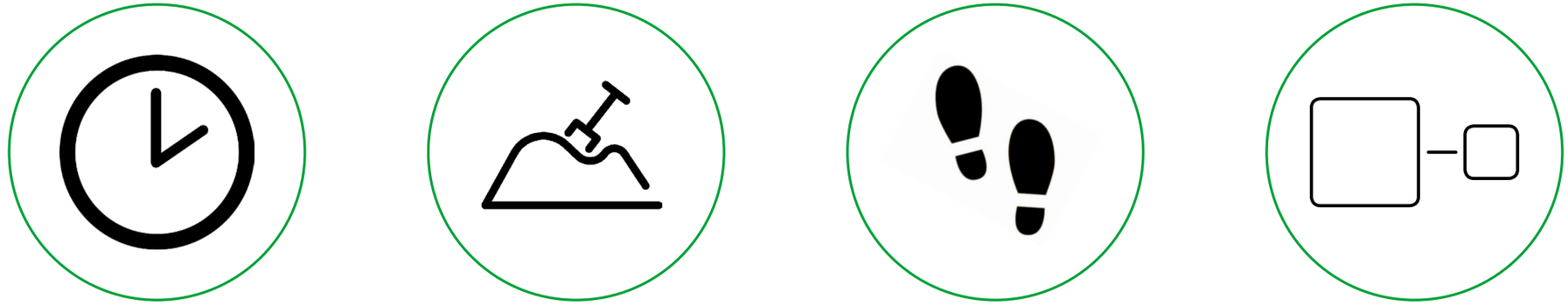


“HOW CAN A GREEN ROOF SYSTEM IMPROVE **BIODIVERSITY** OF PITCHED ROOFS IN DUTCH CITIES?”

- Plants growing in Green roof tile planters providing food and shelter for other living creatures
- Birds breeding in Green roof tile breeding boxes
- Insects nesting, feeding, and hiding in Green roof tile insect hotels
- Other solutions created by people based on Green roof tile baseplates

RECOMMENDATIONS





MILLING

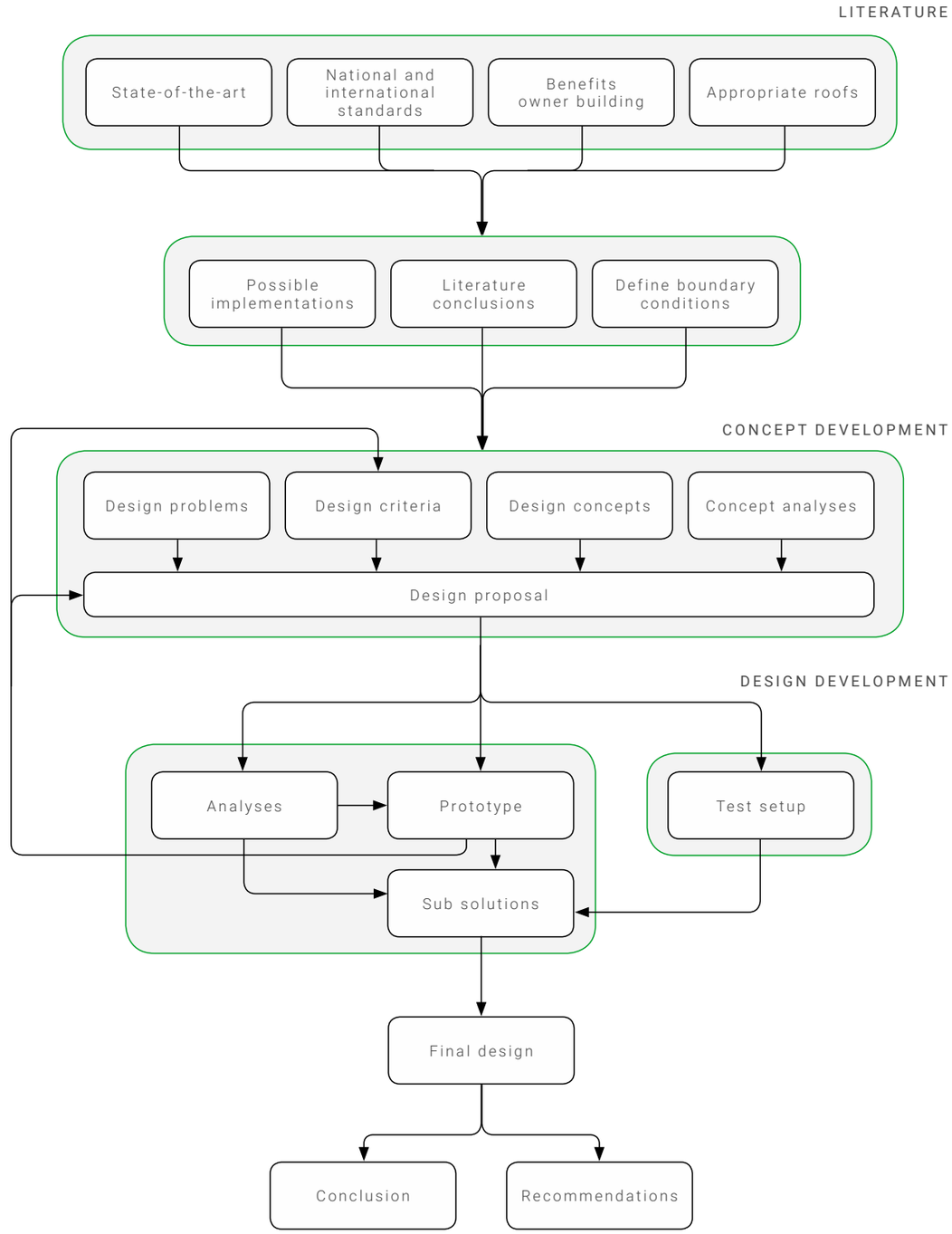
catapultmetaal

THERMOFORMING

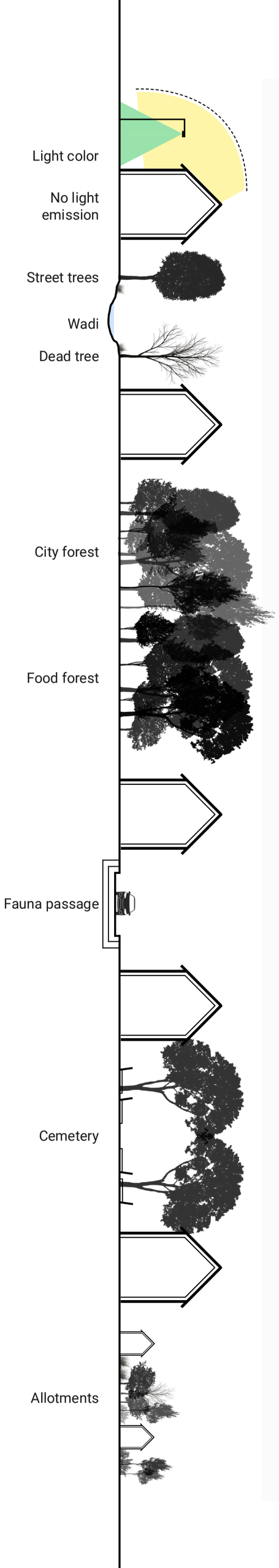
batelaan

THANK YOU

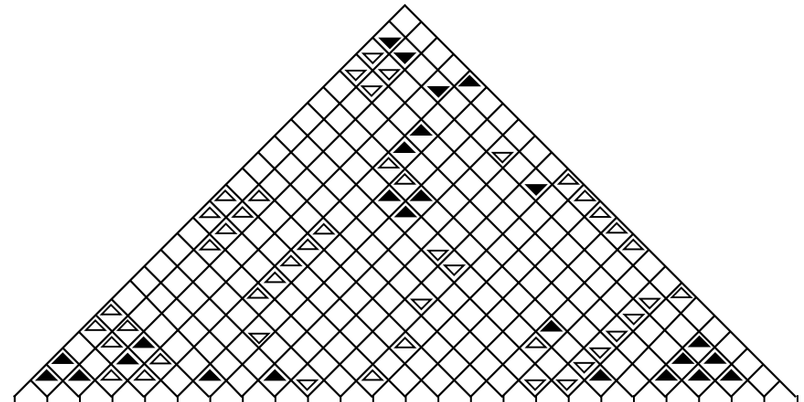
QUESTIONS?


LITERATURE
State-of-the-art
National and international standards
Benefits owner building
Appropriate roofs
Possible implementations
Literature conclusions
Define boundary conditions
CONCEPT DEVELOPMENT
Design problems
Design criteria
Design concepts
Concept analyses
Design proposal
DESIGN DEVELOPMENT
Analyses
Prototype
Test setup
Sub solutions
Final design
Conclusion
Recommendations

	Area	Mammals	Bats	Birds	Insects	Plants
Green private gardens	●●●	●●●	●	●●●	●●●	●●●
City park	●●●	●●●	●●	●●●	●●●	●●●
Helophyte filter	●●		●	●●	●●	●●
Pond	●●	●	●	●●	●●	●●
Sand martin wall	●			●●●		
Nature playground	●●●	●●	●	●●	●●	●●
Green quays	●●			●●	●●	
Floating banks	●●			●●	●●	●●
Ecological bank	●●	●	●●	●●	●●	●●●
Tiny forest	●●	●●●	●●	●●●	●●●	●●●



	Area	Mammals	Bats	Birds	Insects	Plants
Light color	● ●	● ●	● ●	●	●	●
No light emission	● ●	● ●	● ●	●	●	●
Street trees	● ●	●	●	● ●	● ●	● ●
Wadi	● ●	●	●	● ●	● ●	● ●
Dead tree	●	●		●	● ●	●
City forest	● ● ●	● ● ●	● ●	● ● ●	● ● ●	● ● ●
Food forest	● ● ●	● ● ●	● ●	● ● ●	● ● ●	● ● ●
Fauna passage	●	● ● ●				
Cemetery	● ● ●	● ● ●	● ● ●	● ● ●	● ● ●	● ● ●
Allotments	● ● ●	● ● ●	●	● ● ●	● ● ●	● ● ●



		Gradient	Diversity	Opportunities	Native flora, fauna	Impact	Adaptability	Maintenance	Aesthetics	Freedom of design	Tolerance	Cooling effect	Water storage	Acoustics	Air filtration	Environmental impact	Building speed	Number of components	Replacing modules	End of life	Batch size	Scalability	Process time	Overall costs	Marketability	TOTAL	WEIGHT
BIODIVERSITY	Gradient		1	1	1	1	1	0	1	0	0	0	1	1	0	1	0	0	0	0	0	1	1	1	0	12	●●●
	Diversity	1		1	1	1	1	0	1	0	0	1	1	1	1	1	0	0	0	0	0	1	1	1	0	14	●●●
	Opportunities	1	1		1	1	1	0	1	0	0	1	1	1	1	0	0	0	0	0	0	1	1	0	0	12	●●●
	Native Flora, Fauna	1	1	1		1	1	1	1	0	0	0	0	0	0	1	0	0	0	1	1	1	1	1	0	13	●●●
	Impact	1	1	1	1		1	0	1	0	0	1	1	1	1	1	0	0	0	1	1	1	0	0	1	15	●●●
USE	Adaptability	1	1	0	0	1		1	1	1	0	1	1	0	0	1	0	0	1	1	0	0	0	0	0	11	●●
	Maintenance	0	0	0	1	0	1		0	0	1	0	0	0	0	1	1	1	1	1	0	0	0	0	0	8	●●
DESIGN QUALITY	Aesthetics	1	1	1	1	1	1	0		1	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	12	●●●
	Freedom of design	0	0	0	0	0	1	0	1		1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	4	●
	Tolerance	0	0	0	0	0	0	1	0	1		0	0	0	0	0	1	0	1	0	0	0	0	1	0	5	●
	Cooling effect	0	1	1	0	1	1	0	0	0	0		1	0	1	0	0	0	0	0	0	0	0	0	1	7	●●
	Water storage	1	1	1	0	1	1	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	0	1	7	●●
	Acoustics	1	1	1	0	1	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	1	5	●
	Air filtration	0	1	1	0	1	0	0	0	0	0	1	0	0		0	0	0	0	0	0	0	0	0	1	5	●
MATERIAL	Environmental impact	1	1	0	1	1	1	1	0	0	0	0	0	0	0		0	1	1	1	0	0	0	0	1	10	●●
ASSEMBLY	Building speed	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0		1	1	0	0	0	0	0	0	4	●
	Number of components	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1		0	1	0	0	1	1	0	6	●
	Replacing module	0	0	0	0	0	1	1	0	1	1	0	0	0	0	1	1	0		1	0	0	0	0	1	8	●●
	End of life	0	0	0	1	1	1	1	1	0	0	0	0	0	0	1	0	1	1		0	0	0	0	1	9	●●
PRODUCTION	Batch size	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0		1	1	1	0	6	●
	Scalability	1	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1		1	1	0	9	●●
	Process time	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1		1	0	8	●●
COSTS	Overall costs	1	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	1	1	1		1	10	●●
	Marketability	0	0	0	0	1	0	0	1	0	0	1	1	1	1	1	0	0	1	1	0	0	0	1		10	●●

Risk	Consequence	Probability	Urgency	Detection	Risk Priority Number	Conclusion/design change
Installation						
1. Screws roof tile not installed	Roof system can fall from roof	3	5	4	60	Write clear manual
2. Screws planter not installed	Planter can fall from roof	3	4	4	48	Write clear manual
3. Panhaak not installed	System is less structural safe	3	3	4	36	Write clear manual
4. Compriband not installed	Roof system is not waterproof	3	3	4	36	Write clear manual
5. Roof tiles are not possitioned well on roof	Leakage	2	4	4	32	Write clear manual
6. Protection not removed adhesive layer aluminum part	Aluminum part can come loose from roof tiles	3	2	4	24	Write clear manual
7. Installed on steep roof > 60 degrees	System not structural safe	2	5	1	10	
8. Installed on flat roof < 20 degrees	System not waterproof	2	4	1	8	
9. Purlins bigger or smaller than standard	Green roof system cannot be installed	2	3	1	6	
10. Roof tile installed wrong way around	System does not function or falls from roof	1	5	1	5	
11. Aluminum part not bent into form roof tiles	Connection less waterproof	2	2	1	4	
12. Turned screw	Replace part is laborious	4	1	1	4	
Damage						
1. Hook planter detaches	Planter falls from roof	2	5	4	40	Secure hook with screw
2. Aluminum part not strong enough to keep roof tile in position	Leakage and not structural safe	2	5	4	40	Test 1:1 prototype
3. Holes planter clog	Roots plants can rot	4	3	3	36	Include more holes and increase diameter
4. Screws break	System can fall from roof	1	5	5	25	Use strong screws
5. Screws rust	Screws become weaker and can break	1	5	5	25	Use stainless steel screws
6. Hook planter break	Planter falls from roof	2	5	4	20	Make hook planter stronger
7. Planter leaks	Negative effect on development plants					Make planter out of one part and use right material
8. Roof tile breaks	Leakage and not structural safe					Make roof tile strong enough
9. Adhesive compriband dissolves in water	System not waterproof					

Risk	Consequence	Probability	Urgency	Detection	Risk Priority Number	Conclusion/design change
External factors						
1. Brittle material due to UV-light	Material can become weak and breaks	2	5	5	50	Select right material
2. Extreme wet winter	Roots of plants can rot	4	3	3	36	Include more holes and increase diameter
3. Autumn leaves on roof	Too much water and nutrients in planter	4	3	3	36	Include more holes and increase diameter
4. Something heavy hits roof	Part of system breaks	3	4	2	24	Make hooks planter and roof tile strong enough
5. Someone cleanes roof with high-pressure cleaner	Roof system can be damaged or breaks	3	4	2	24	Write clear manual
6. Someone cleanes roof with chemicals	Roof system can be damaged or breaks	3	4	2	24	Write clear manual
7. High temperature due to sunlight or close to chimney	Negative effect on development plants	2	3	3	18	
8. Fire	Roof system melts or deforms	3	5	1	15	
9. Storm	Roof system breaks and falls from roof	3	5	1	15	
10. Extreme dry summer	Plants dry out or die	4	3	1	12	
11. Electric cable hits roof	Nothing happends	2	1	3	6	
12. Water in planter freezes	Open system, so no consequences	5	1	1	5	
13. Snow on roof	Snow load included in calculations	5	1	1	5	
14. Earthquake	Roof system breaks and falls from roof	1	5	1	5	
External factors plants						
1. To much nitrogen in soil	Negative effect on development plants	3	3	5	45	Include chalk in substrate
2. Only one green roof tile system on roof	Roof becomes warm and has negative effect on development plants	5	2	4	40	Select right plants
3. Mold and algea grow in planter	Negative effect on development plants	2	3	4	24	Use opaque material
4. Ant nest in planter	Negative effect on development plants	2	3	4	24	Replace planter if needed
5. Wrong substrate	Negative effect on plants/system too heavy	1	4	4	16	
6. Substrate washes away by rain	Not enough substrate for plants	2	3	2	12	
7. Wrong plants	Less impact on biodiversity	1	2	4	8	

Strength

1. Simple and clear design
2. Uses standard parts
3. Universal design - large application area
4. Replaces conventional roof tiles 1:1
5. Injection molding - cheap production process
6. Many plant species, nature decides which grow best in every situation
7. Solution with high quality green for slanted roofs

Weakness

	Conclusion/design change
1. Opening in roof tile for planter hook - not 100 percent water proof	Raise rime before opening
2. Screws required to ensure structural safety	Write clear manual
3. Small planter - little substrate	Test 1:1 prototype
4. Replacing roof tile is laboriously	Possibility to slide up one roof tile
5. Maintenance and cleaning on slanted roof is laboriously	As little maintenance needed as possible

Opportunity

1. Position of holes decide how much water remains in planter
2. Roof tile can be used for products for birds and insects too
3. Product on roof, so no perfect finish necessary

Threats

1. Hooks planter fragile	One hook can hold a planter, so no concequences if other breaks
2. Too little water during hot and dry summer days	Test 1:1 prototype
3. Compriband does not foam enough	Select right compriband
4. Panhaak does not fit	Make enough room for panhaak
5. Aluminum part does not work	Test 1:1 prototype
6. Material is not sustainable/circulair/recyclable	Select right material
7. Material gets brittle due to UV-light	Select right material

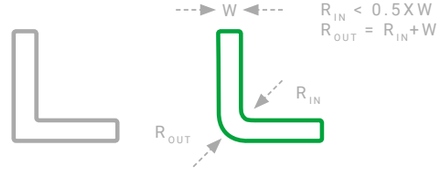
AVOID UNDERCUTS

USE SHUT-OFFS

ADD DRAFT ANGLES

USE THREADED INSERTS

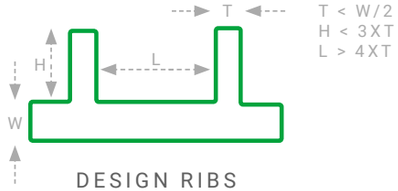
USE CONSTANT WALL THICKNESS



ROUND ALL EDGES

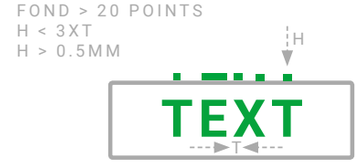
ADD SMOOTH TRANSITIONS

CONSIDER SECONDARY OPERATIONS

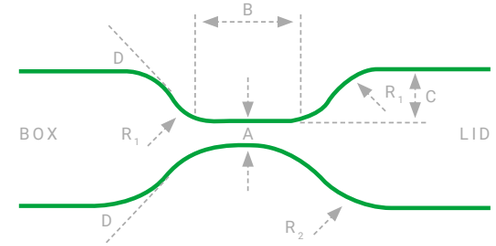


DESIGN RIBS

MINIMIZE PART VOLUME

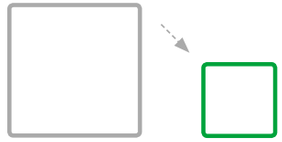


DESIGN TEXT AND SYMBOLS

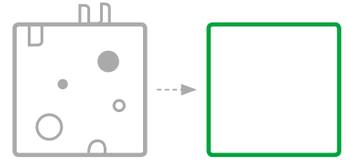


DESIGN FLEXIBLE HINGES

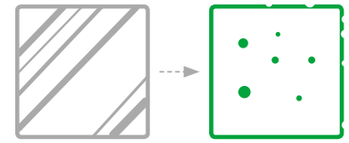
A = 0.20-0.35MM
B = 1.5MM
C = 0.25MM
D = 45°
R_1 = 0.25MM
R_2 = AS LARGE AS POSSIBLE



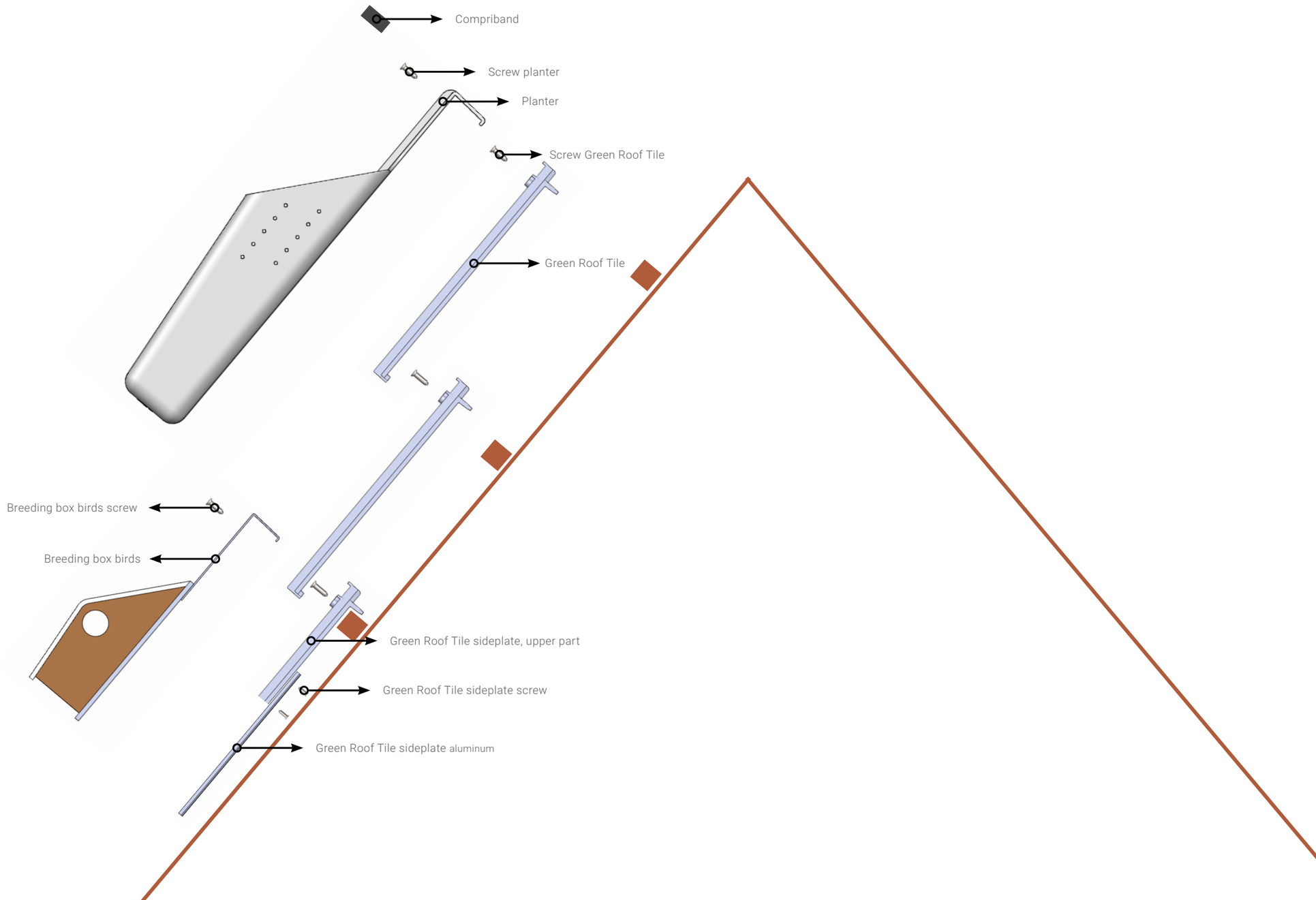
MAKE PART SMALLER

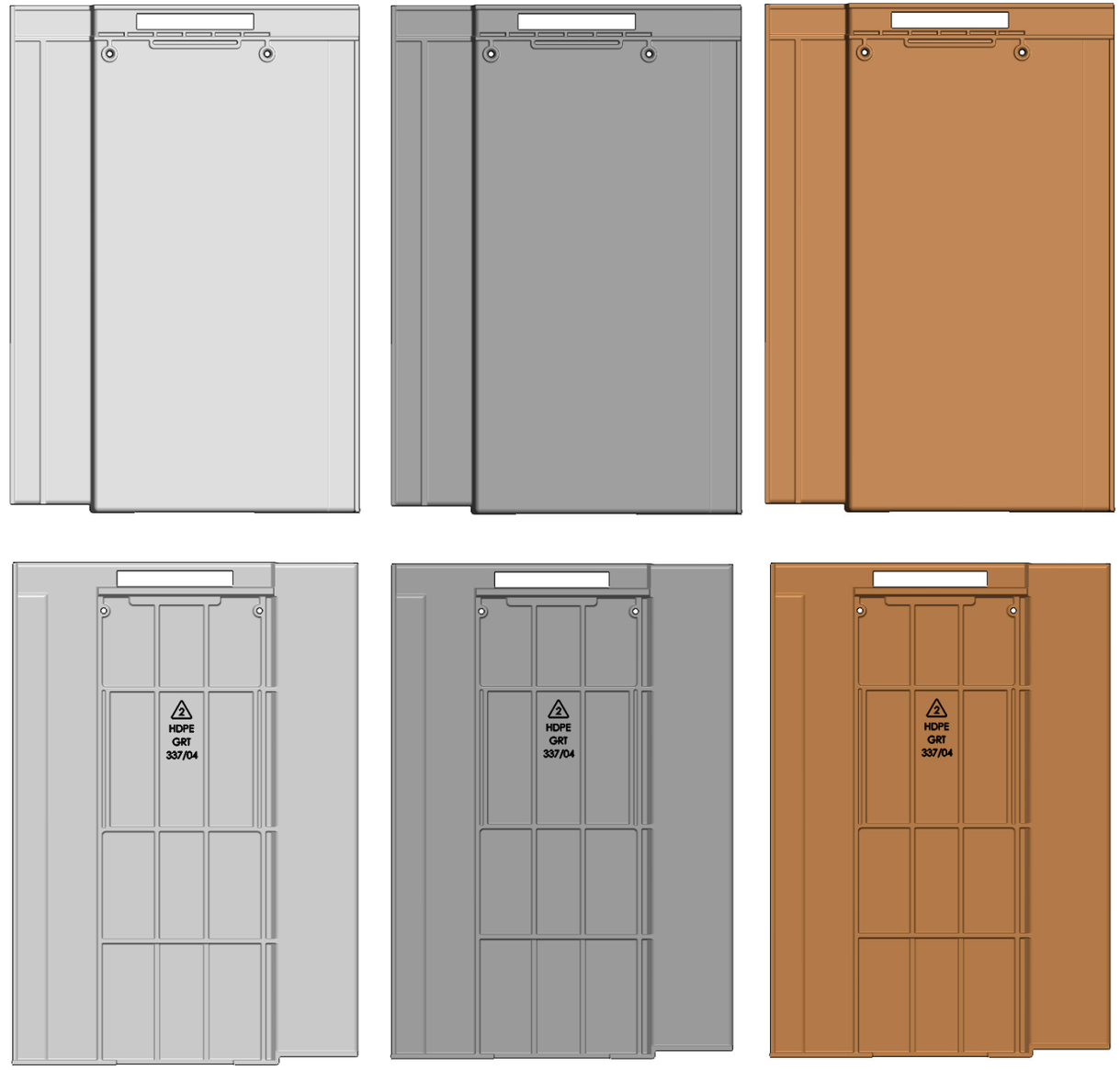


AVOID SMALL DETAILS



USE LOWER GRADE FINISHES


Compriband
Screw planter
Planter
Screw Green Roof Tile
Green Roof Tile
Breeding box birds screw
Breeding box birds
Green Roof Tile sideplate, upper part
Green Roof Tile sideplate screw
Green Roof Tile sideplate aluminum


2
HDPE
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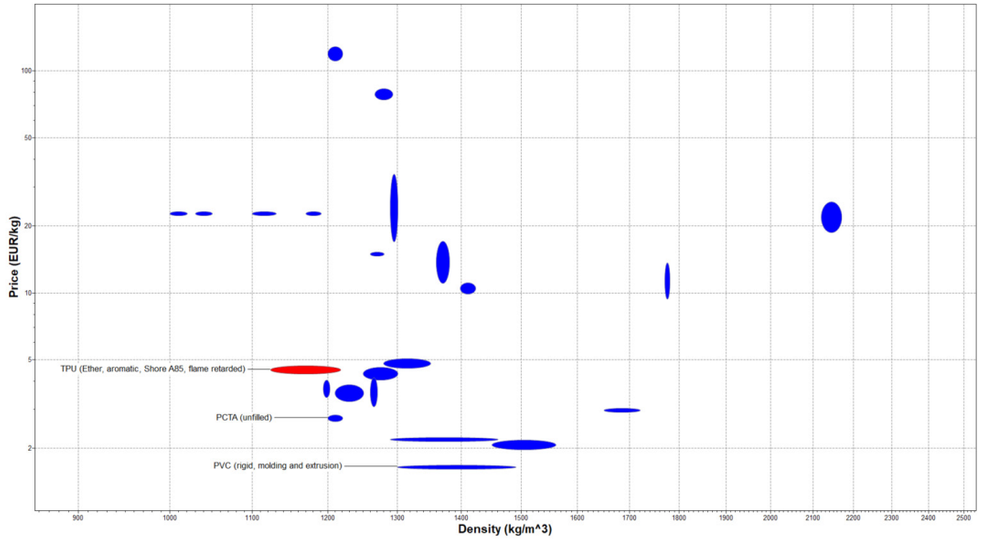
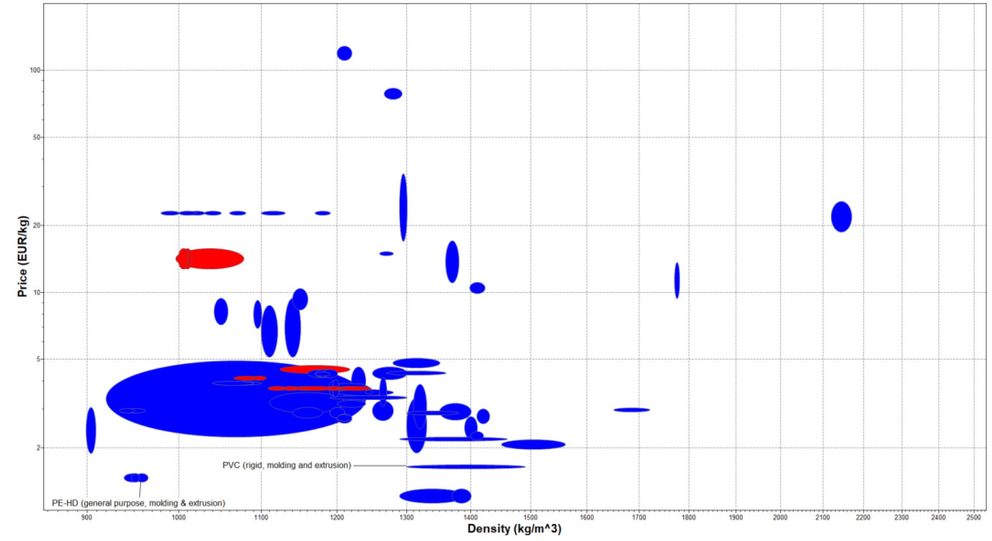
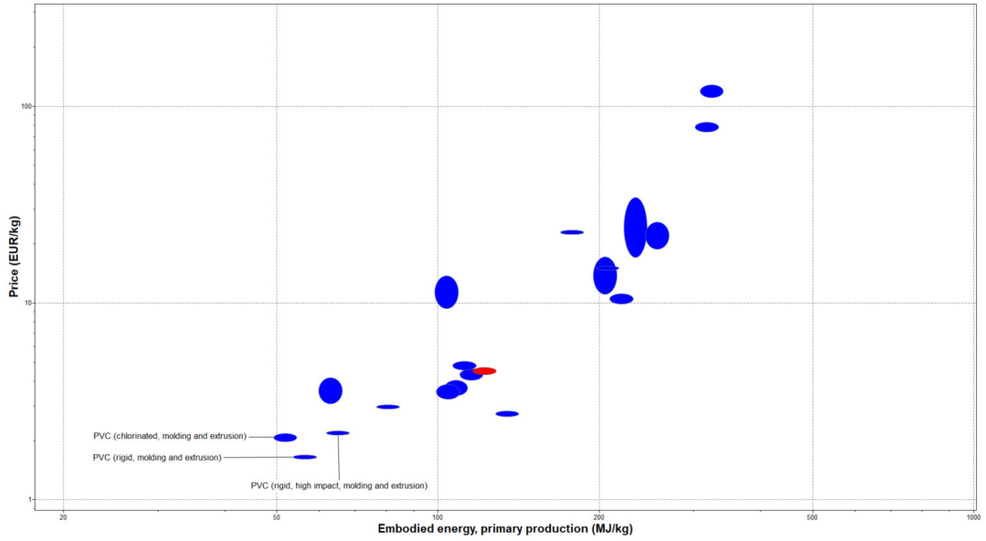
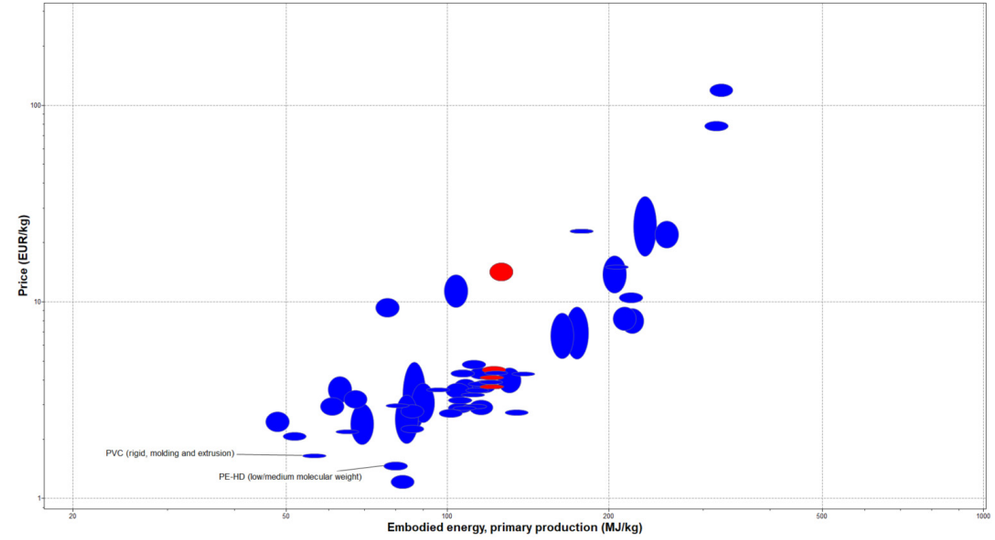
Achilea millefolium	Duizenblad
Allium Schoenoprasum	Bieslook
Anthoxanthum odoratum	Gewoon reukgras
Armeria maritima	Engels gras
Campanula rotundifolia	Grasklokje
Clinopodium vulgare	Borstelkrans
Dianthus armeria	Ruige anjer
Dianthus carthusianorum	Kartuizer anjer
Dianthus deltoides	Steenanjer
Erigeron acer	Scherpe fijnstraal
Erodium cicutarium	Gewone rijgersbek
Festuca ovina	Schapengras
Festuca rubra	Rood zwenkgras
Galium verum	Geel walstro
Jasione montana	Zandblauwtje
Linaria vulgaris	Vlasbekje
Lotus cornuculatus	Gewone rolklaver
Origanum vulgare	Wilde marjolein
Pilosella officinarum	Muizenoor
Plantago media	Ruige weegbree
Prunella vulgaris	Gewone brunel
Rumex acetosella	Schapenzuring
Sempervivum	Huislook
Sedum rupestre	Tripmadam
Silene vulgaris	Blaassilene
Thymus pulegioides	Grote tijm
Trifolium arvense	Hazenpootje


Price (EUR/kg)
Density (kg/m^3)
TPU (Ether, aromatic, Shore A85, flame retarded)
PCTA (unfilled)
PVC (rigid, molding and extrusion)


Price (EUR/kg)
Density (kg/m^3)
PVC (rigid, molding and extrusion)
PE-HD (general purpose, molding & extrusion)


Price (EUR/kg)
Embodied energy, primary production (MJ/kg)
PVC (chlorinated, molding and extrusion)
PVC (rigid, molding and extrusion)
PVC (rigid, high impact, molding and extrusion)


Price (EUR/kg)
Embodied energy, primary production (MJ/kg)
PVC (rigid, molding and extrusion)
PE-HD (low/medium molecular weight)

11.31

6.89

1.52

23.95

24.95

23.99

Costs	Planter 1.250/year		Roof tile 3.000/year		Roof tile sideplate 2.000/year		Breeding box bird 1.250/year		Insect hotel 1.250/year		Source
	Total costs	Costs/ product	Total costs	Costs/ product	Total costs	Costs/ product	Total costs	Cost/ product	Total costs	Cost/ product	
Mold	30.000	2.40	12.500	1.00	12.500	1.00					Promolding
Injection molding		5.00		4.00		3.00					Promolding
Substrate		0.93									Groendak
Seed		0.17									Cruydt hoeck
Screws		0.08		0.30		0.08		0.08		0.08	rvs-paleis
Compriband						0.43					Kitcentrum
Ondervorst						0.83					EPDM
Baseplate								3.00		3.00	-
Wood								1.00		1.00	goedkoop bouwmaterialen
Paint								0.50		0.50	goedkoop bouwmaterialen
Insect hotel infill										0.50	-
Production/Assembly		0.75				0.50		4.25		4.25	25 euro/uur
External startup costs	2.000	0.16	2.000	0.07	2.000	0.10	1.000	0.08	1.000	0.08	-
Total prod. costs		**9.49**		**5.37**		**5.94**		**9.63**		**10.13**	
Product margin		19.20		12.00		12.00		14.40		14.40	
Product price		**28.69**		**17.37**		**17.94**		**24.03**		**24.53**	
Selling price		29.95		19.95		19.95		24.95		24.95	


Z
sz
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mw

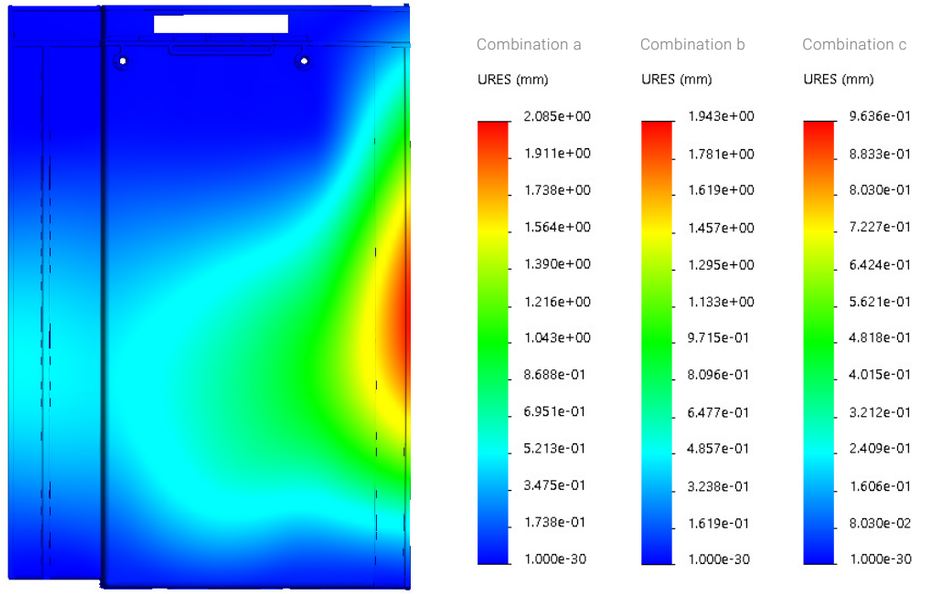

Figure 7.3 | Results displacement load combinations a, b, and c (Solidworks 2019)

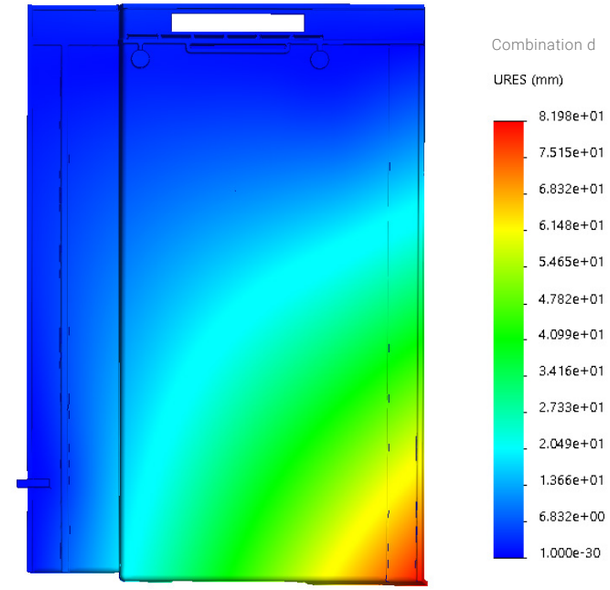

Figure 7.6 | Results displacement load combinations d (Solidworks 2019)