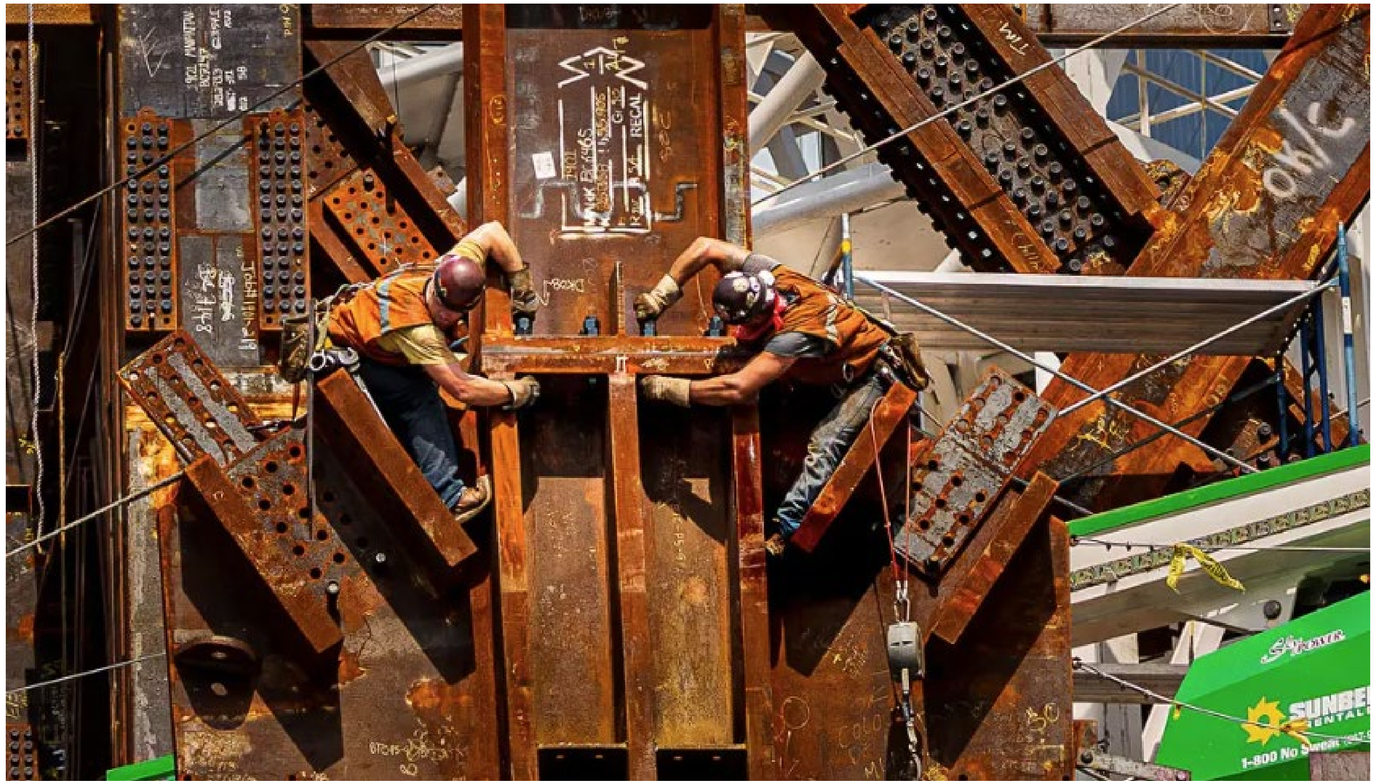
I want **you**

I want **you**

to think of **building materials**

Courtesy of: Adobe AI

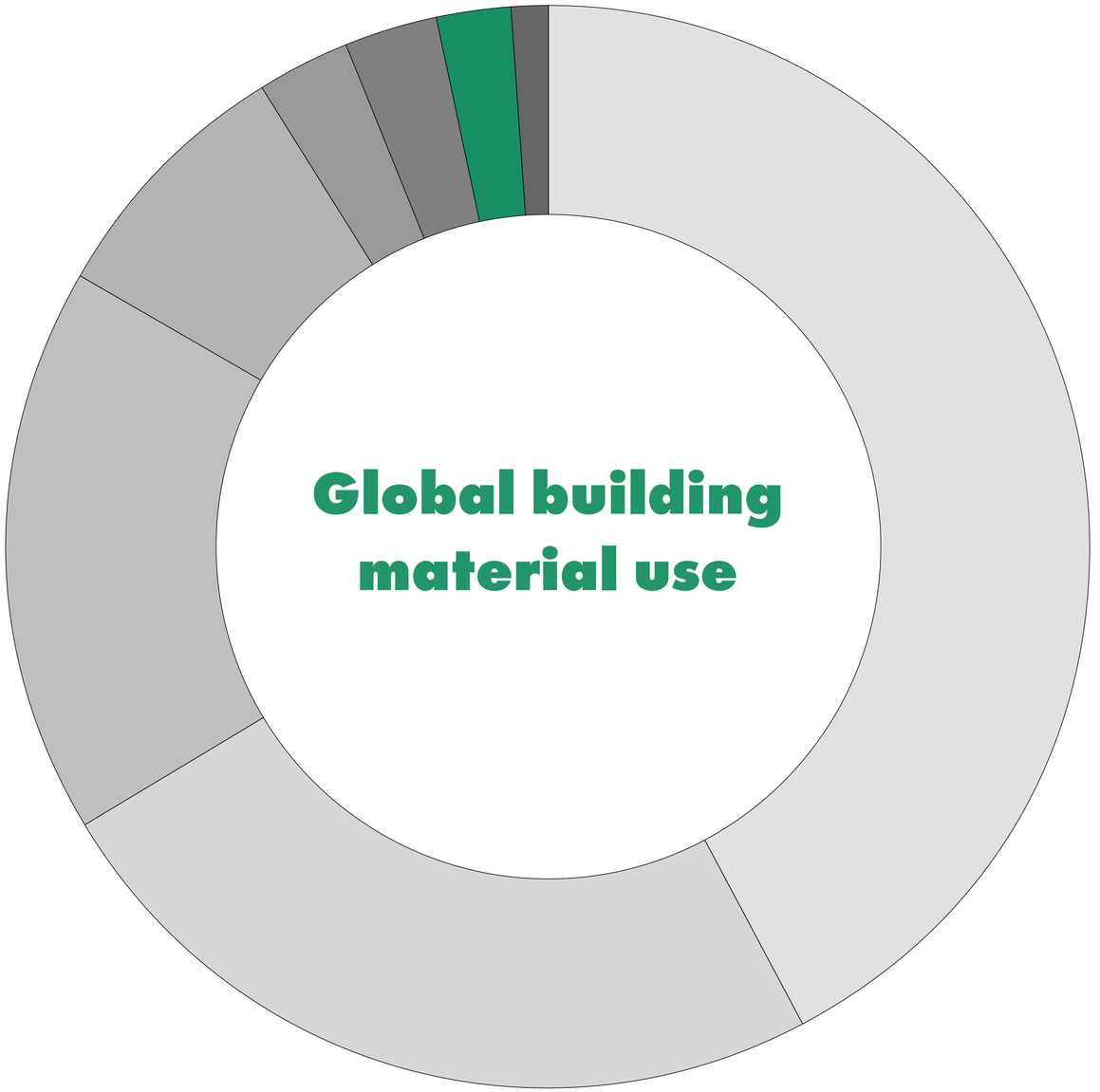


Courtesy of: https://www.waltersgroupinc.com/project/manhattan-west-southeast-tower-two-manhattan-west/

Courtesy of: https://www.rubi.com/en/blog/how-to-build-a-brick-wall-step-by-step/

Today's issues

Materials



Can we **Change** this?

Hygromorphic Timber

Master Research Thesis

P5

Passive curving method for multi-layer structural timber floor elements

-5079810-

2 July 2024

Raymen Lenno François Borst

Stijn Brancart & **Gilbert** Koskamp

Master Research Thesis **P5** Presentation

Courtesy of: https://www.mm-holz.com/en/products/engineered-glulam

Today’s issues

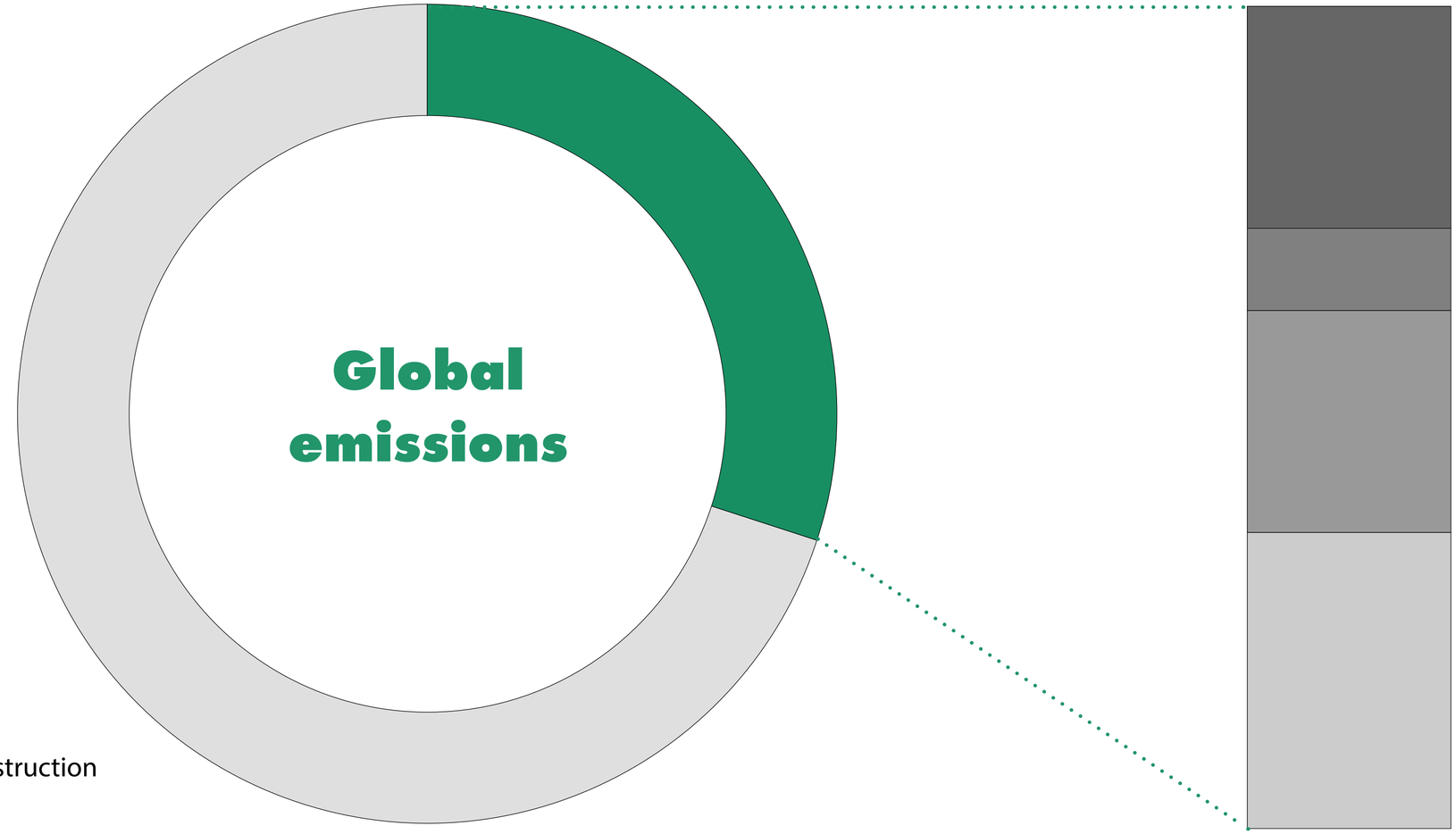
There are **problems**

Today’s issues

Courtesy of: https://www.un.org/en/climatechange/what-is-climate-change

Today’s issues

Materials



Today's issues

Architecture

Heydar Aliyes Centre

Courtesy of: https://www.designboom.com/architecture/zaha-hadid-heydar-aliyev-cultural-centre-progress/
com/architecture/zaha-hadid-heydar-aliyev-cultural-centre-progress/

Today's issues
Materials

Timber absorbs CO_2:
Wood is **Good**

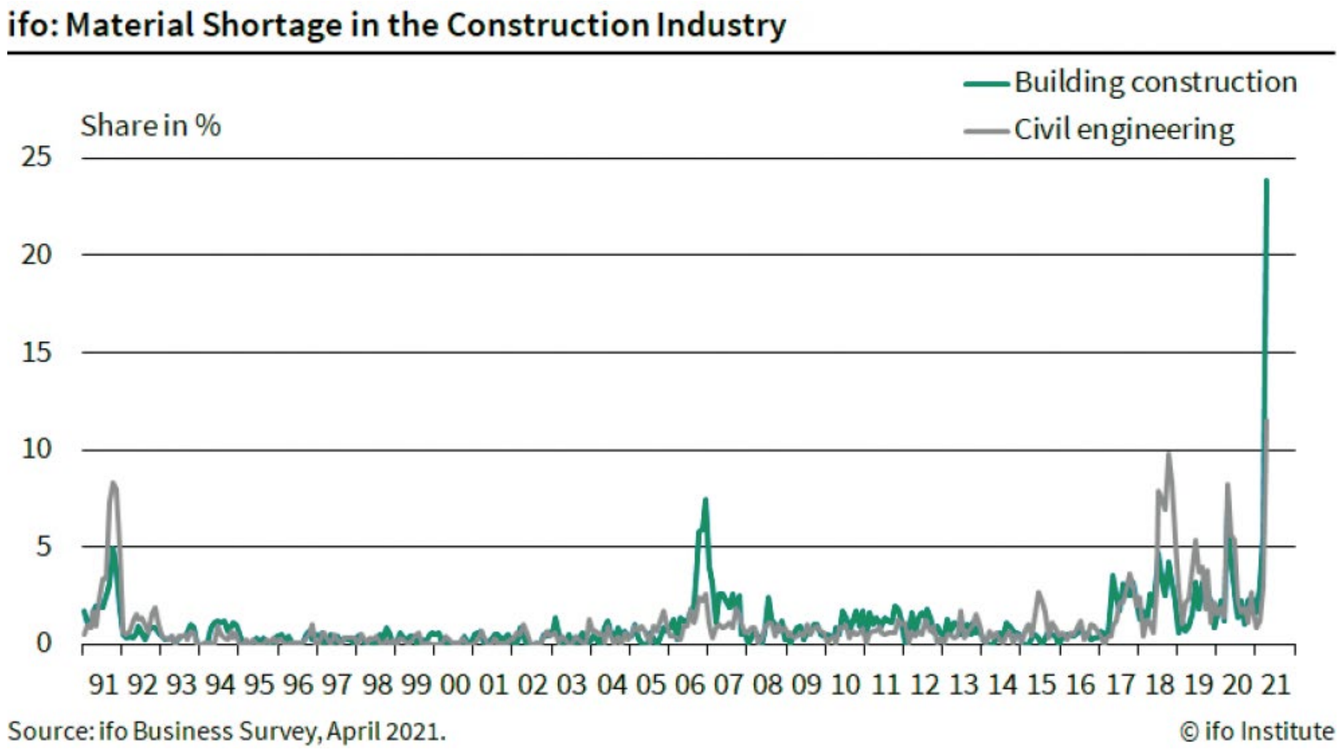
Today’s issues
Materials

Courtesy of: Adobe AI

Today's issues
Materials

Materials become **Scarcer**

Today's issues
Materials



Courtesy of: https://www.ifo.de/en/press-release/2021-05-17/material-shortage-has-hit-german-construction-industry

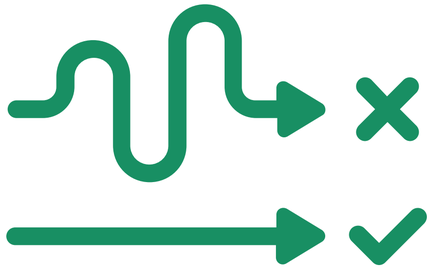
Today's issues
Materials

Is there a solution to **Reduce Emissions** while also **Limit** the **Material Usage**?

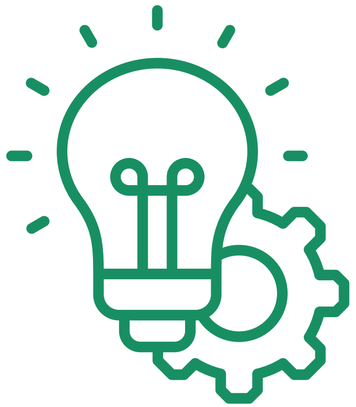
Today’s issues

Materials

Efficient



Innovative

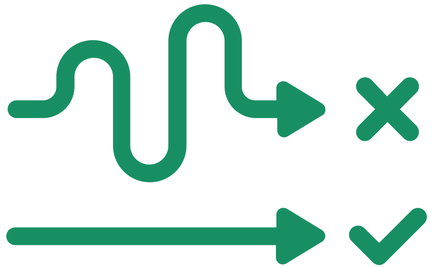


New

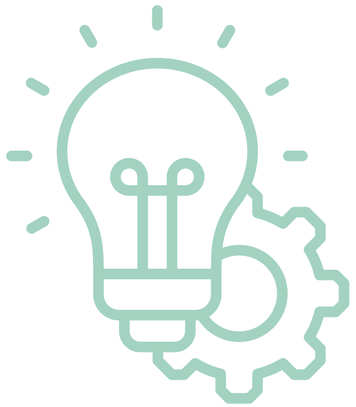
Today’s issues

Materials

Efficient



Innovative

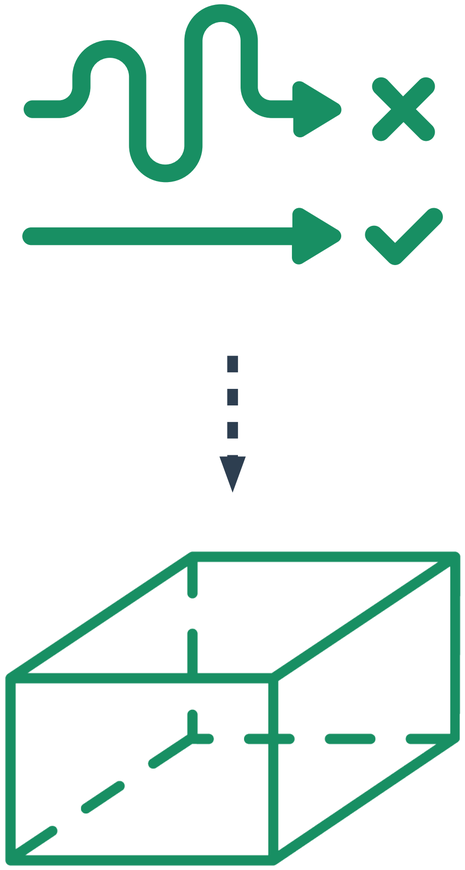


New

Today’s issues

Materials

Efficient



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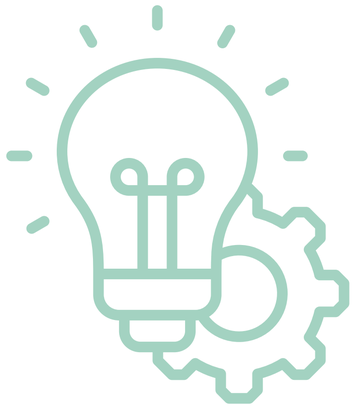


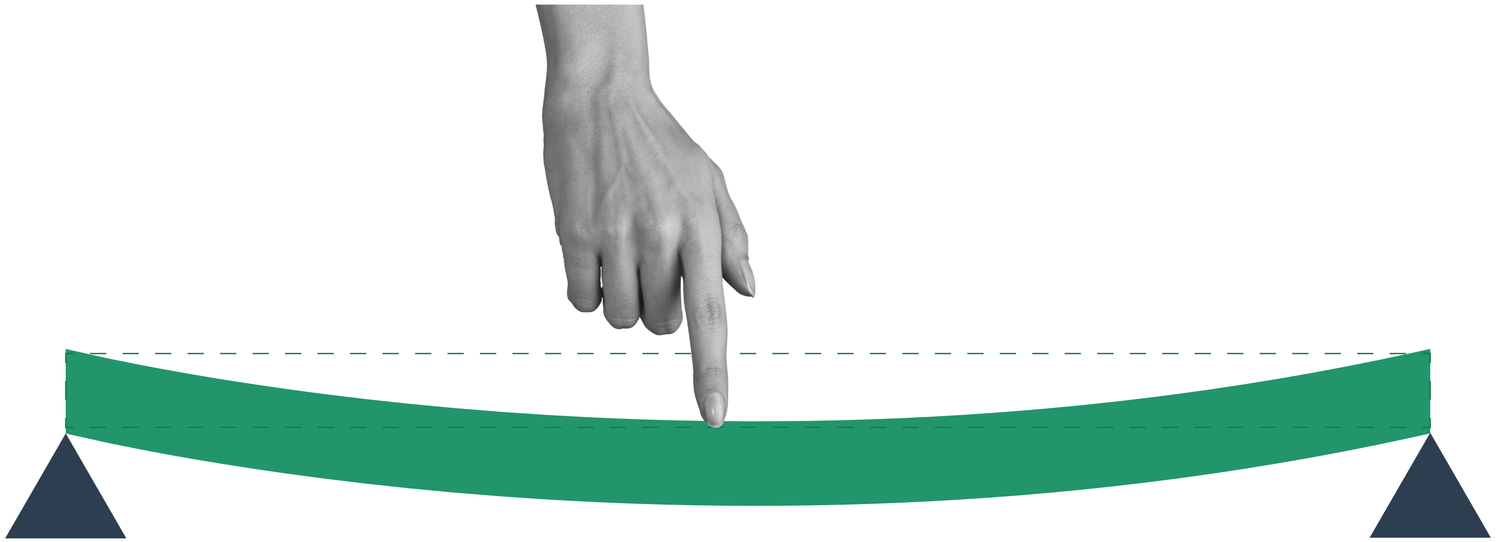
New

Today's issues
Materials

Sustainable material constructed in an **efficient structural form**

Today’s issues
Materials

Today’s issues
Materials



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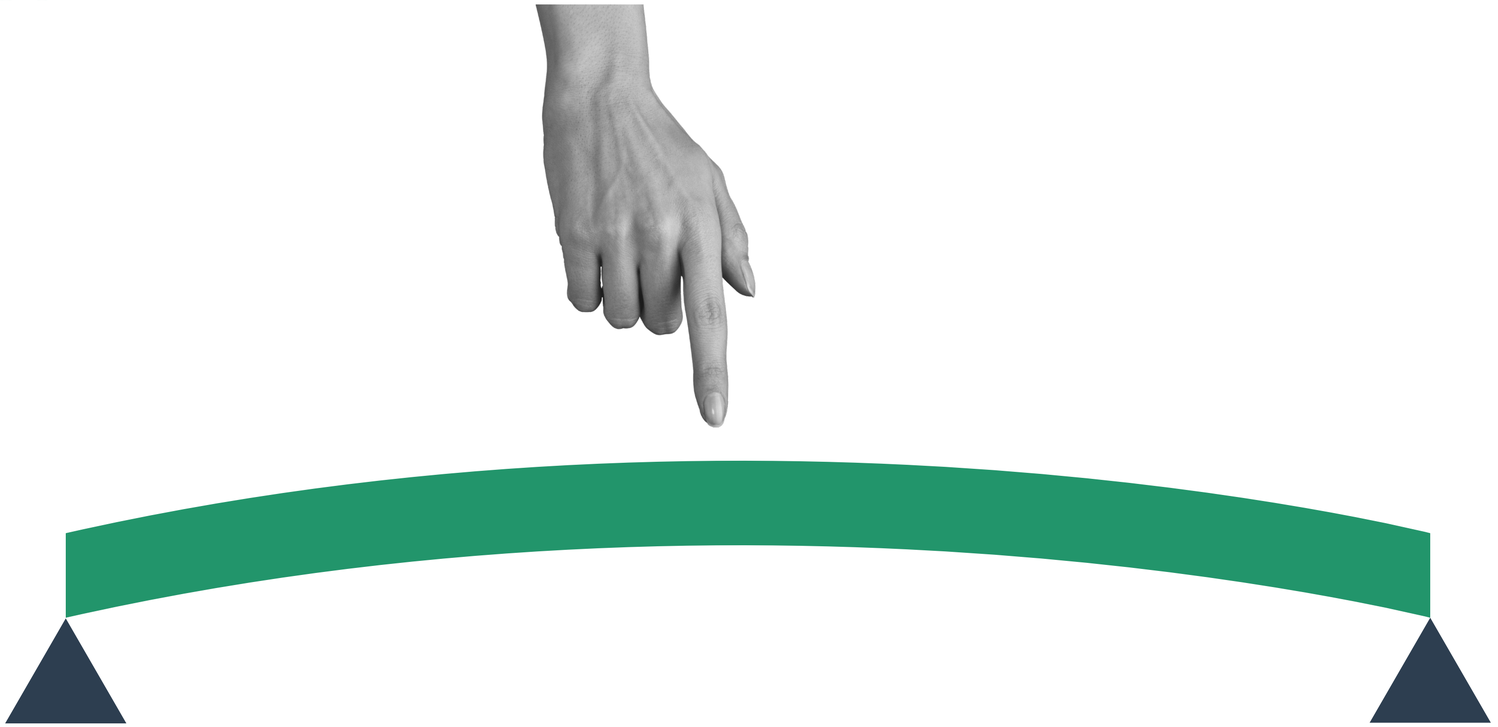
Materials



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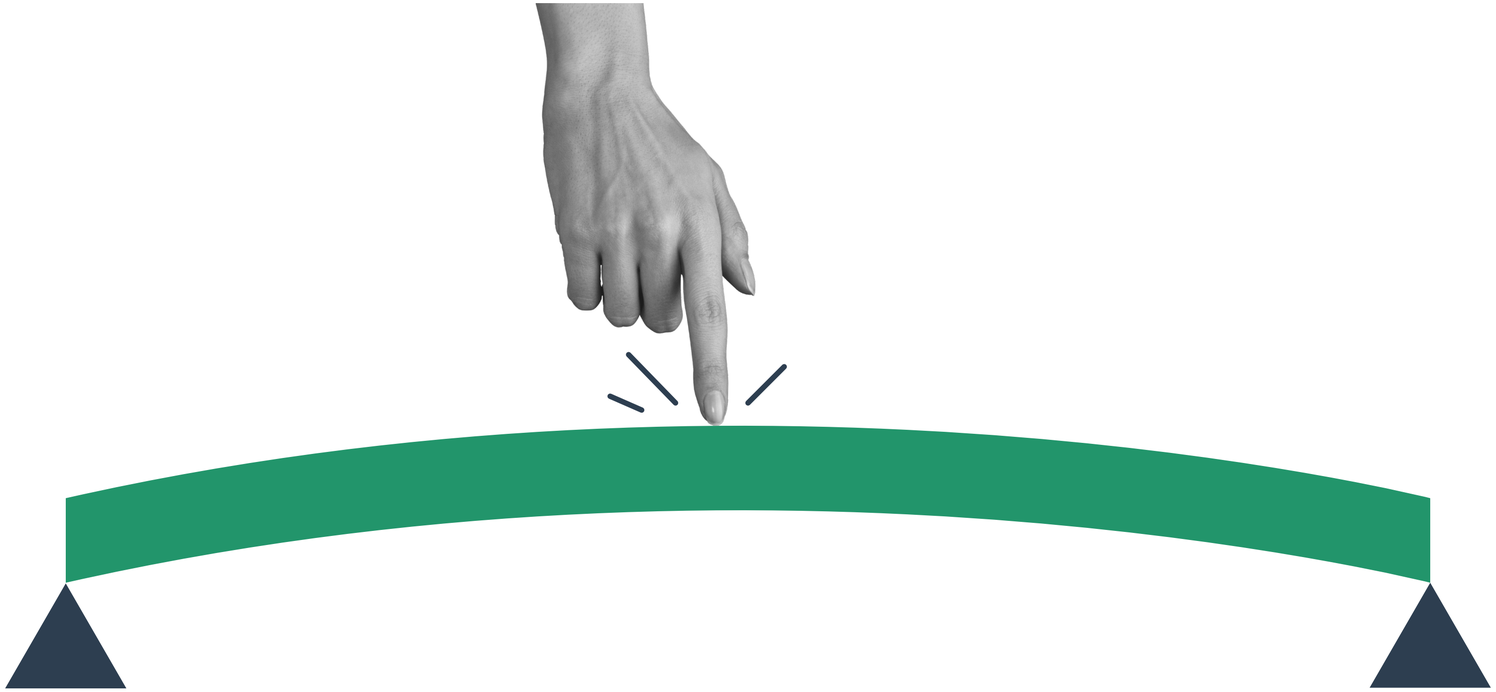
Materials



Today's issues

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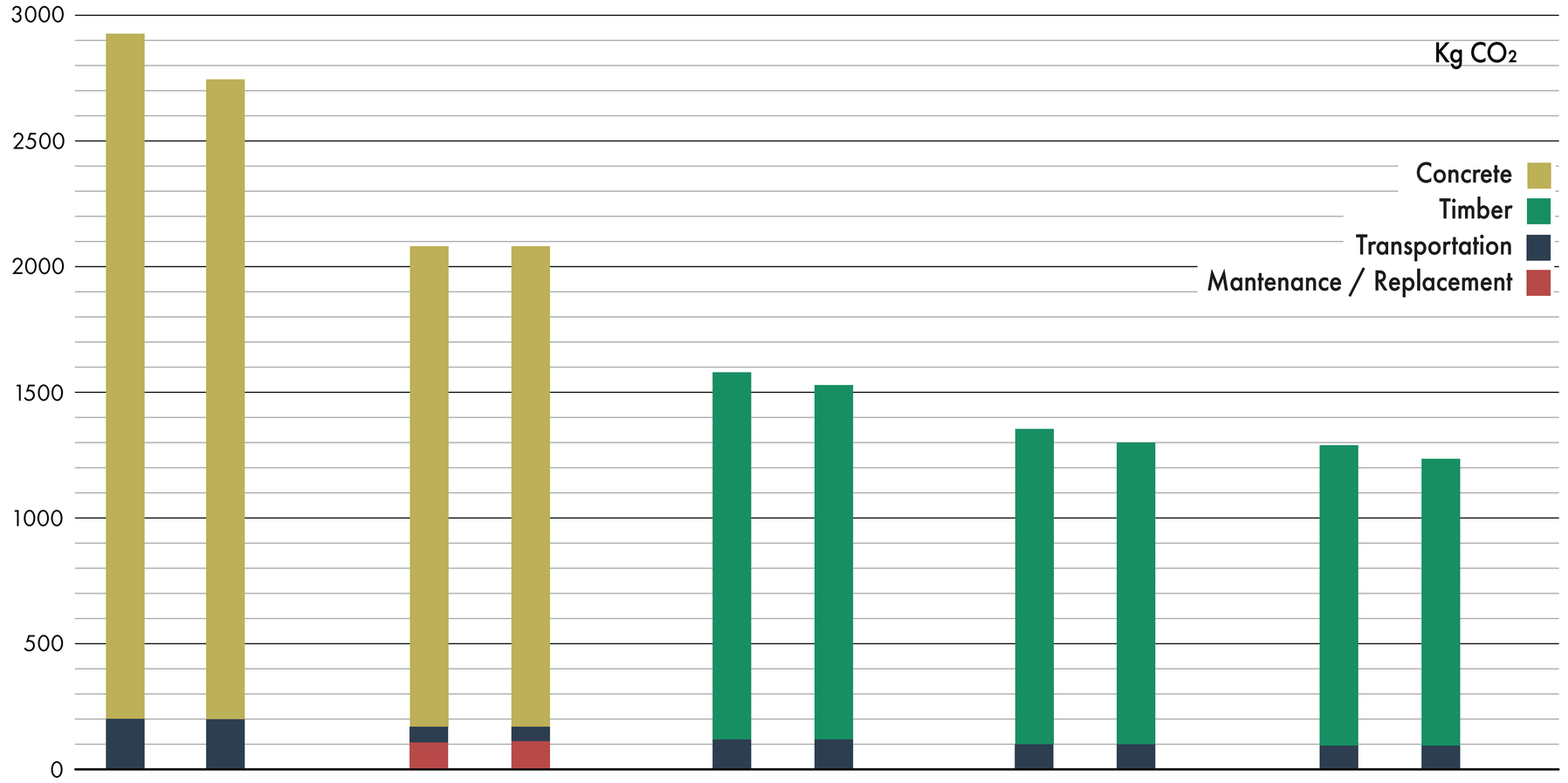
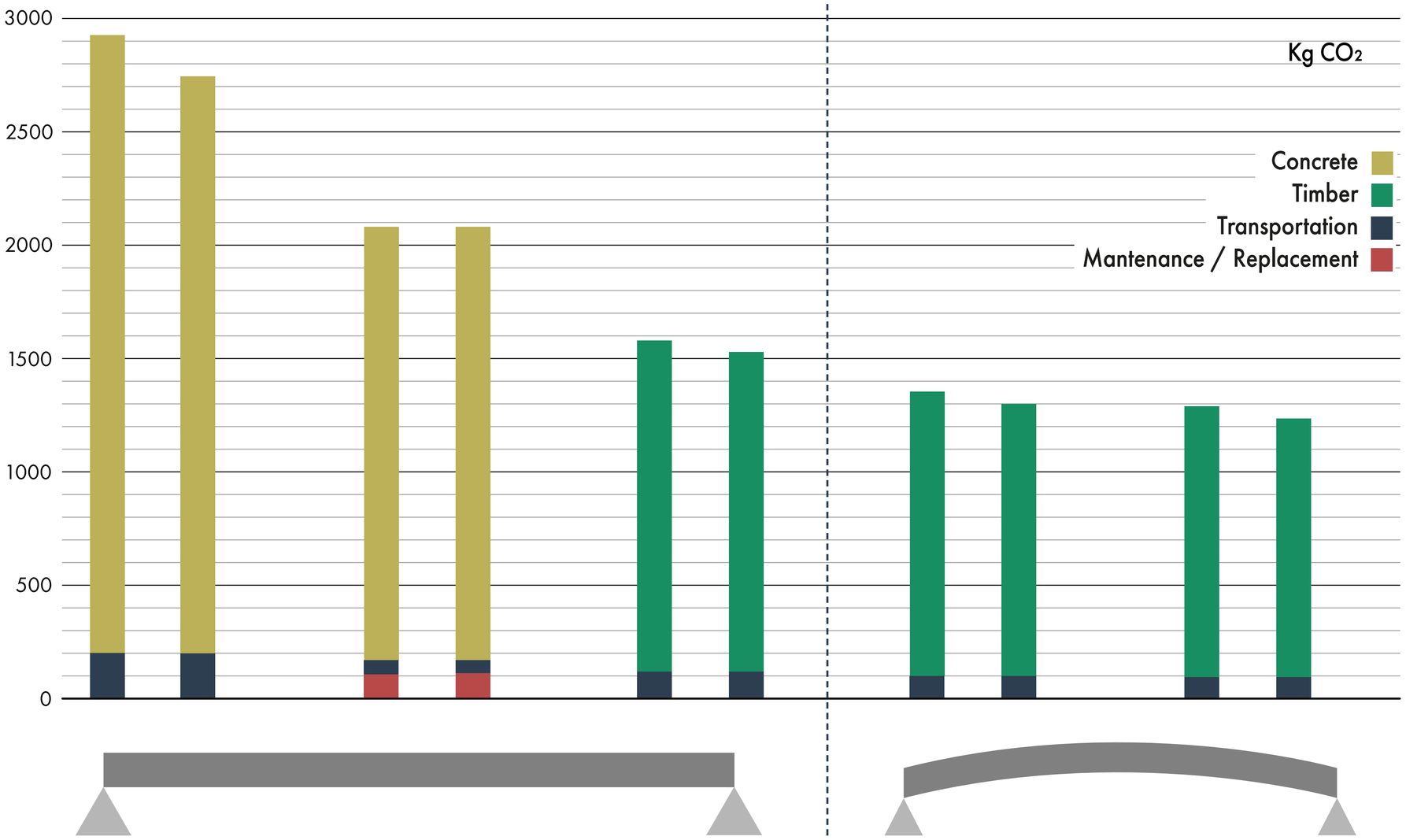


Courtesy of: https://link.springer.com/chapter/10.1007/978-3-031-36554-6_25

Today's issues

Materials



Today's issues

Form

The timber sector cannot meet the **growing demand** for complex **curved** architectural designs, resulting in its **irrelevance** compared to steel and concrete

Courtesy of: https://www.science.org/doi/10.1126/sciadv.aax1311org/10.1126/sciadv.aax1311

Today's issues

Form

Production of **curved timber** elements is **not possible**?

Courtesy of: https://www.science.org/doi/10.1126/sciadv.aax1311org/10.1126/sciadv.aax1311

Today’s issues

Form

Pudasjärvi Campus

Courtesy of: https://www.archdaily.com/871586/the-purity-of-expressive-timber-structure-celebrated-in-finlands-pudasjar-vi-campus?ad_medium=gallery

Today’s issues

Form

Kingsway pedestrian bridge, CA

Courtesy of: https:https://www.naturallywood.com/project/kingsway-pedestrian-bridge/

Today's issues

Form

Production of **curved timber** is **possible**

Today's issues

Form

Active bending by **steaming** and **adhesives** to create **curved timber** elements

Today’s issues

Form

Courtesy of: https://timberlinemag.com/2021/07/west-fraser-is-reaping-the-benefits-of-new-continuous-dry-kiln-at-pine-mill-in-florida/

Today's issues

Form

Courtesy of: https://unalam.blogspot.com/2017/

Today's issues

Form

Not an optimal bending **method**

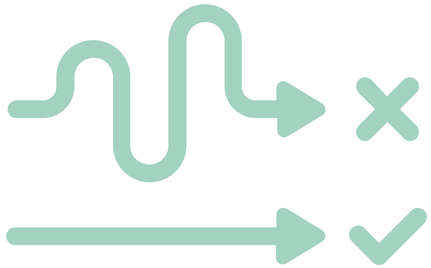
Today's issues
Form

Will **Passive** bending be the **solution**?

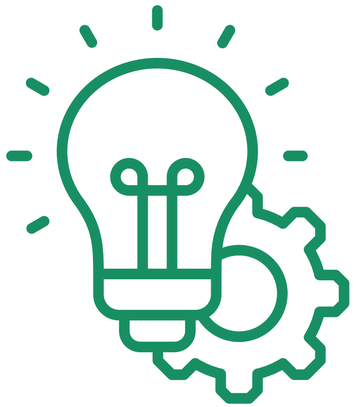
Today’s issues

Materials

Efficient



Innovative

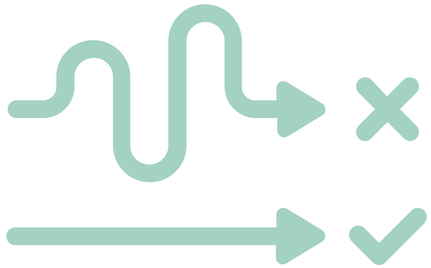


New

Today’s issues

Materials

Efficient



Innovative

New

Today’s solutions

Form

The Oseberg Ship

Courtesy of: https://nl.m.wikipedia.org/wiki/Bestand:Osebergskipet_2016.jpg

Today’s solutions

Form

Urbach Tower

Courtesy of: https://www.archdaily.com/917581/urbach-tower-icd-itke-university-of-stuttgart

Today's issues

Form

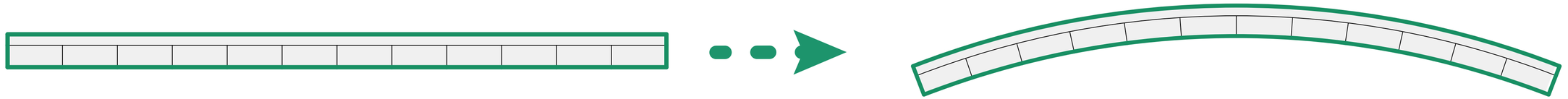
Hygroshell

Courtesy of: https://www.icd.uni-stuttgart.de/projects/hygroshell/

Manufacturing

Bi-layer

SLAB



Research Gap
Multi-layer

From **bi-layer** to complexe **multi-layer** to support structural timber floor elements

Research Question

How can curved structural floor elements be created based on self-shaping hygromorphic bi-layers?

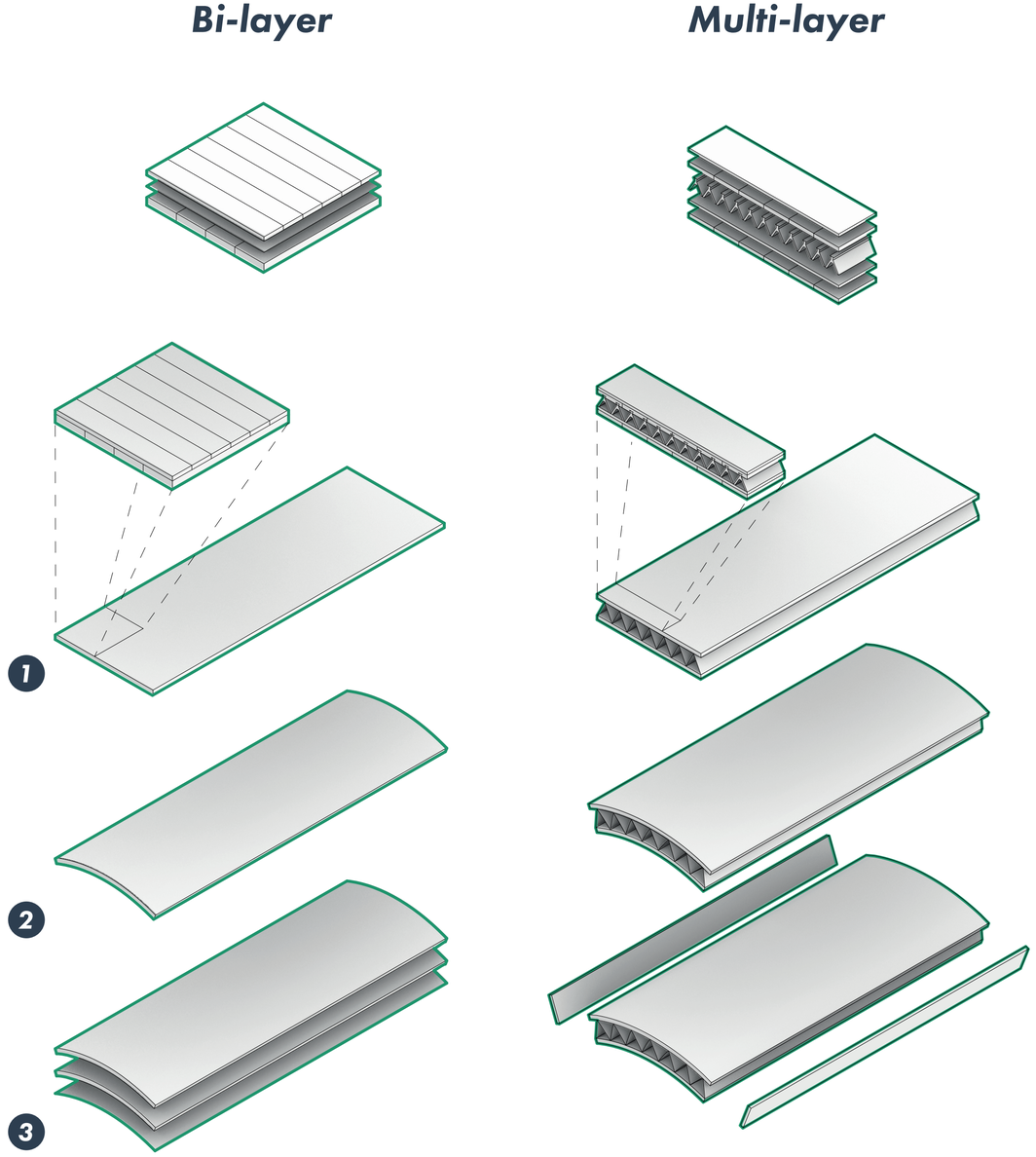
Methodology
Comparison

Bi-layer

1. Part of a whole
2. Curving due to moisture change
3. Two bi-layers + locking layer

Multi-layer

1. Part of a whole
2. Curving due to moisture change
3. Boxfloor elements



Detailing
Passive bending

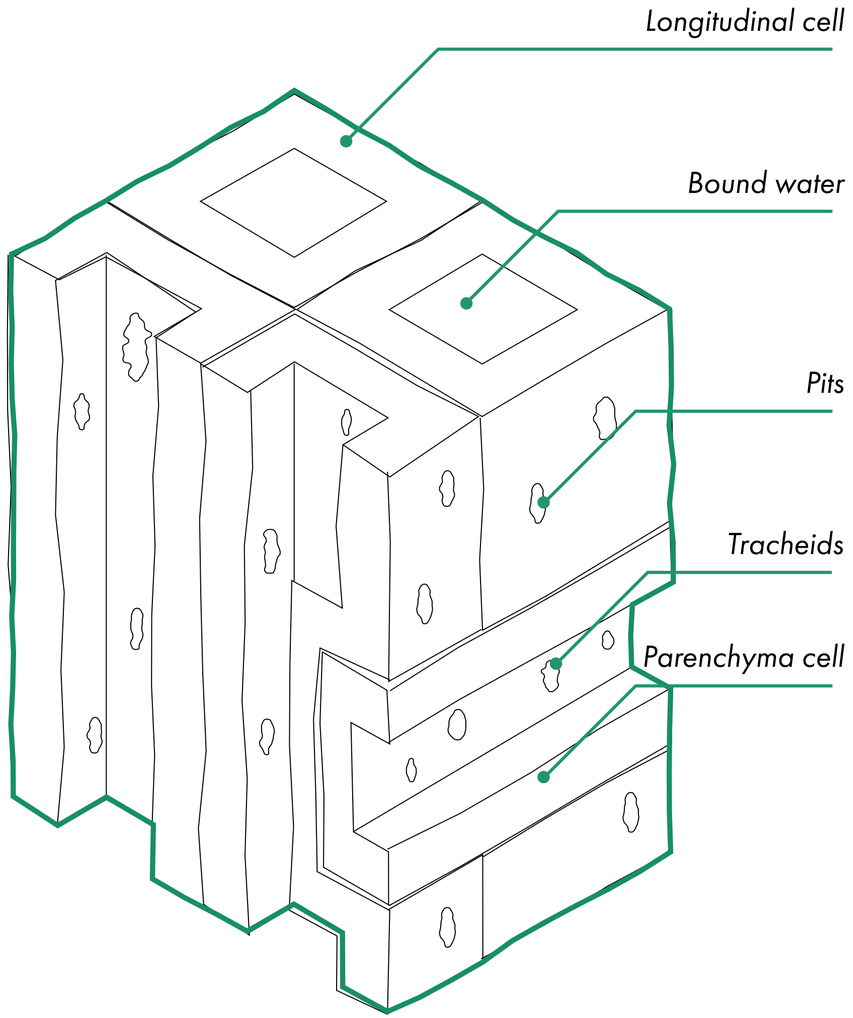
How does **hygromorphic self-shaping** work?

Detailing
Passive bending

Look at the **details**

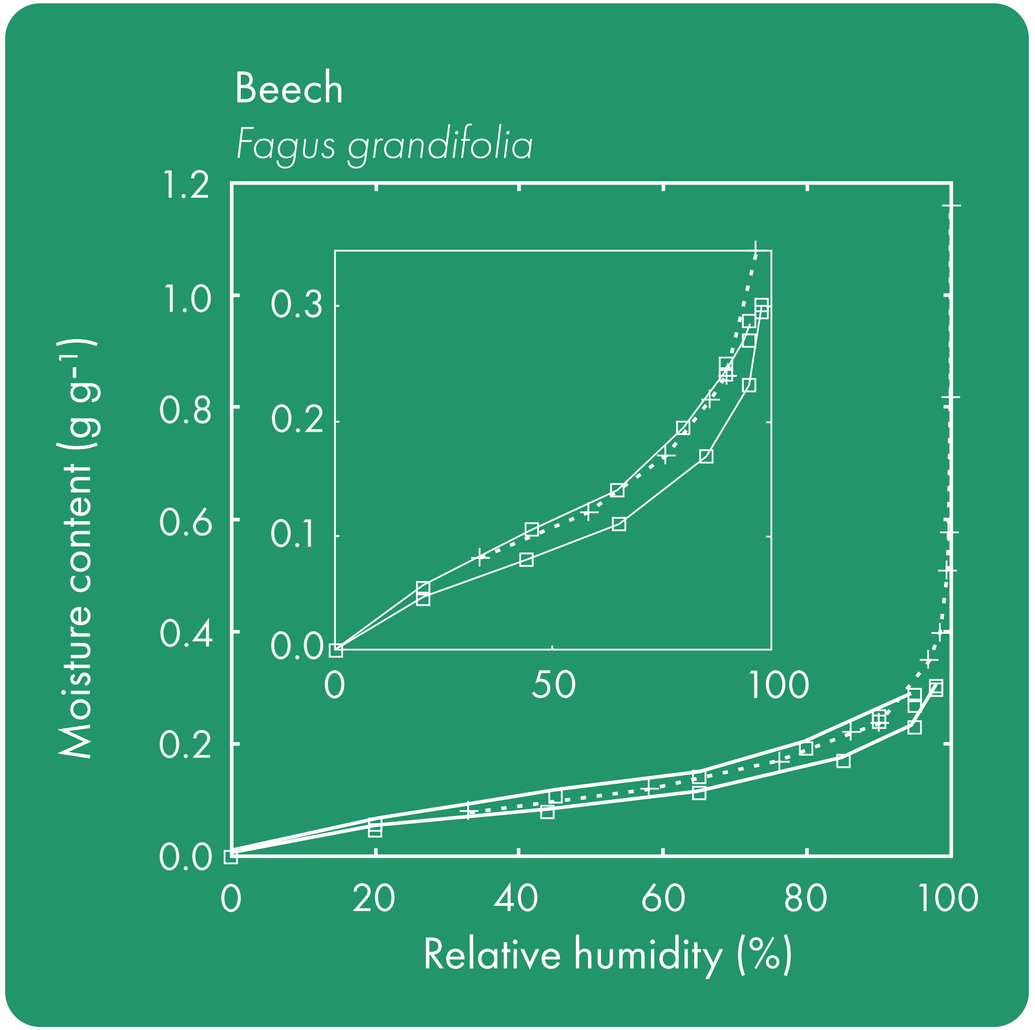
Detailing

Passive bending



Courtesy of: https://www.youtube.com/watch?v=bmmMXBd2054&list=LL&index=1&ab_channel=AaltoUniversity-Wood-Science

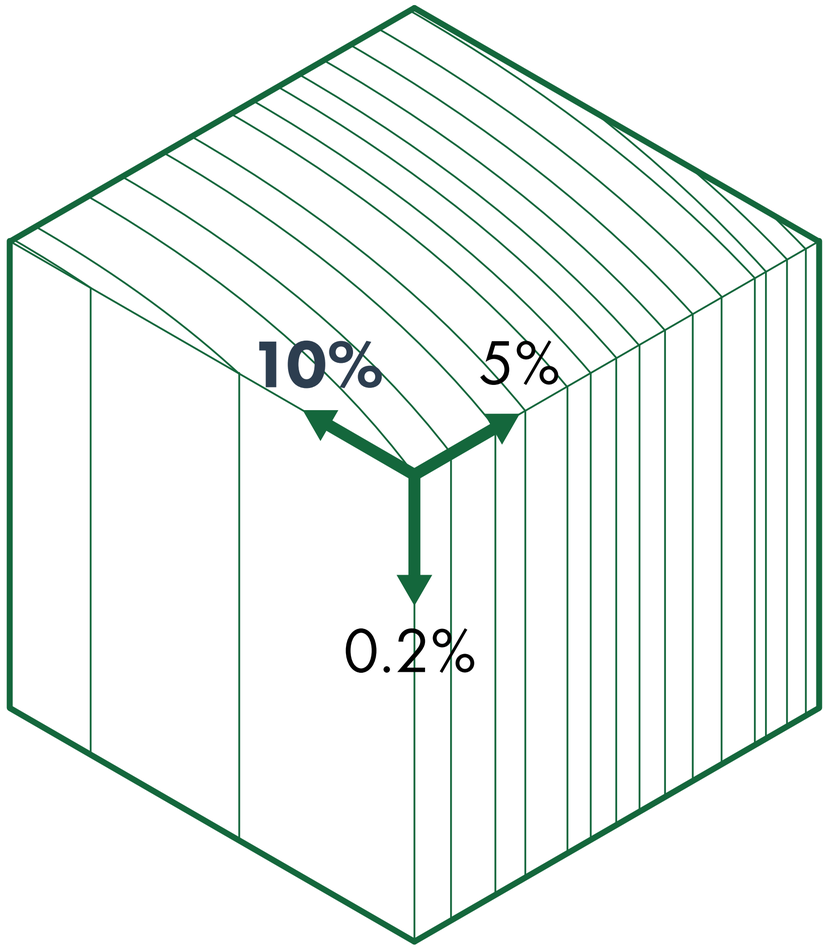
Detailing
Passive bending



Courtesy of: https://doi.org/10.1007/978-3-030-81315-4_7

Detailing

Passive bending



Courtesy of:http://www.at-carpentry.co.uk/uncategorized/is-hardwood-or-softwood-better-for-your-wooden-stair-parts/

Detailing
Passive bending

Experiment?

Detailing
Passive bending

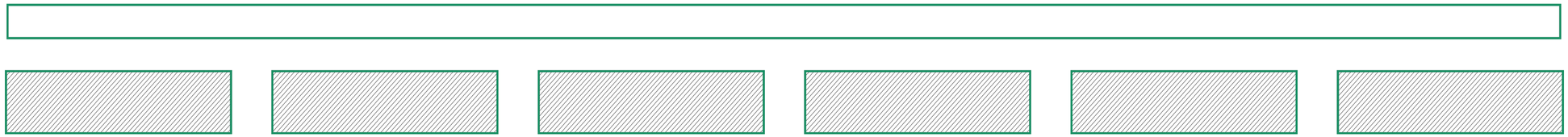
How do we **utilize** these **hygromorphic** characteristics **now**?

Manufacturing

Passive bending

Passive layer

Softwood

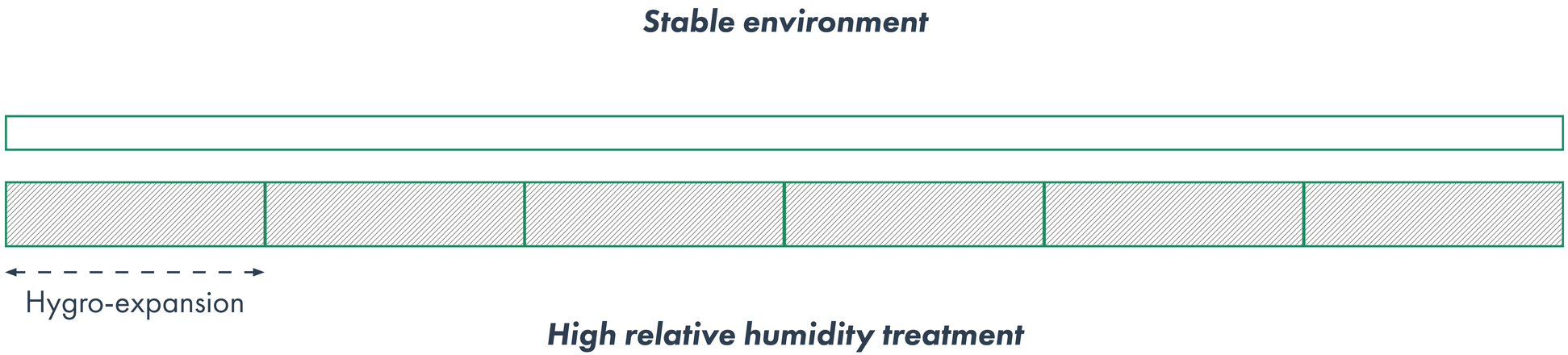


Active layer

Hardwood

Manufacturing

Passive bending

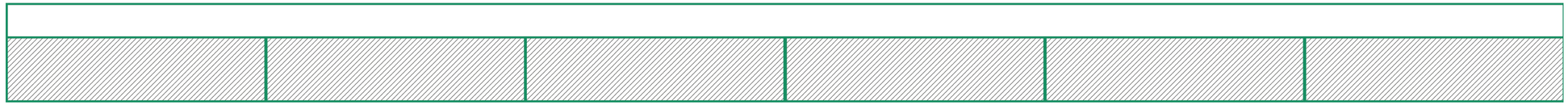


Manufacturing

Passive bending

Assembly

Adhesives

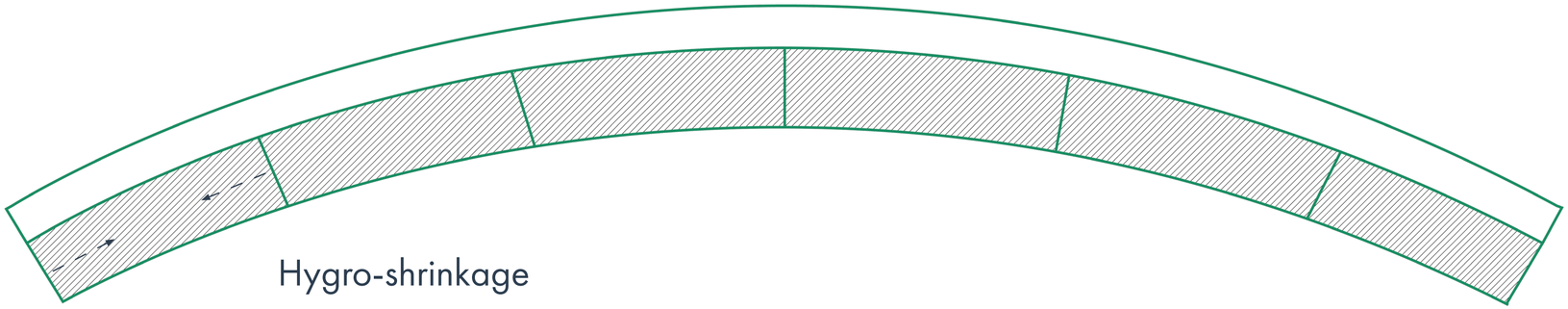


Manufacturing

Passive bending

Self-shaping

Curvature



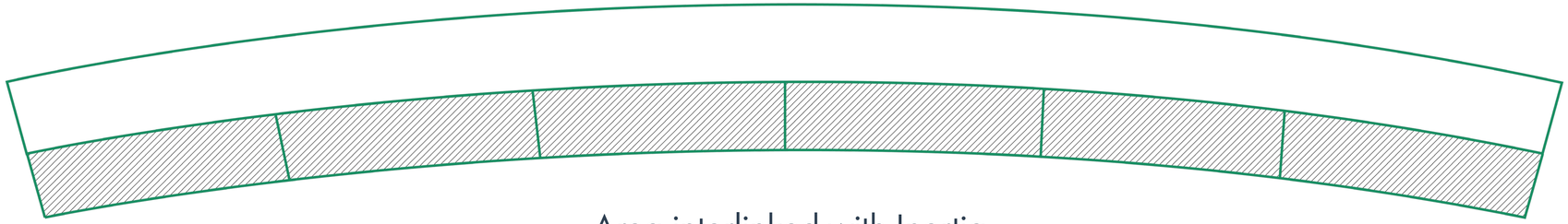
Hygro-shrinkage

Manufacturing

Passive bending

Thickness

Bending stiffness



Area interlinked with Inertia

Manufacturing

Passive bending

Courtesy of: https://www.dezeen.com/2023/03/17/tamedia-office-building-shigeru-ban-timber-revolution/

Manufacturing
Passive bending

Focus on **light elements**,
Exclude thick solid objects

Manufacturing
Passive bending

From Bi-layer to **Multi-layer** to shift from thin slabs
to **Floor elements typologies**

Practise

Bi-layer

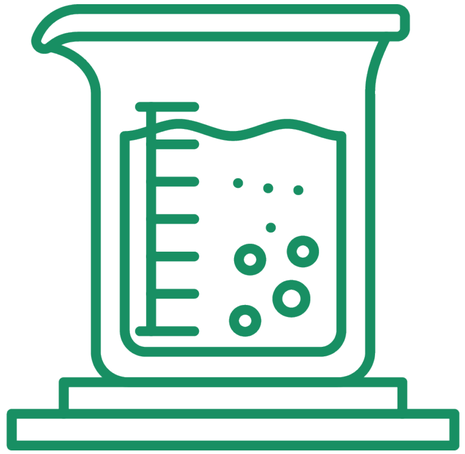
First test

Practise

Bi-layer

Analytical

Physical

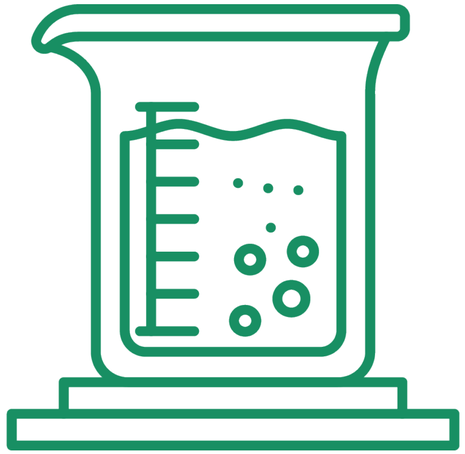


Practise

Bi-layer

Analytical

Physical



Practise

Bi-layer

Bi-layer

Practise

Bi-layer

Bi-layer

Length: 1025mm
Curve height: 10mm

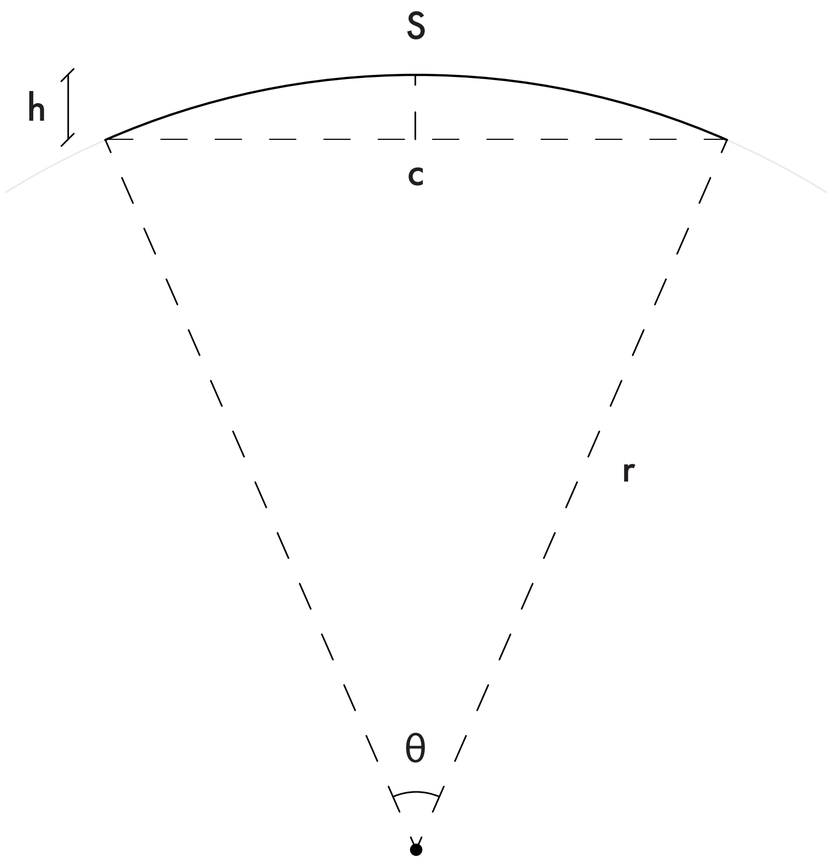
Practise

Bi-layer

$$k \approx k_0 \left[\frac{h_1 + h_2}{2} + \frac{2(E_1 I_1 + E_2 I)_2}{h_1 + h_2} \left(\frac{1}{E_1 h_1} + \frac{1}{E_2 h_2} \right) \right]^{-1} (\alpha_2 - \alpha_1)$$

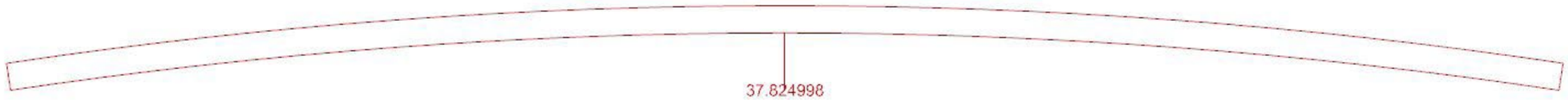
E : Young's modulus (Stiffness)
I : Inertia (Area)
a : Poisson ratio (Direction of cells)
h : Height (Thickness)

Timoshenko



Practise

Bi-layer



Practise

Bi-layer

Curve height: 10mm vs 37.8mm

Resemblance / Reached : 26.4%

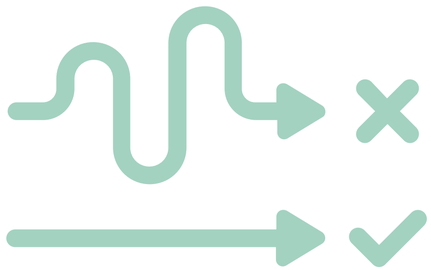
Manufacturing
Passive bending

Self-shaping principle works on bi-layer,
now Multi-layer

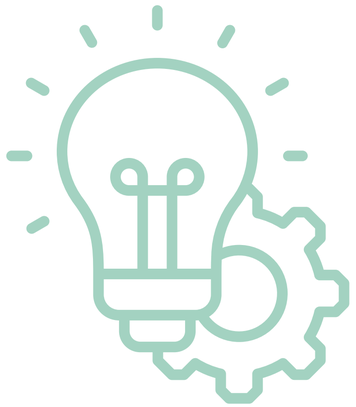
Today’s issues

Materials

Efficient



Innovative

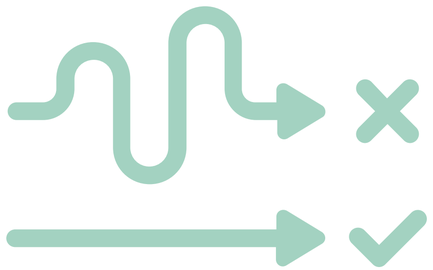


New

Today’s issues

Materials

Efficient



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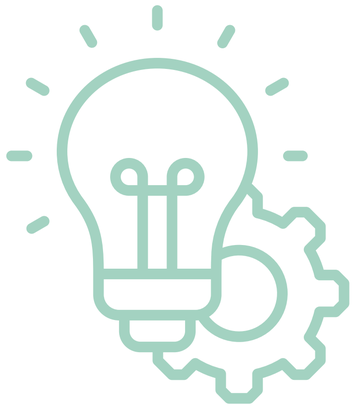
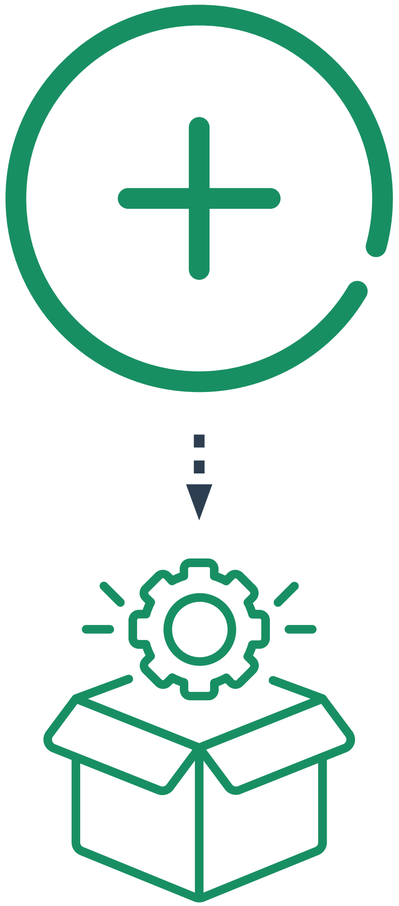


New



Context & Designing

Context

Courtesy of: https://thespaces.com/gallery-like-noho-loft-has-towering-barrel-vaulted-ceilings/

Context

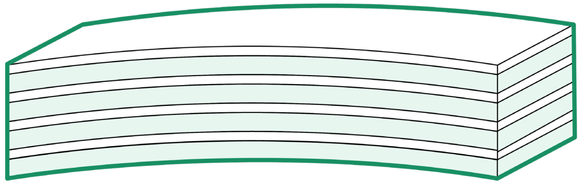
Curvature

Length to height ratio 1:8 to 1:12
Curve height: 10cm :1200mm width

Courtesy of: https://thespaces.com/gallery-like-noho-loft-has-towering-barrel-vaulted-ceilings/

Manufacturing

Passive bending

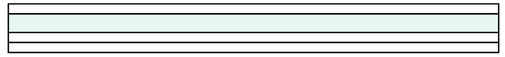


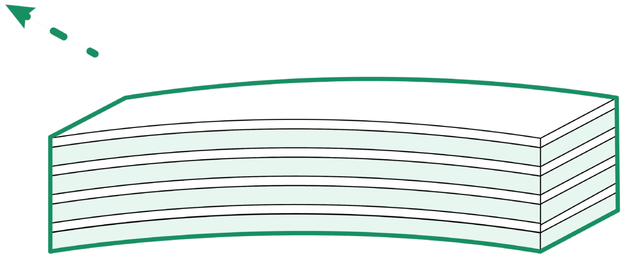
Structural element

Manufacturing

Passive bending

Double passive

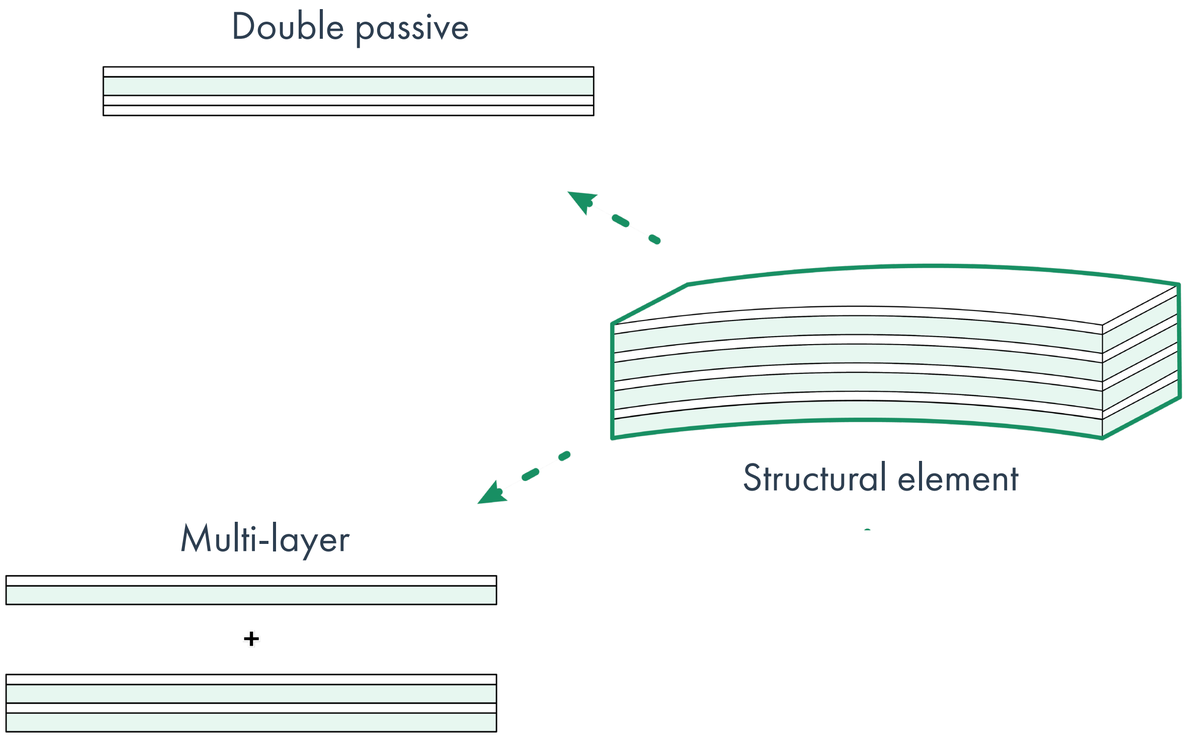




Structural element

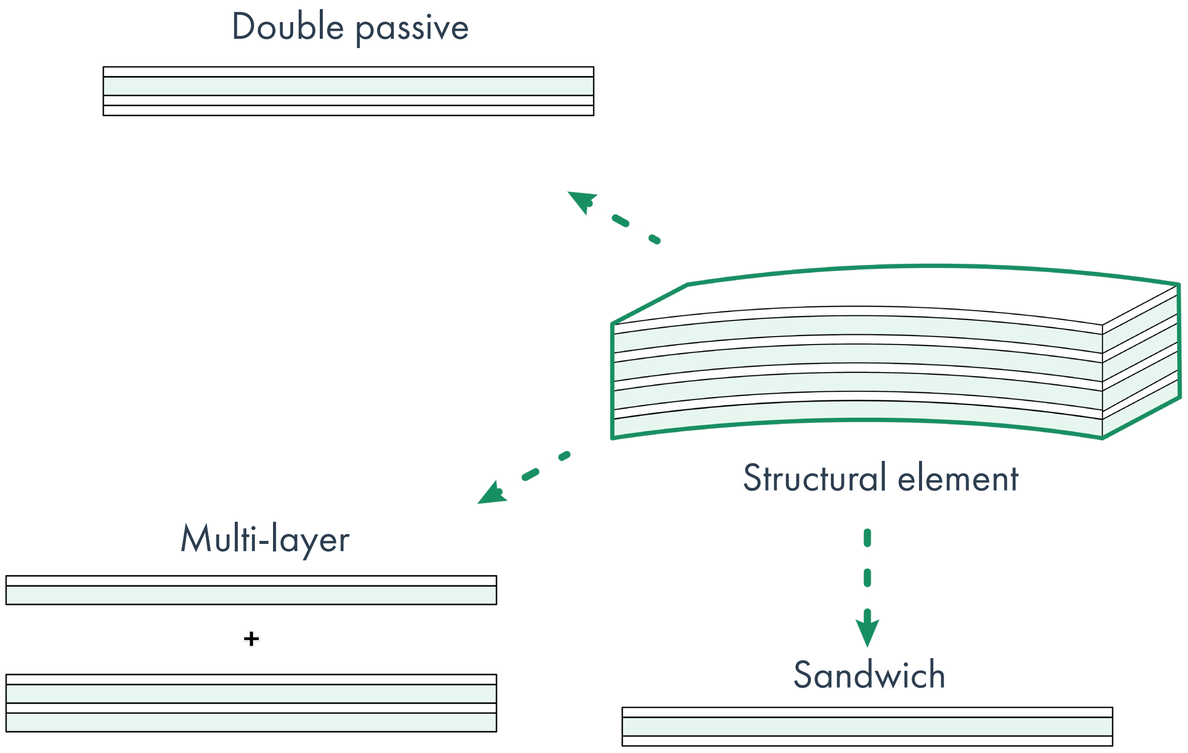
Manufacturing

Passive bending



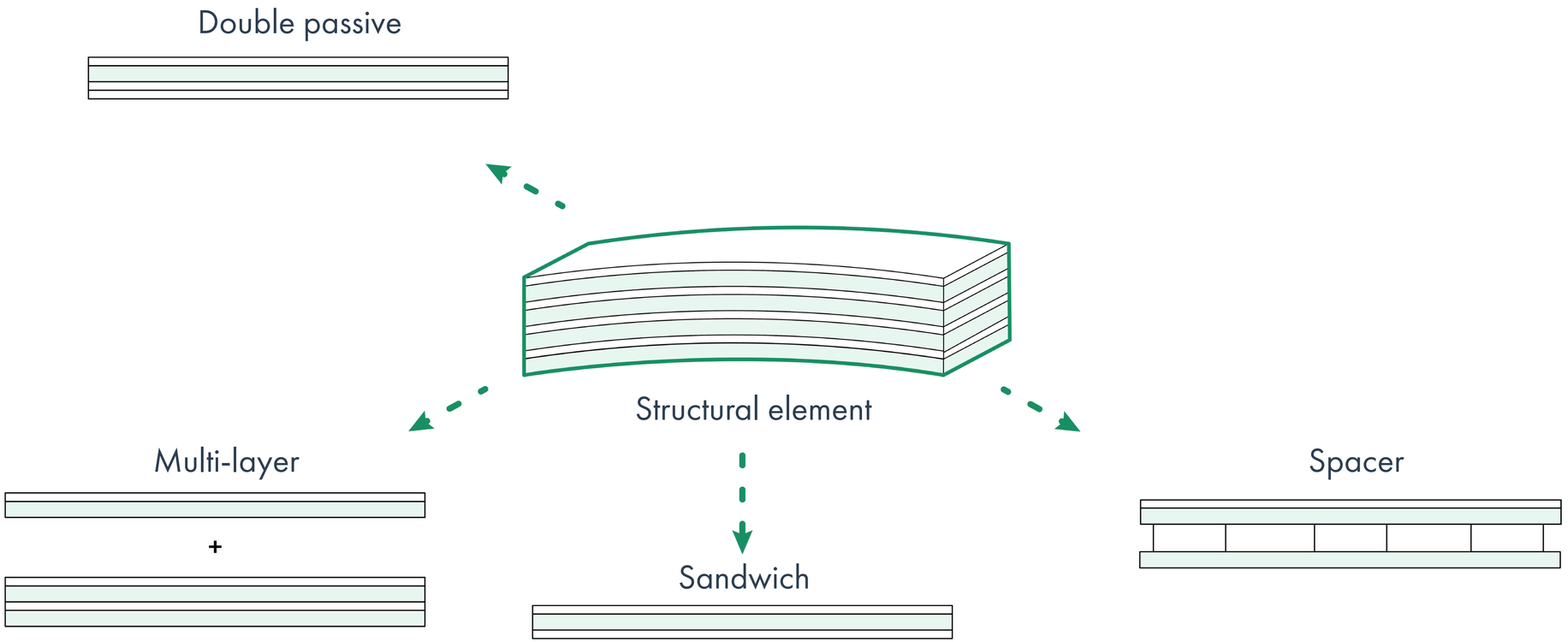
Manufacturing

Passive bending



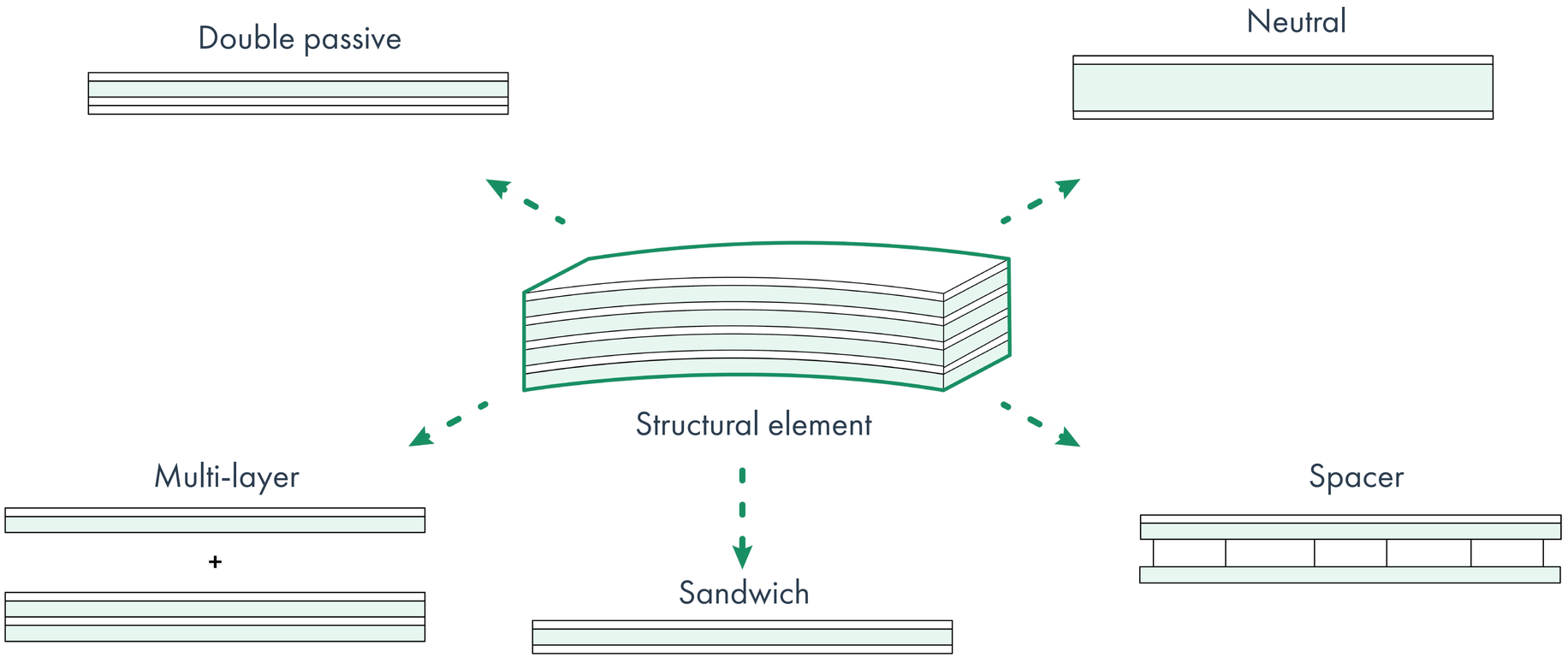
Manufacturing

Passive bending



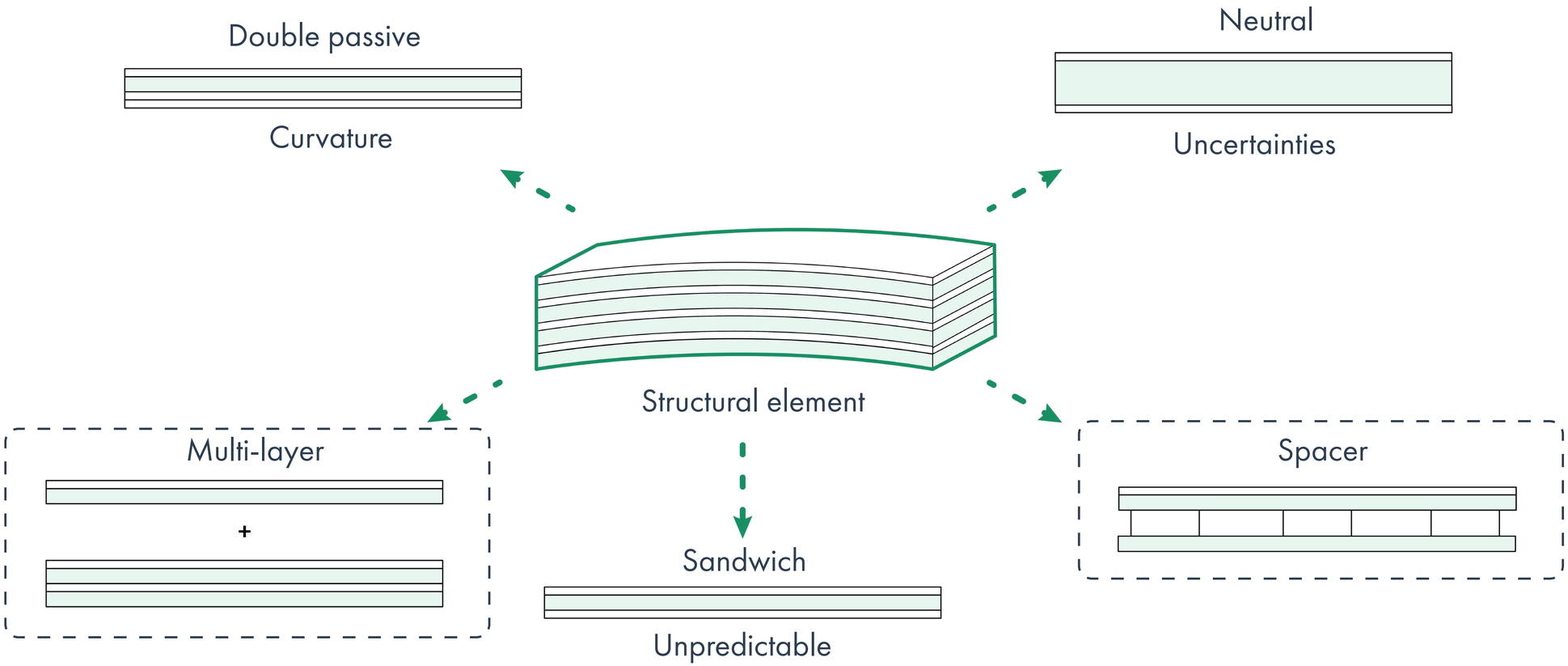
Manufacturing

Passive bending



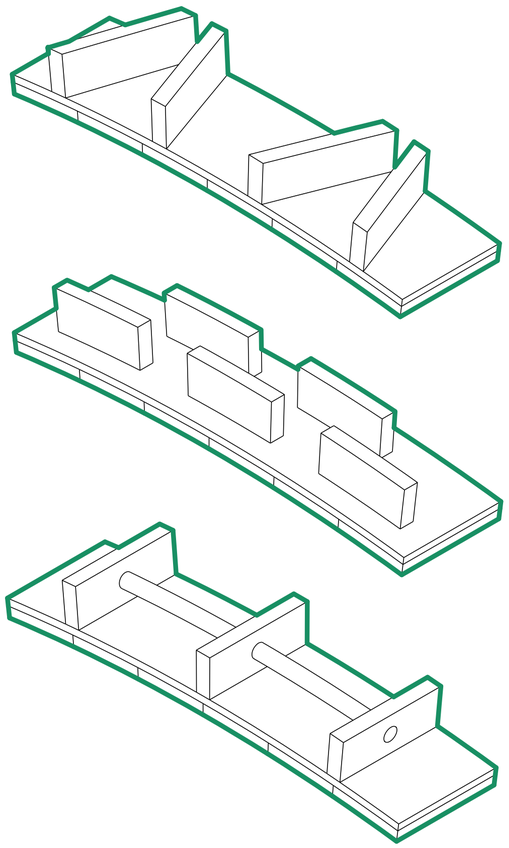
Manufacturing

Passive bending

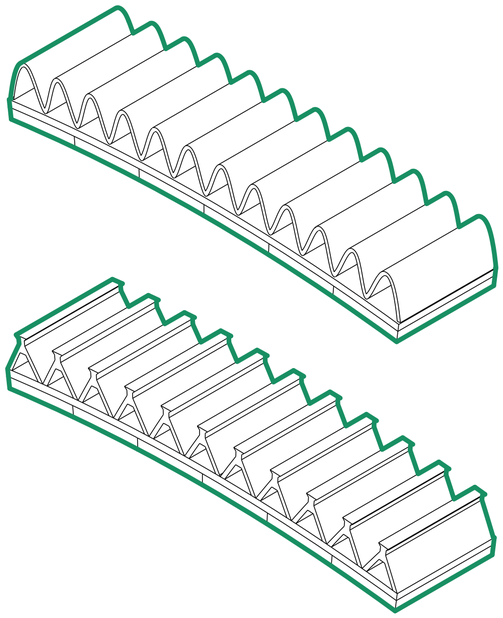


Design
Complex layer

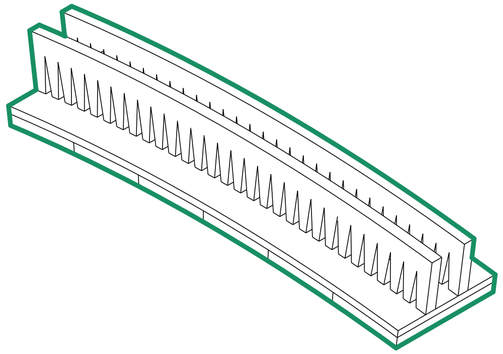
Straight



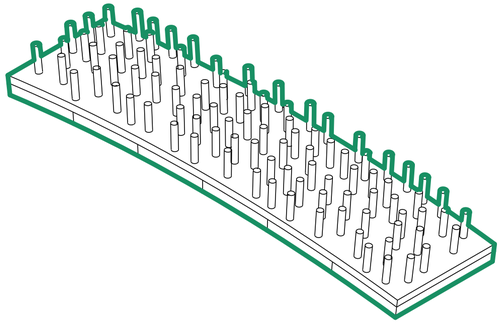
Truss



Comb

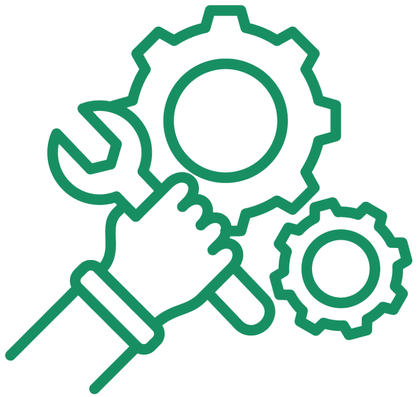


Rods

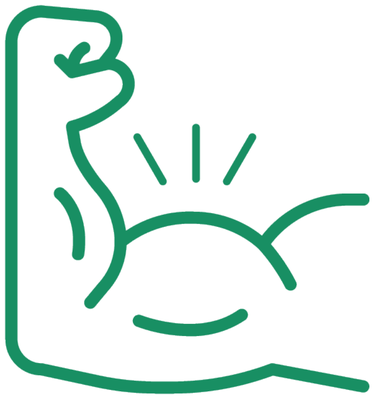


Design
Complex layer

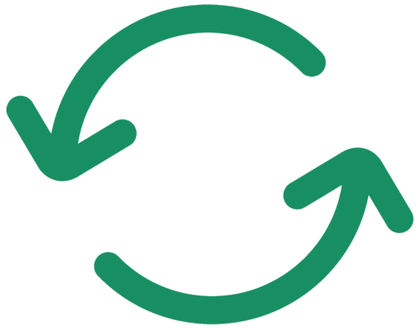
Manufacturing



Structurally



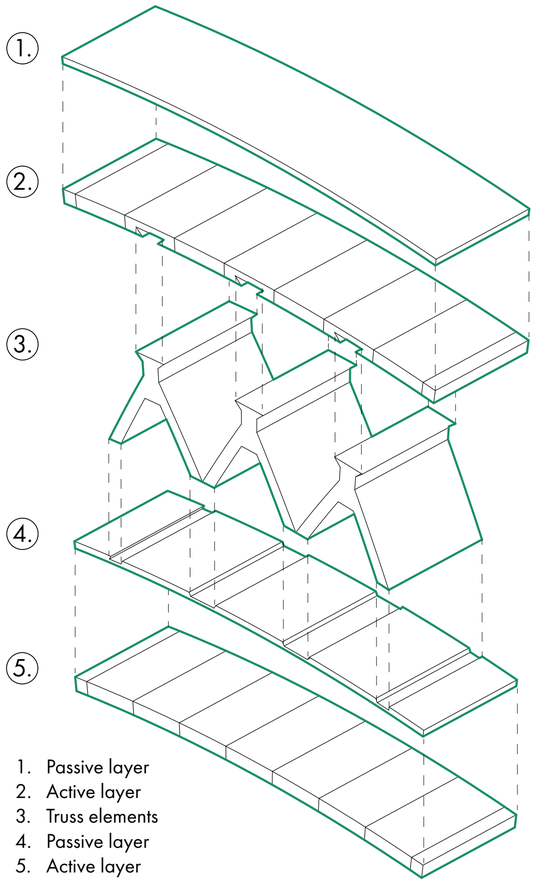
Circularity



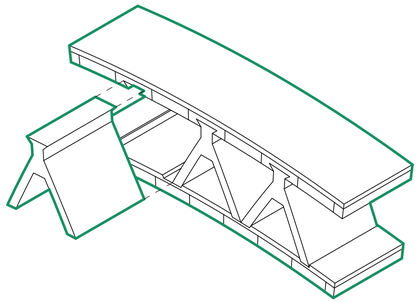
Curvature

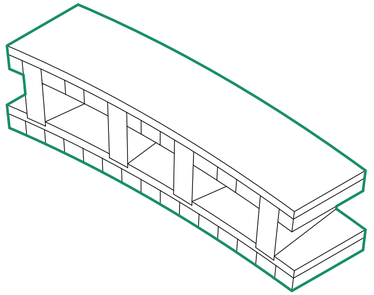
Design
Complex layer

Y-shape

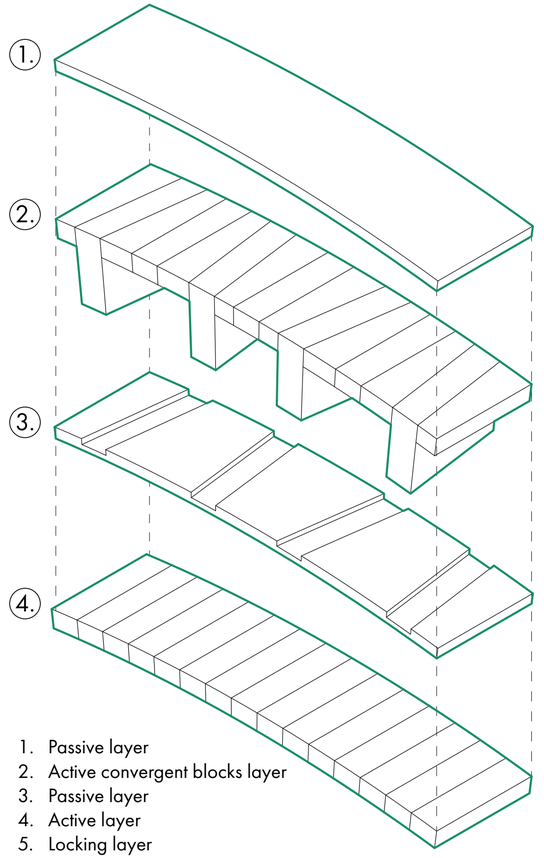


1. Passive layer
2. Active layer
3. Truss elements
4. Passive layer
5. Active layer





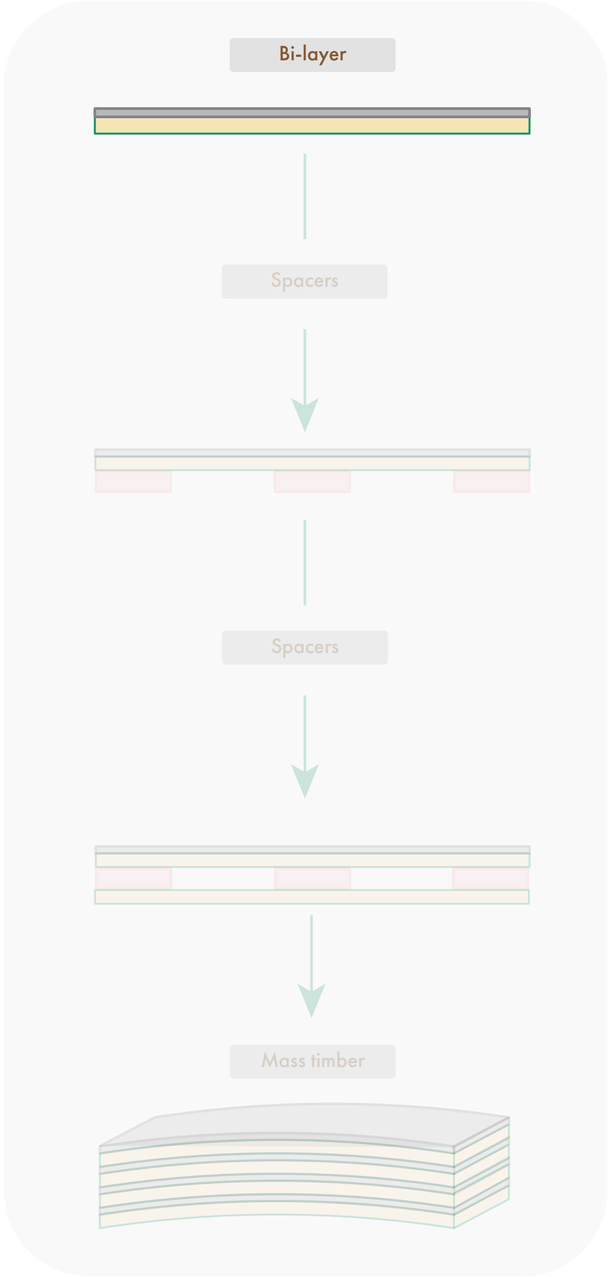
Convergent



1. Passive layer
2. Active convergent blocks layer
3. Passive layer
4. Active layer
5. Locking layer

Testing

Testing
Approach



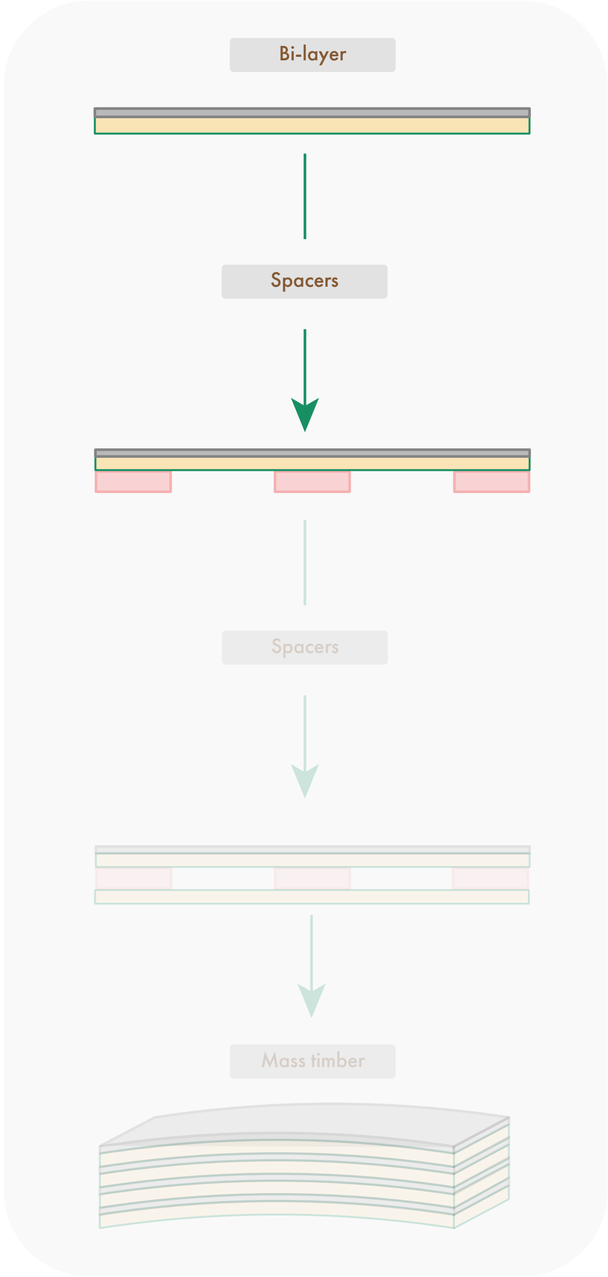
Testing
Laboratory

Testing
Laboratory

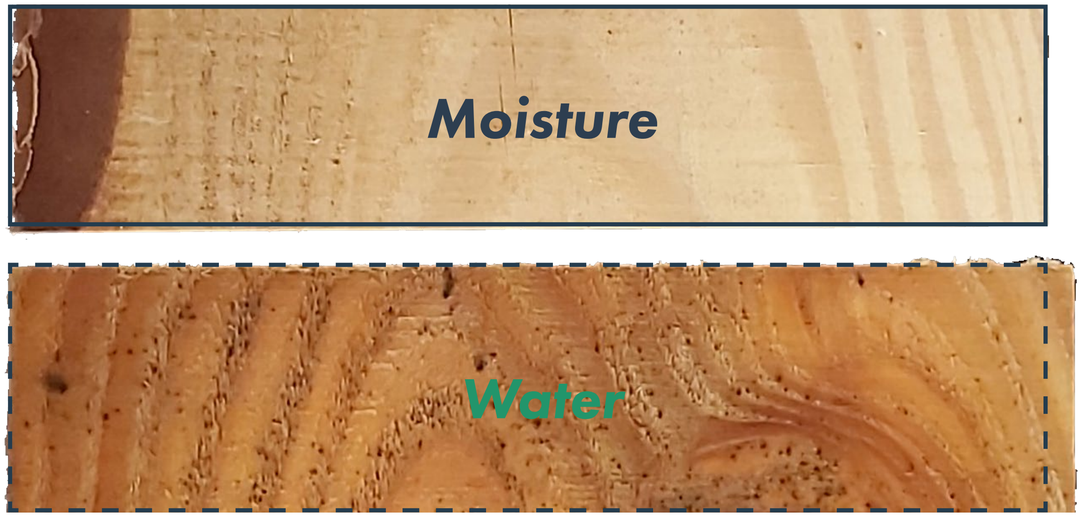
Testing
Laboratory

Testing
2

Testing
Approach



Testing
2



Testing
2

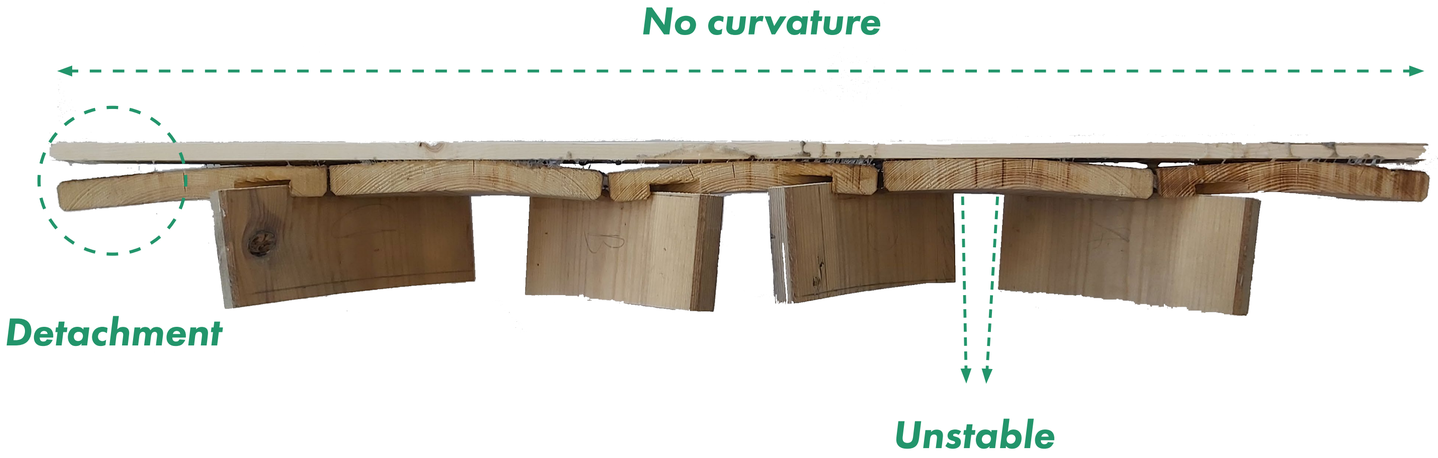
Moisture

No curvature

Testing
2

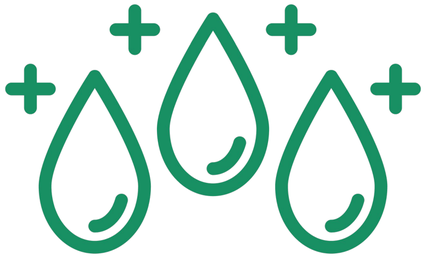
Moisture

Water

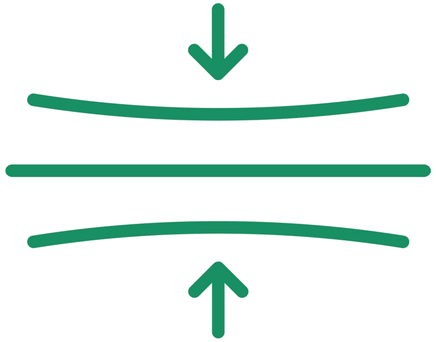


Testing
2

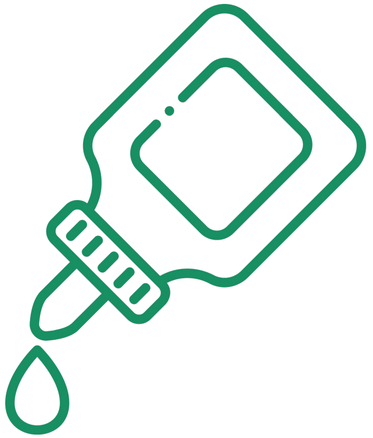
Treatment
Water vs. Moisture



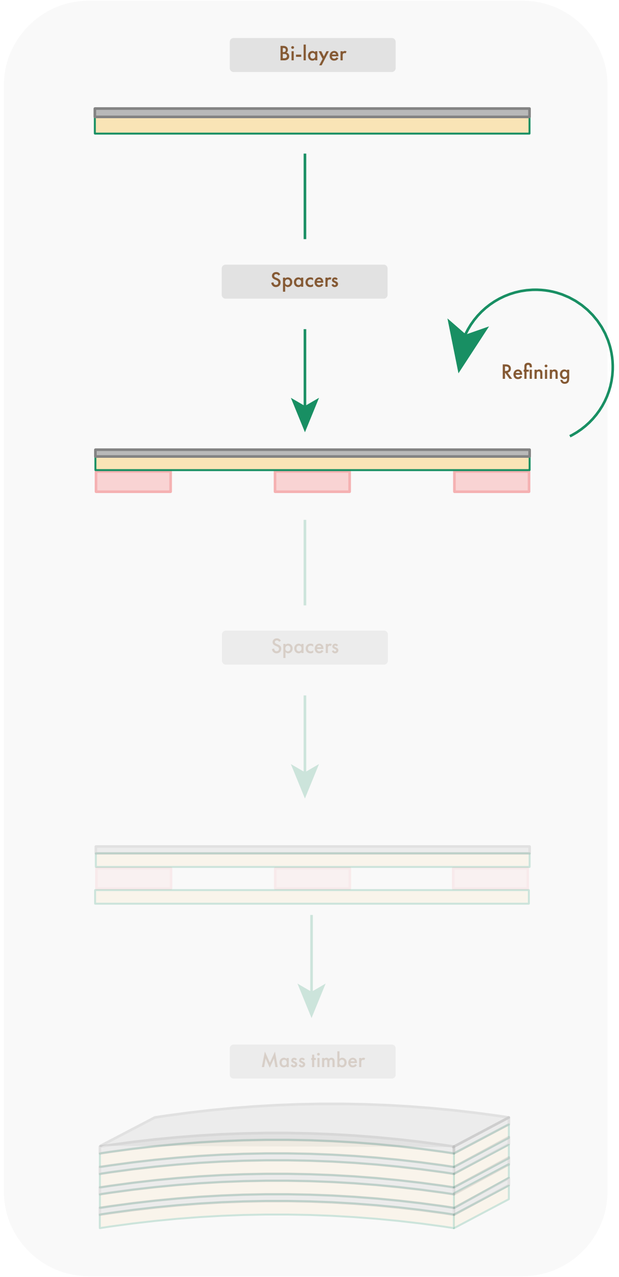
Material
Thickness



Adhesive
Strength



Testing
Approach



Testing
3

Moisture

Length: 1000mm
Curve height: 22,4mm
Reached: 26,8%

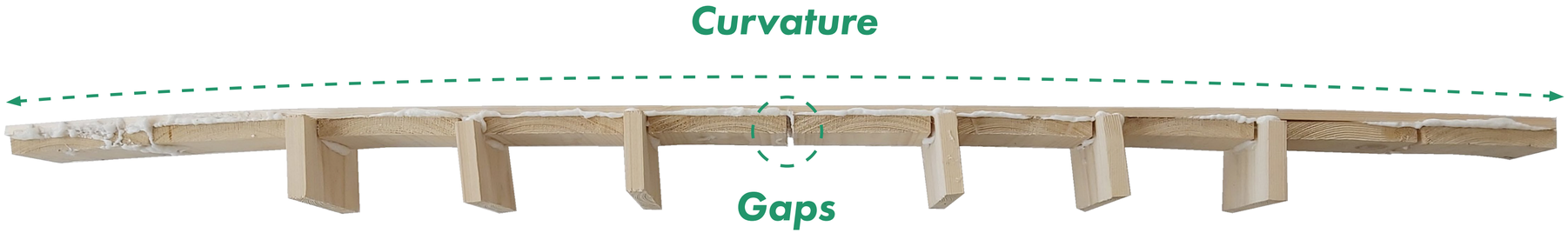
Testing
3

Moisture

Length: 1000mm
Curve height: 22,4mm
Reached: 26,8%

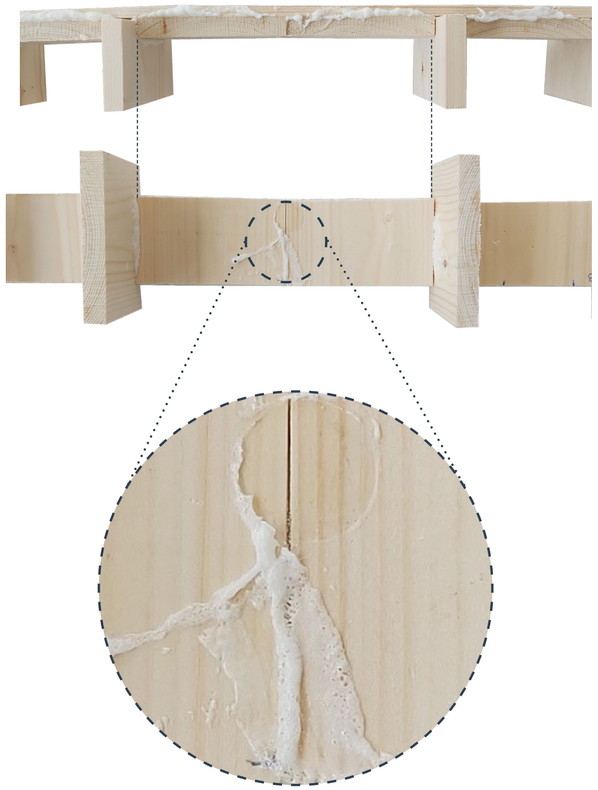
Water

Length: 1000mm
Curve height: 11,8mm
Reached: 13,6%

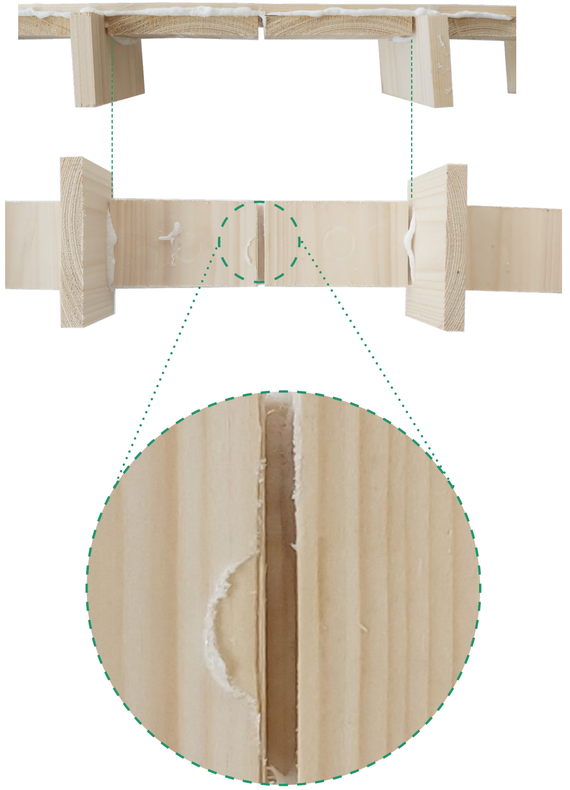


Testing
3

Moisture

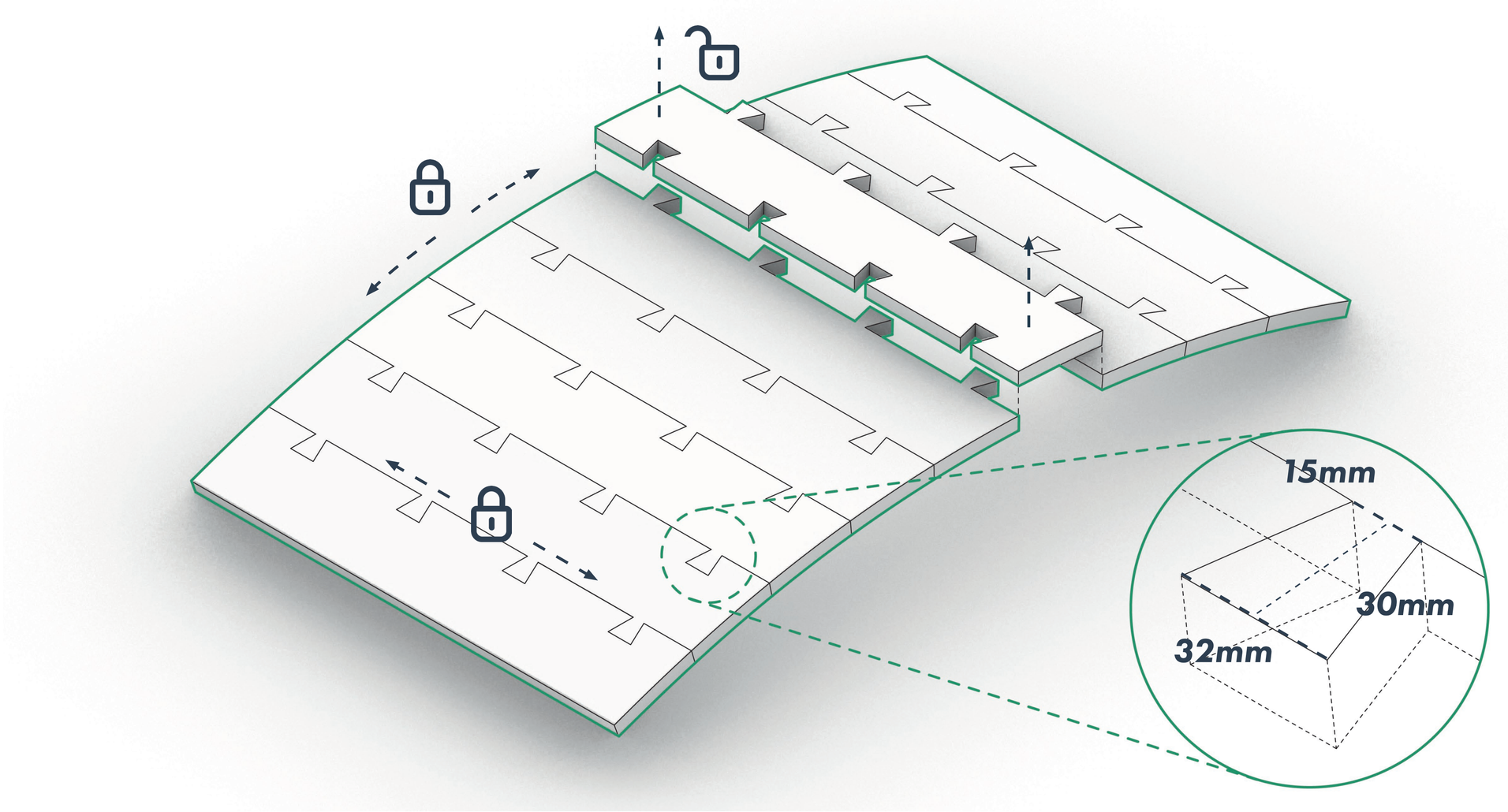


Water

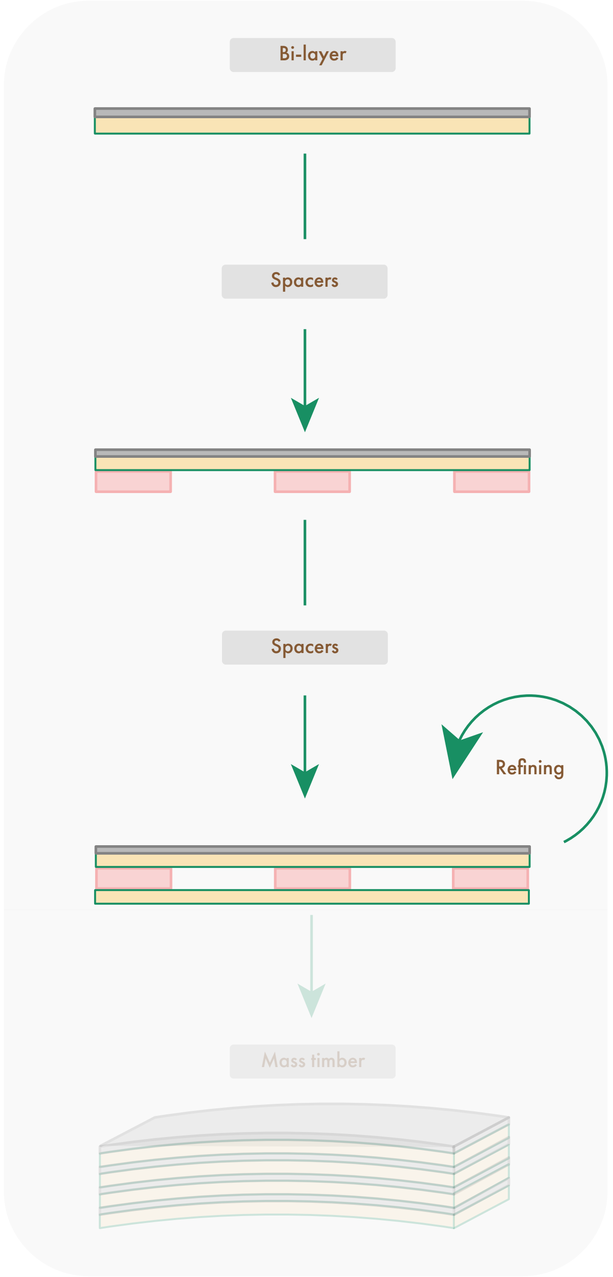


Testing

3



Testing
Approach



Testing

4

Boxfloor
(Softwood)

Moisture

Length: 985mm
Curve height: 5mm
Reached: 6,1%

Convergent

Testing
4

Boxfloor
(Softwood)

Moisture

Length: 985mm
Curve height: 5mm
Reached: 6,1%

Convergent

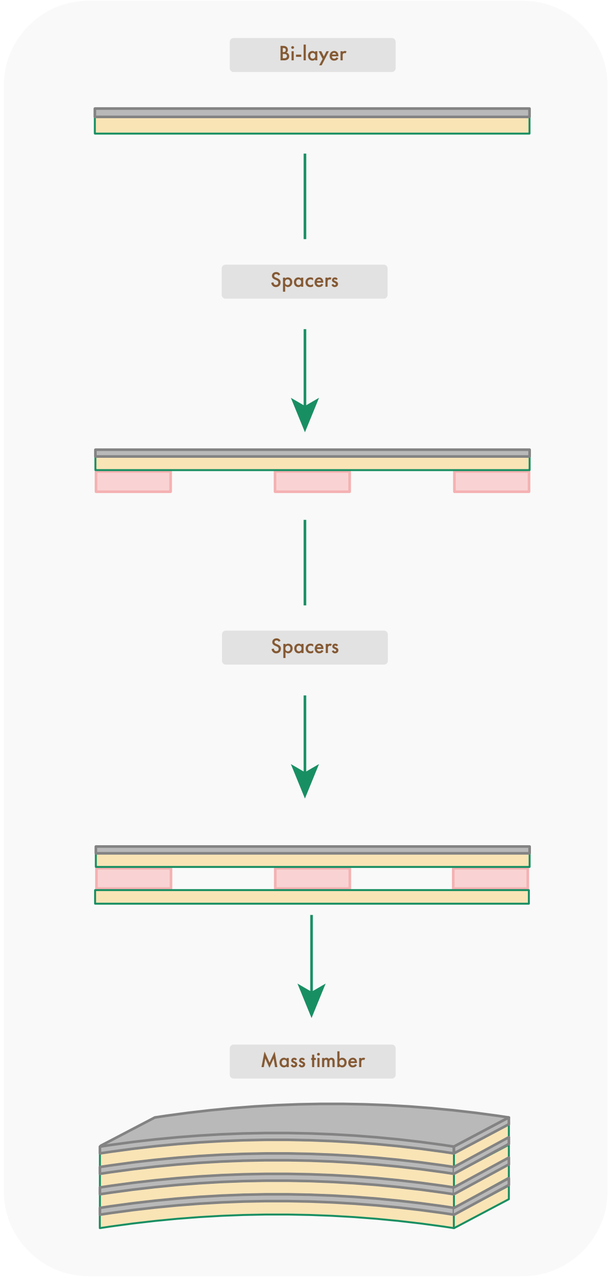
Boxfloor
(Hardwood)

Moisture

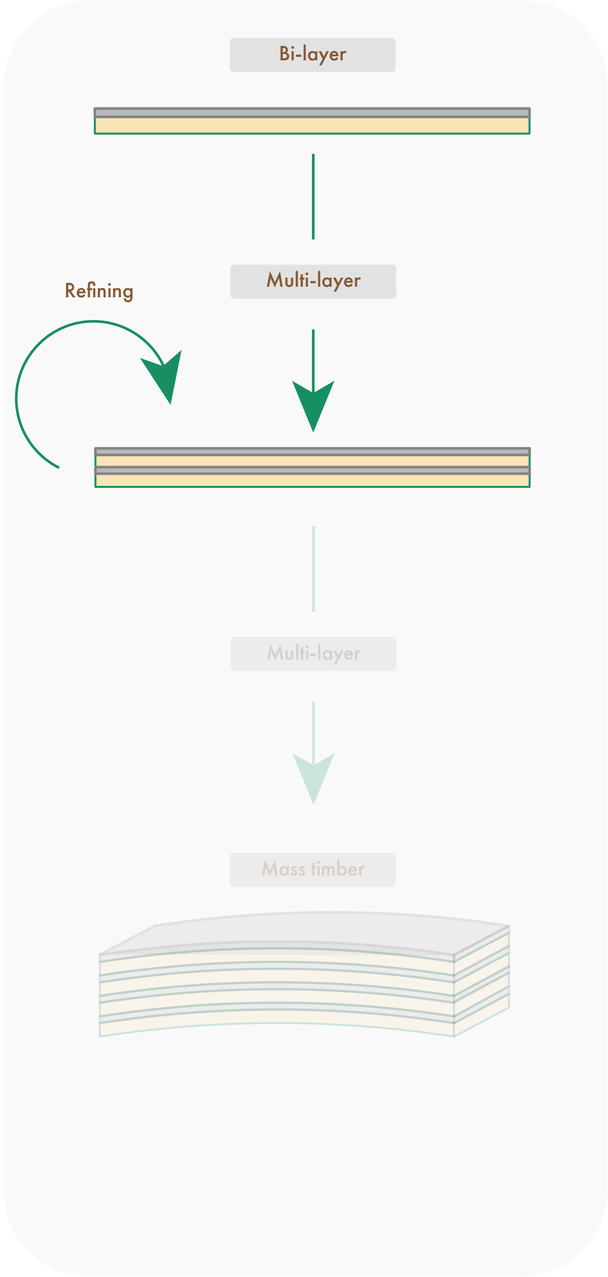
Length: 953mm
Curve height: 7mm
Reached: 8,8%

Hardwood

Testing
Approach



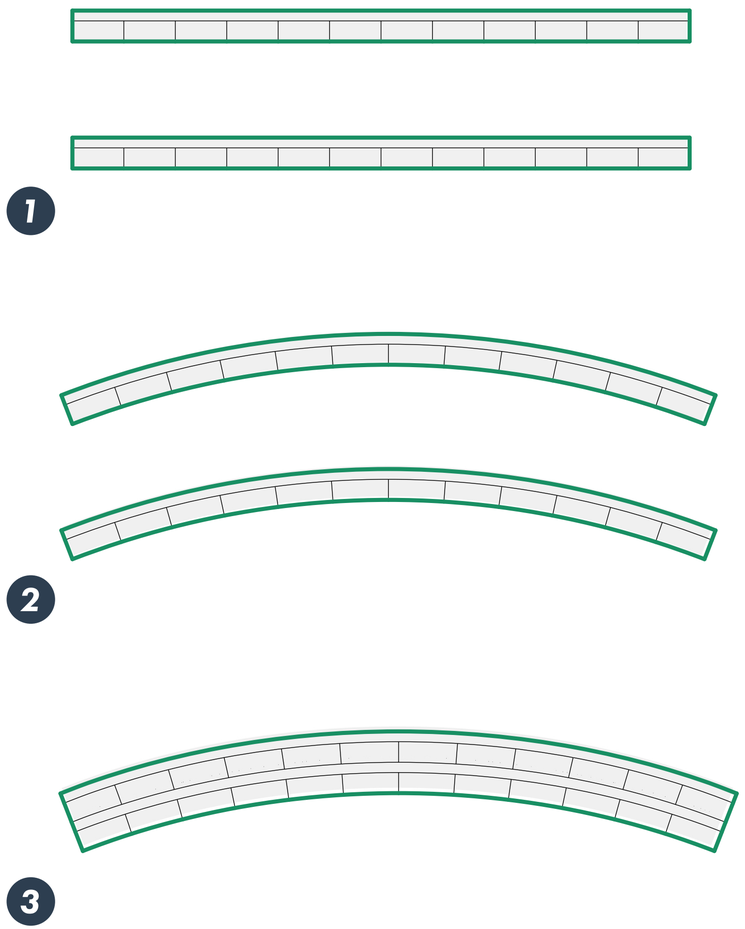
Testing
Approach



Testing

4

Classic

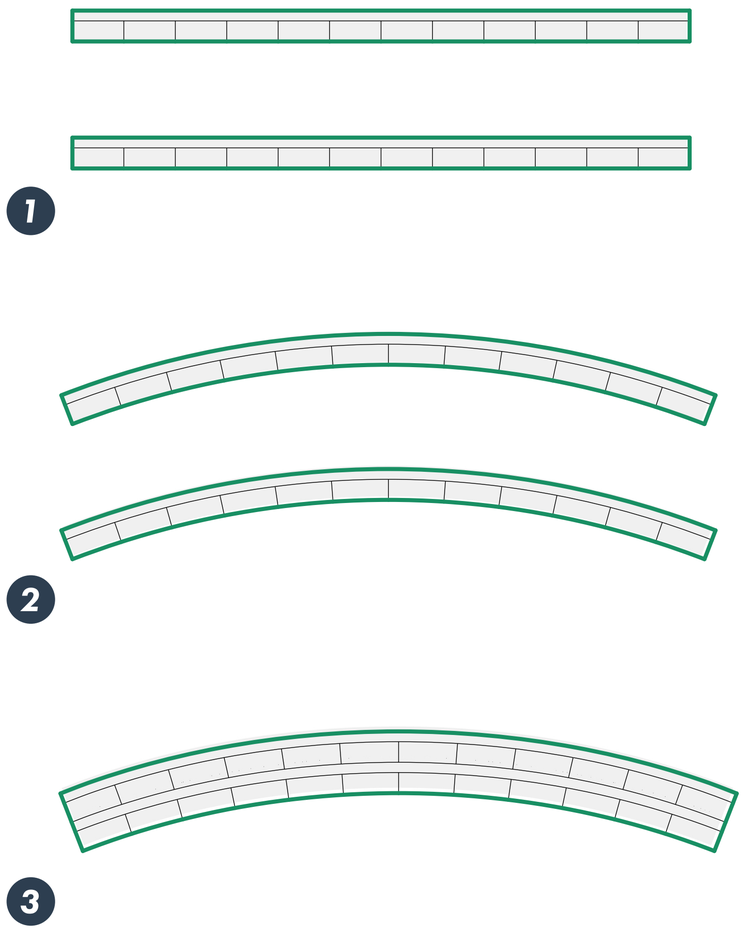


1. Bi-layers
2. Passive self-shaping
3. Assembly

Testing

4

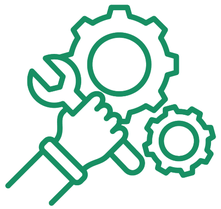
Classic



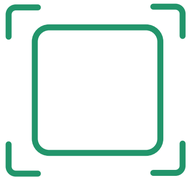
1. Bi-layers
2. Passive self-shaping
3. Assembly

Time-consuming

Work-intensive



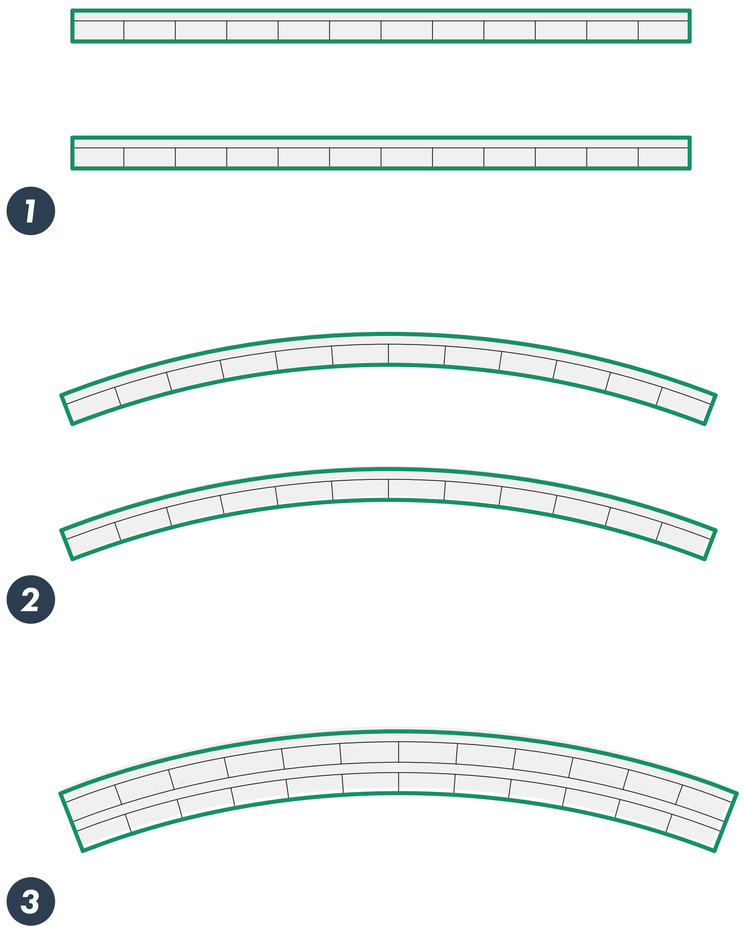
Spacious



Testing

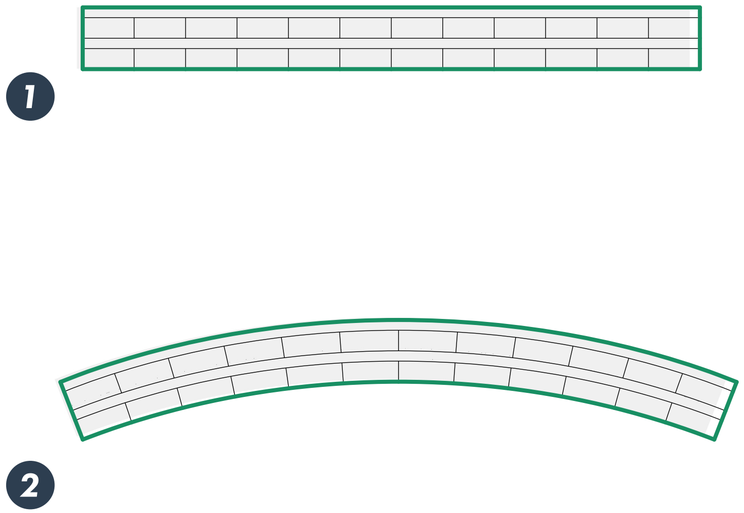
4

Classic



1. Bi-layers
2. Passive self-shaping
3. Assembly

Proposed



1. Assembly bi-layers
2. Passive self-shaping

Testing
4

Multi-layer

Moisture

Testing
4

Boxfloor
(Softwood)

Moisture

Length: 985mm
Curve height: 5mm
Reached: 6,1%

Convergent

Boxfloor
(Hardwood)

Moisture

Length: 953mm
Curve height: 7mm
Reached: 8,8%

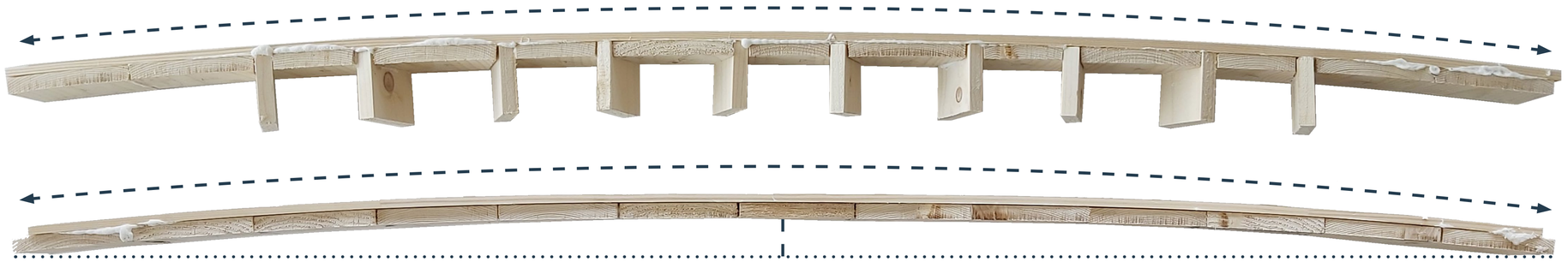
Hardwood

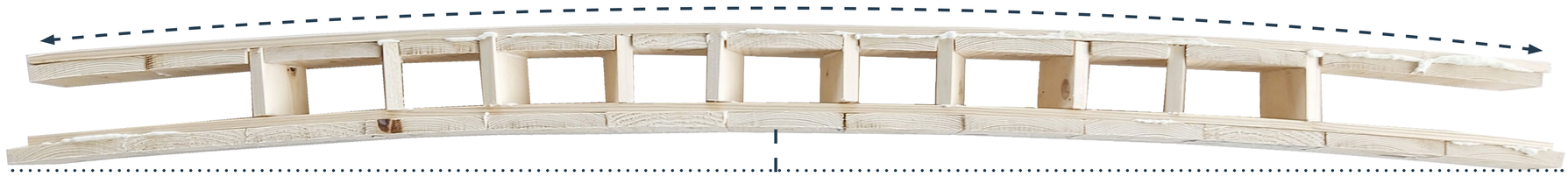
Testing

5

Boxfloor

(Softwood)





Moisture

Length: 1148mm
Curve height: 30mm
Reached: 27,7%

Testing
5

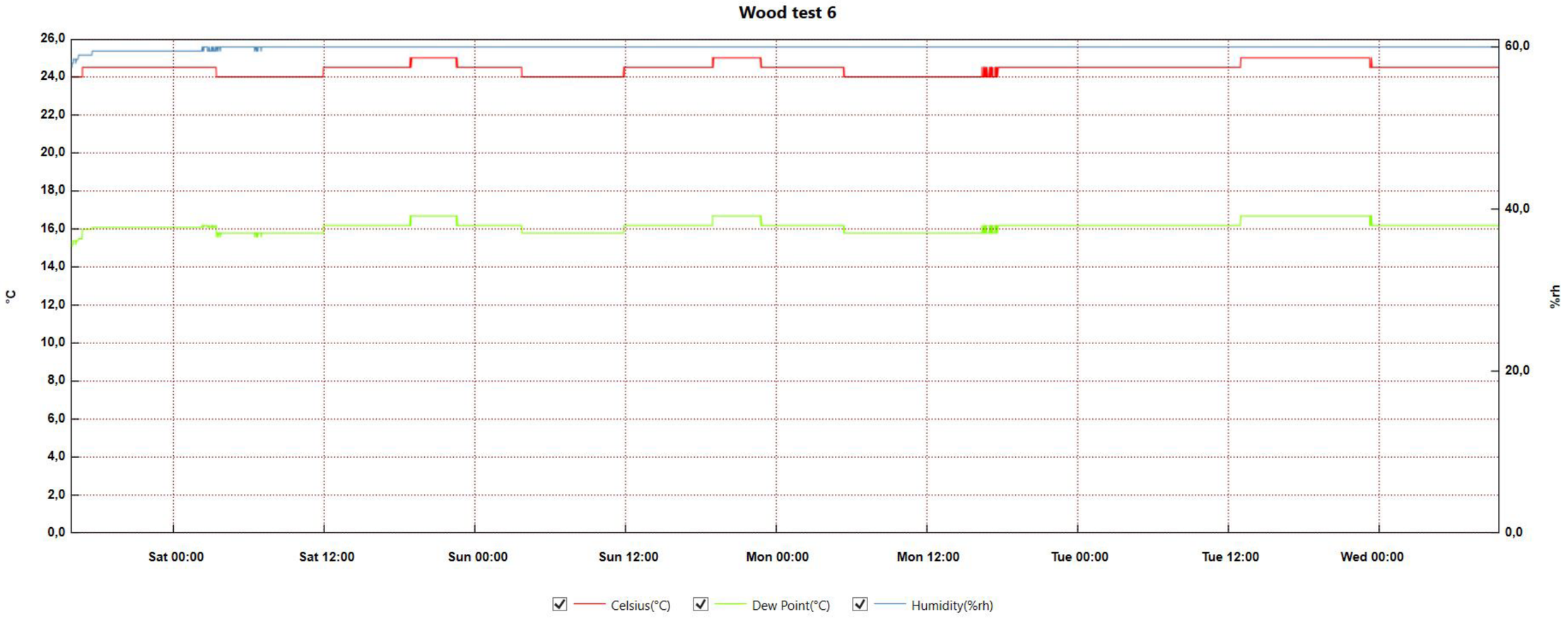
Problems

Testing
5

Potassium chloride (KCl)
(Relative humidity ±85%)

Testing

5

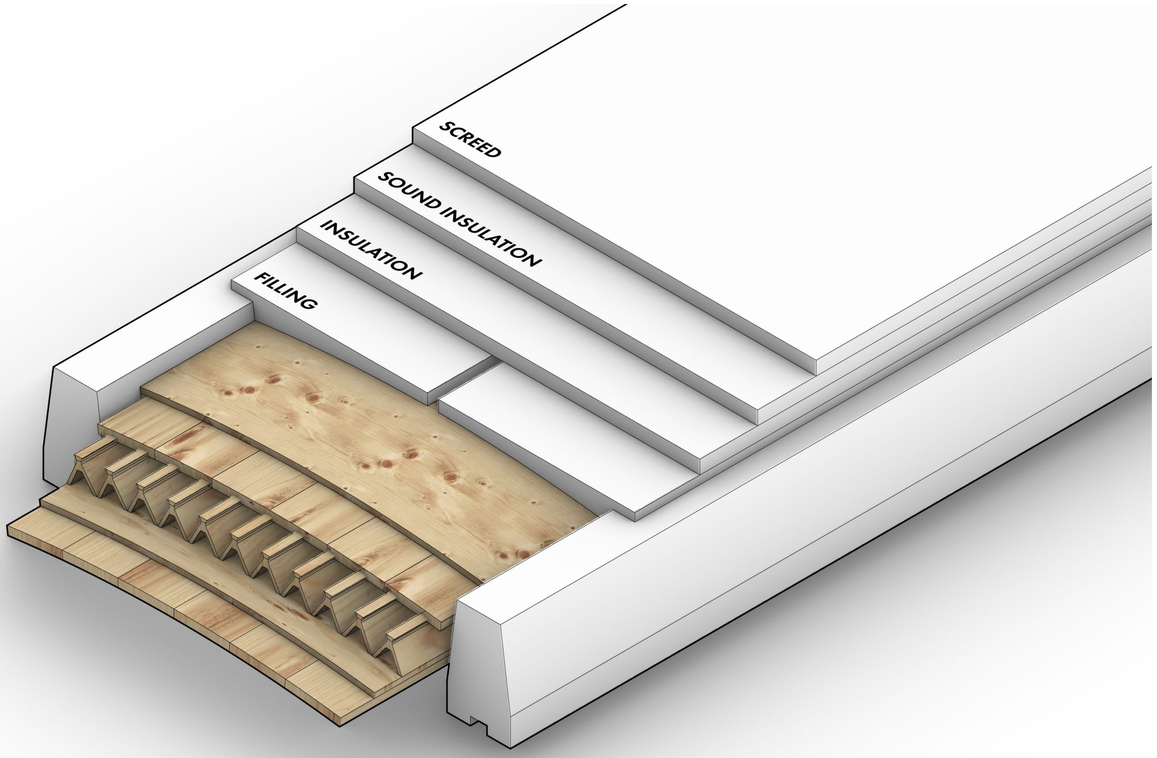


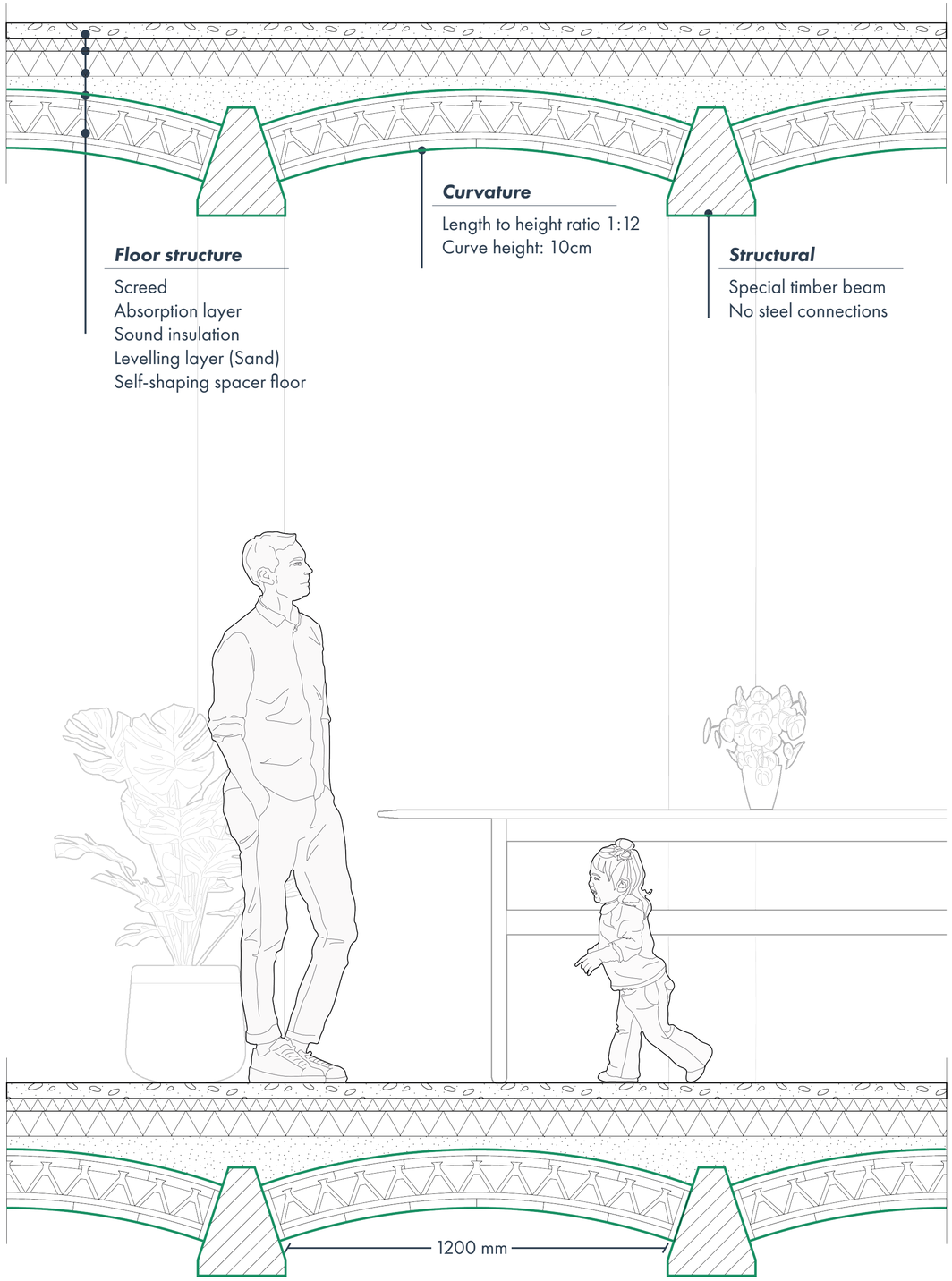
From: vrijdag 17 mei 2024 15:49:14 - To: woensdag 22 mei 2024 09:35:14

Implementation

Implementation

Context





Implementation

Context

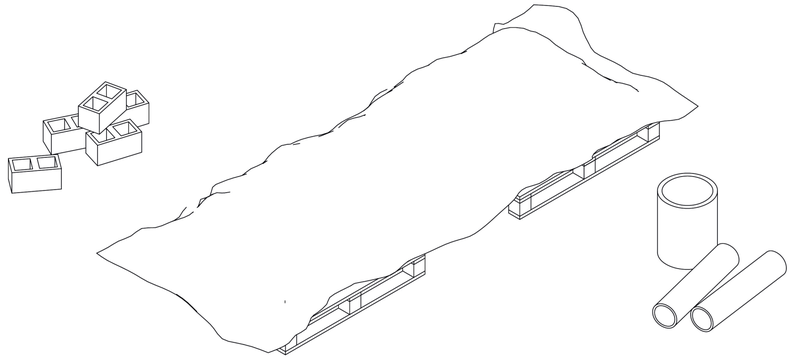
Implementation

Context

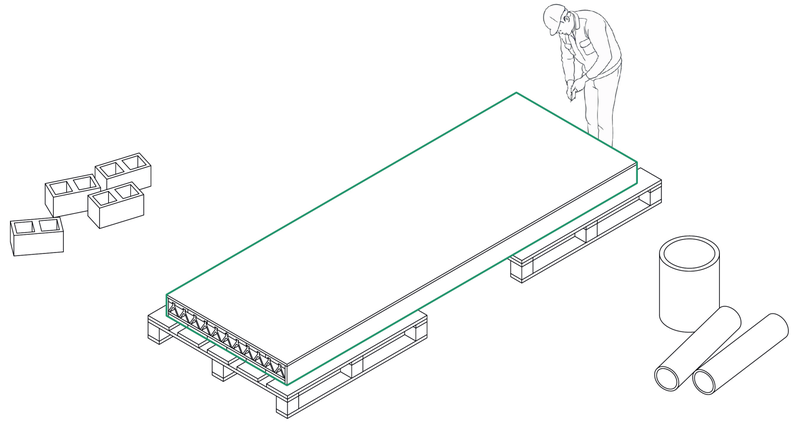
Implementation
Manufacturing

Implementation

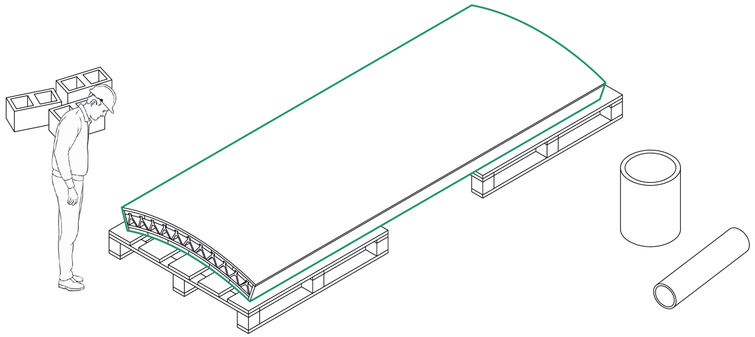
Manufacturing



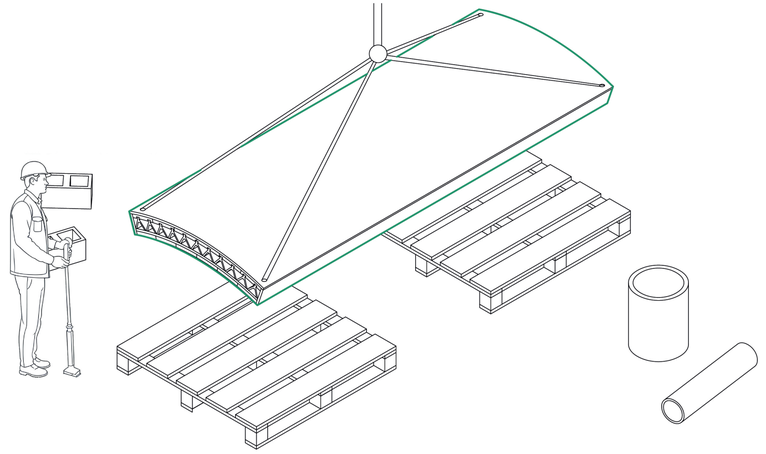
1 Treated & packed



2 Check-up & measurements



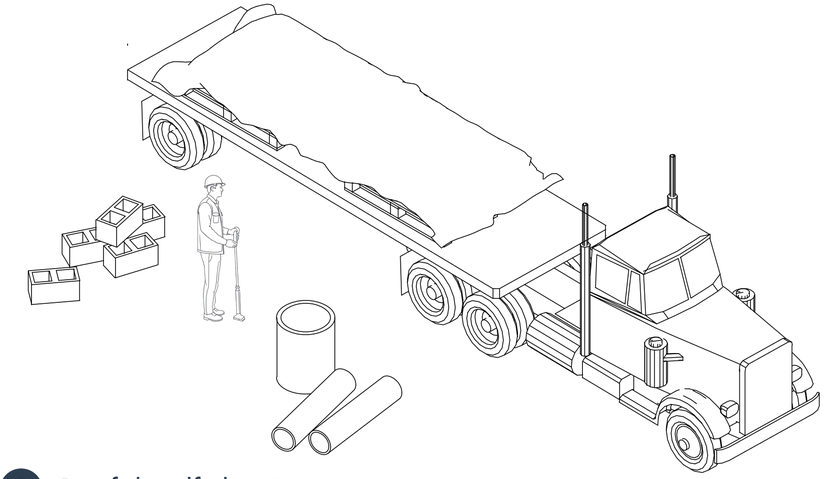
3 Indoor on-site self-shaping?



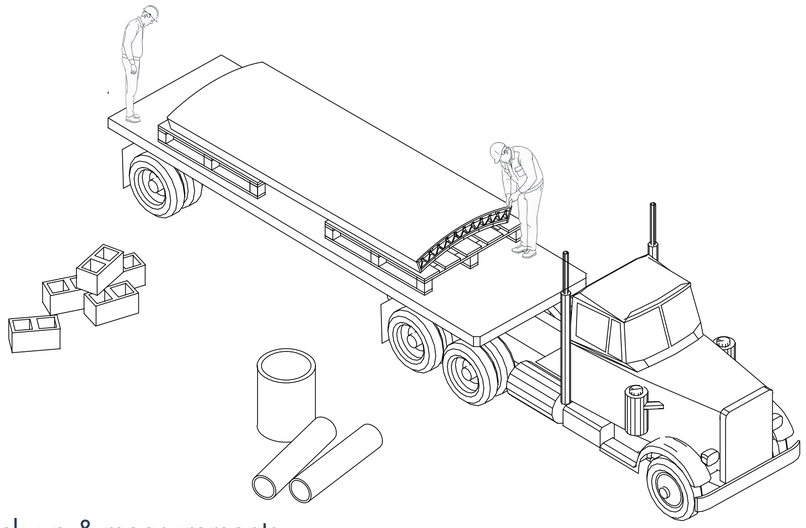
4 Placement

Implementation

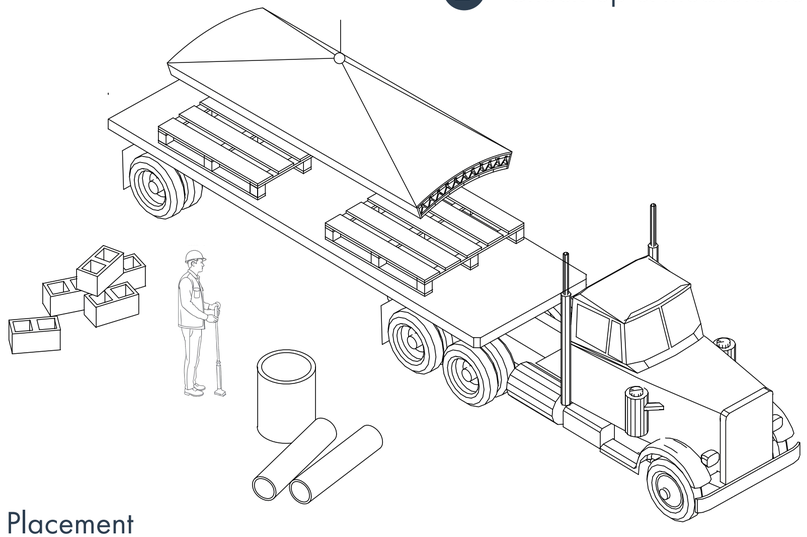
Manufacturing



1 Pre-fab self-shaping



2 Check-up & measurements

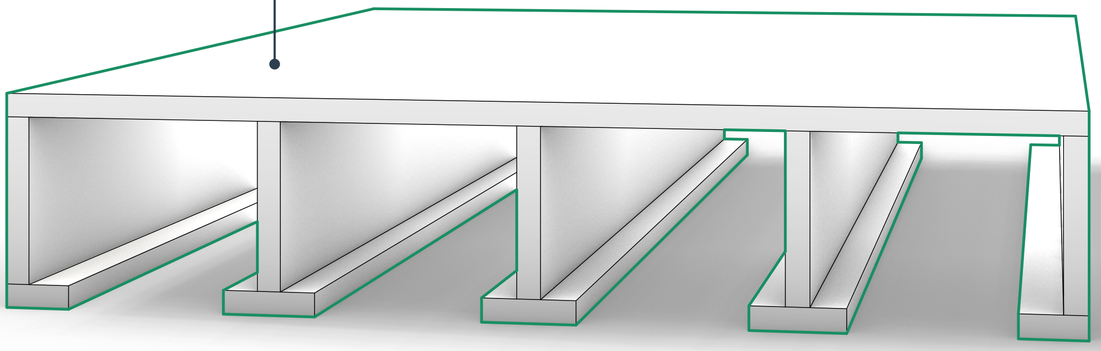


3 Placement

Implementation
Manufacturing

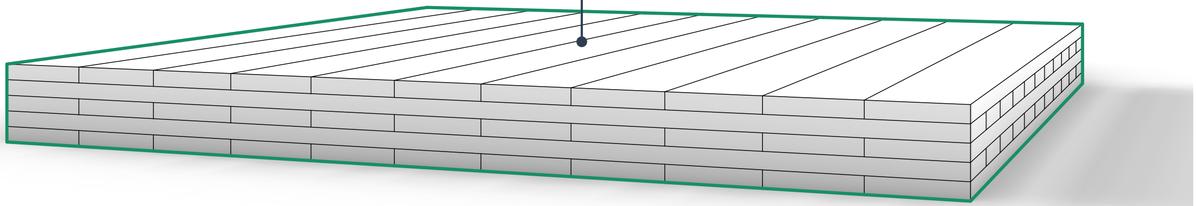
Kerto-ripa system

Ribs & Panels
Closed box or open typologies
Span: 1 direction



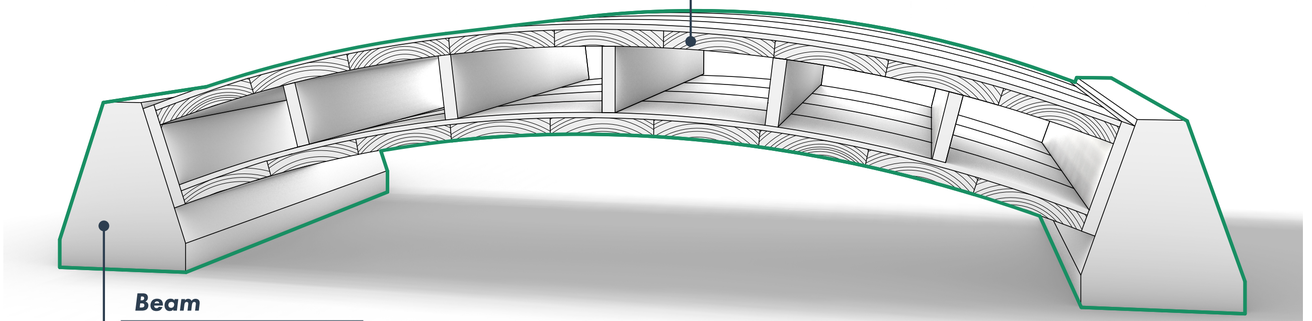
Cross Laminated Timber (CLT)

Layers: 3 to 7 on average
Span: Multiple directions



Spacer floor element

Bi-layers & spacers
Curved geometry
Span: 1 direction



Beam

More material but necessary

Conclusion & Reflection

Conclusion
Discussion

Reliability and **Impact** of results

Conclusion

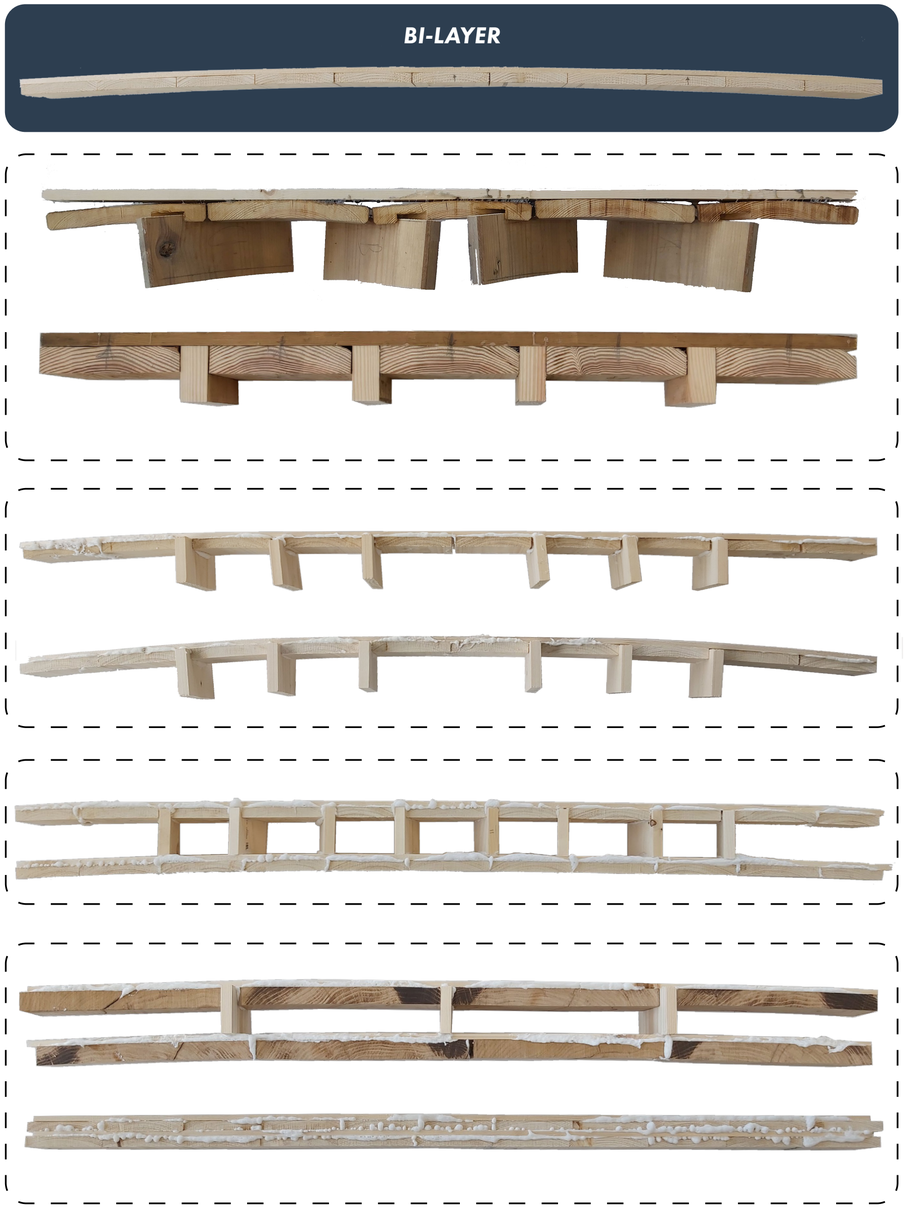
Discussion

Only 9 Test

Non-professional experiment environment

Still curvature

Benchmark for further refined research?



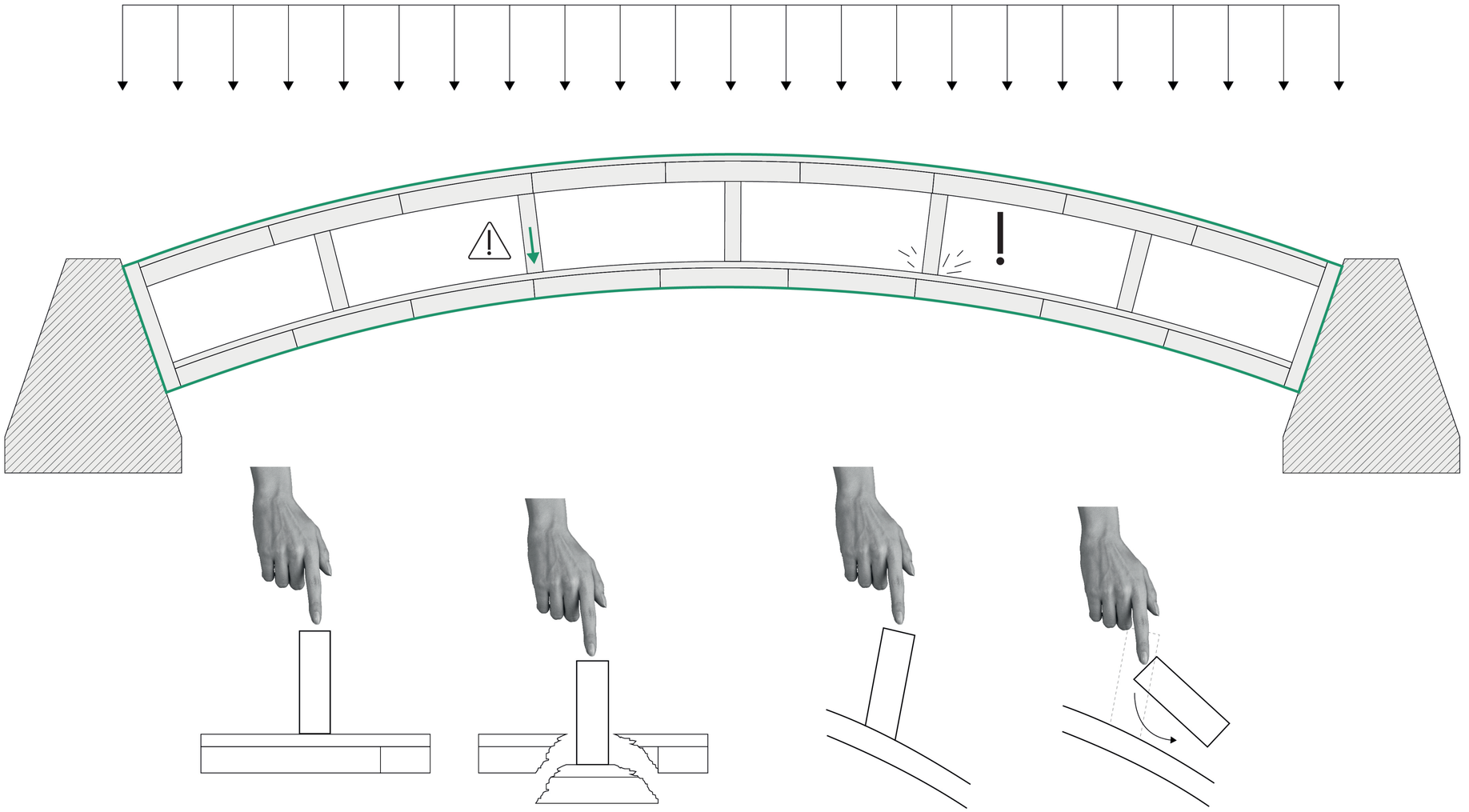
Conclusion

Discussion

New **elements**, thus new **challenges**

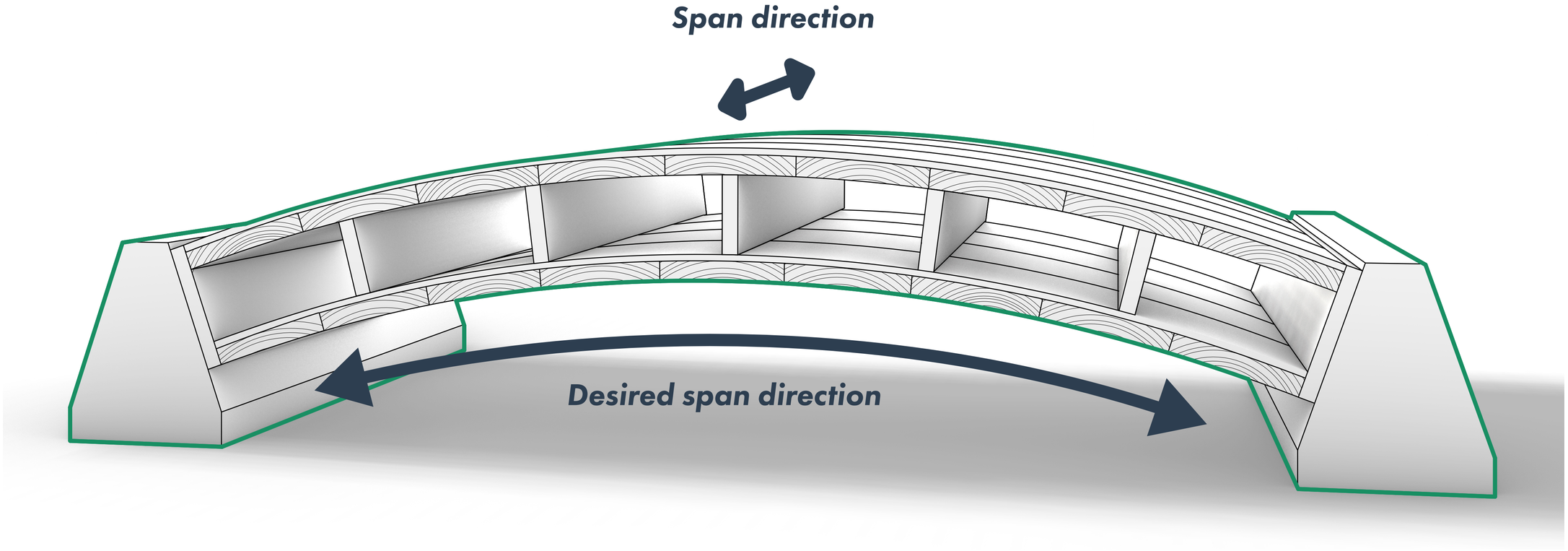
Conclusion

Discussion



Conclusion

Discussion



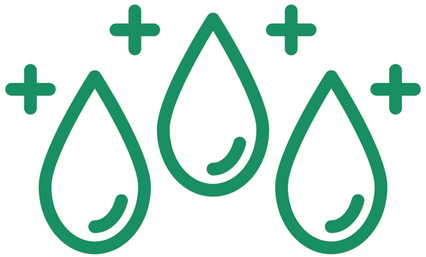
Conclusion

Conclusion

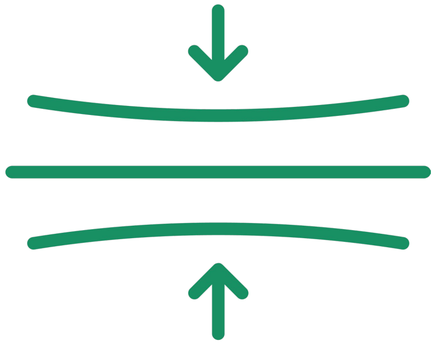
How can curved structural floor elements be created based on self-shaping hygromorphic bi-layers?

Conclusion

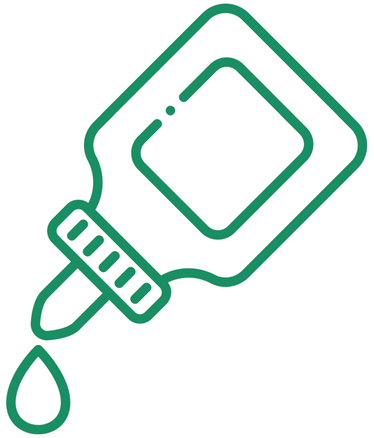
Treatment
Water vs. Moisture



Material
Thickness



Adhesive
Strength

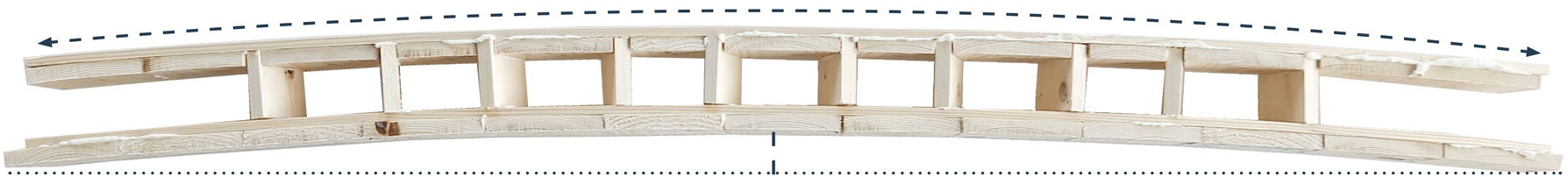


Conclusion

Moisture

Length: 1148mm
Curve height: 30mm
Reached: 27,7%

Boxfloor
(Softwood)



Thank you

-5079810-
23 May 2024
Raymen Lenno François Borst
Stijn Brancart & **Gilbert** Koskamp
Master Research Thesis **P4** Presentation

Reflection

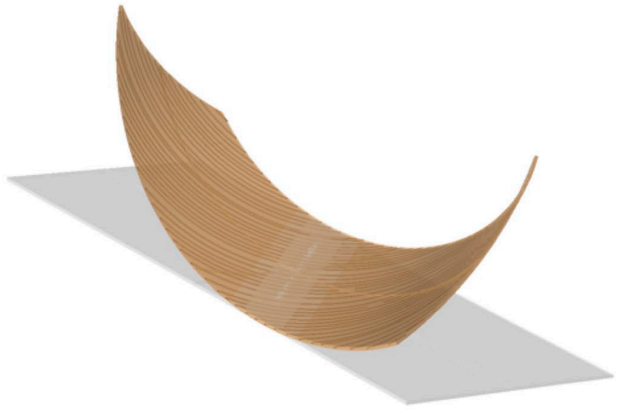
Reflection

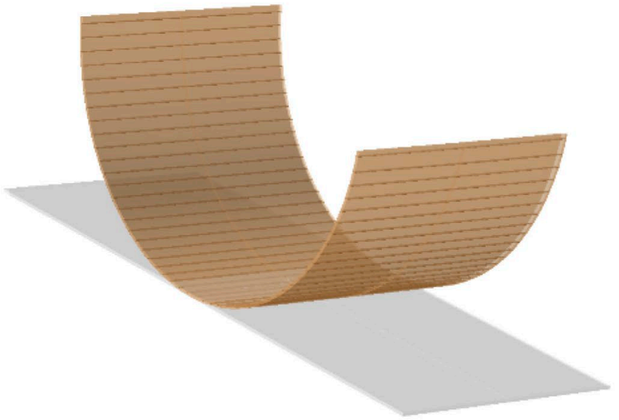
Reflection

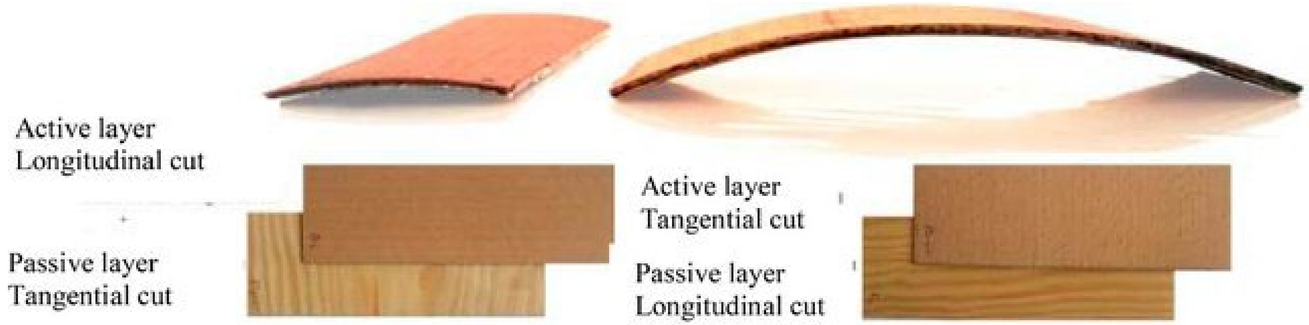
High-risk research

Disappointing results, but results

Original **objective achieved**?



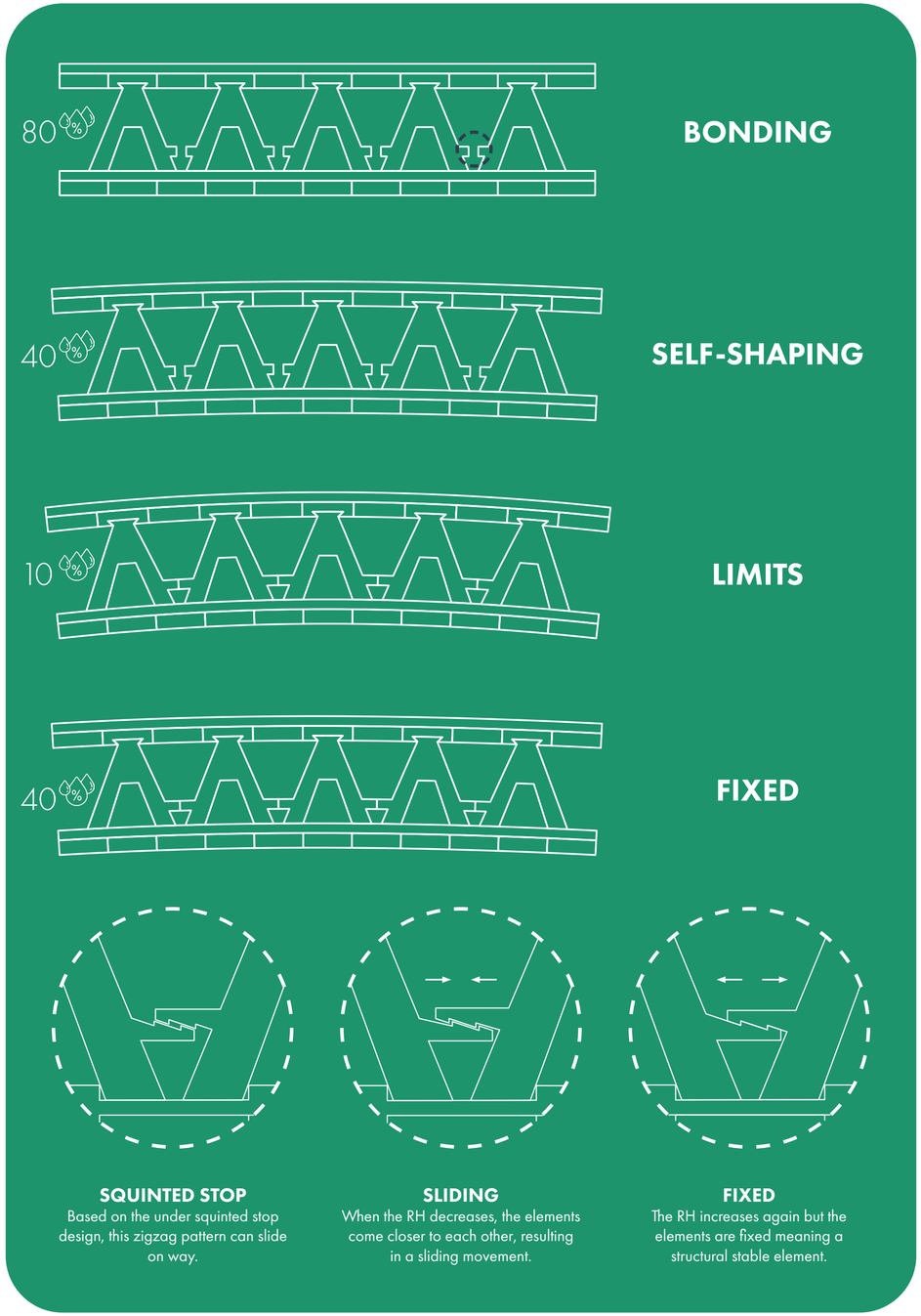


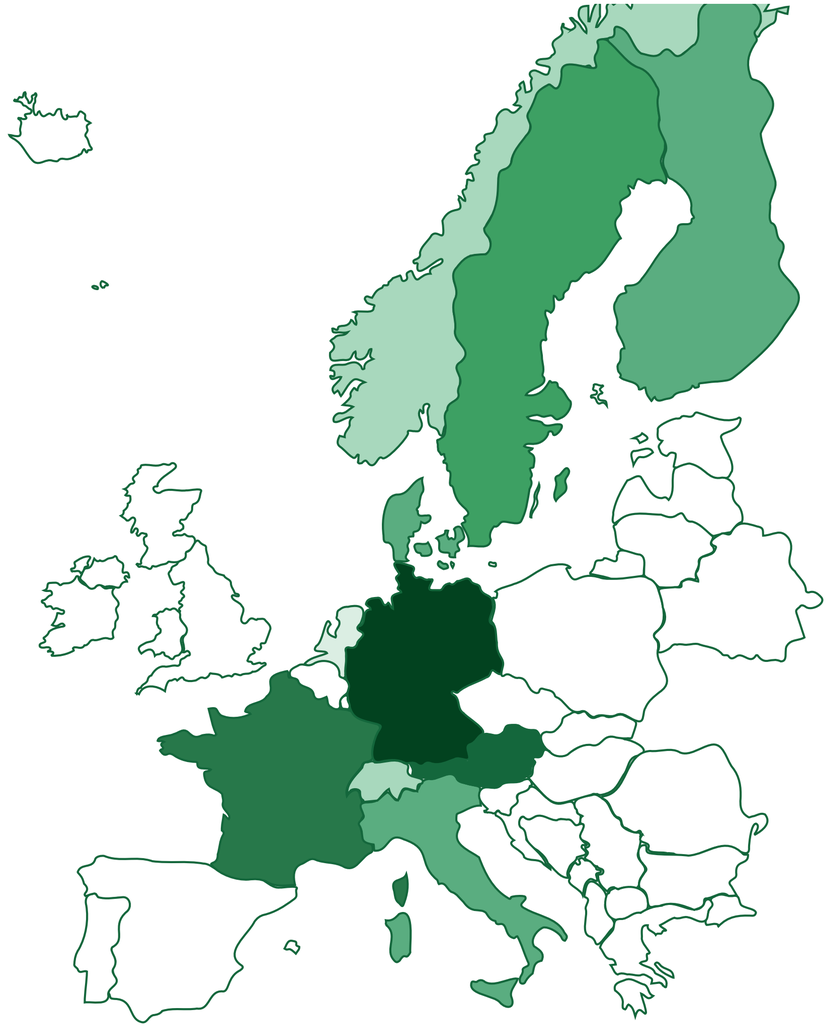


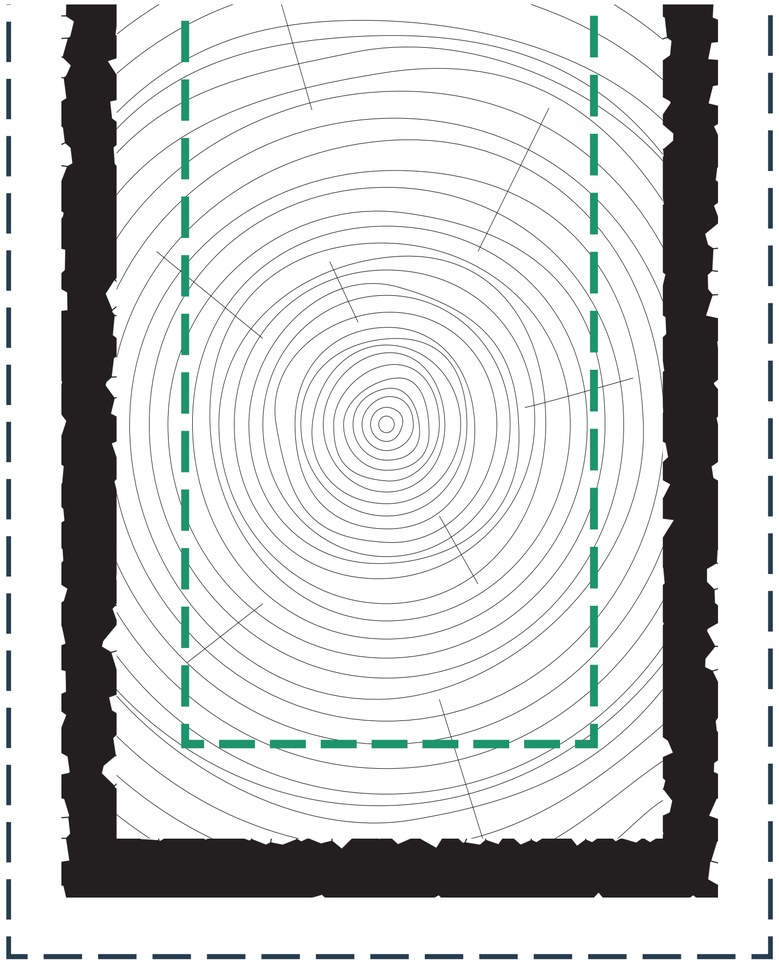
(a) (b) (c)

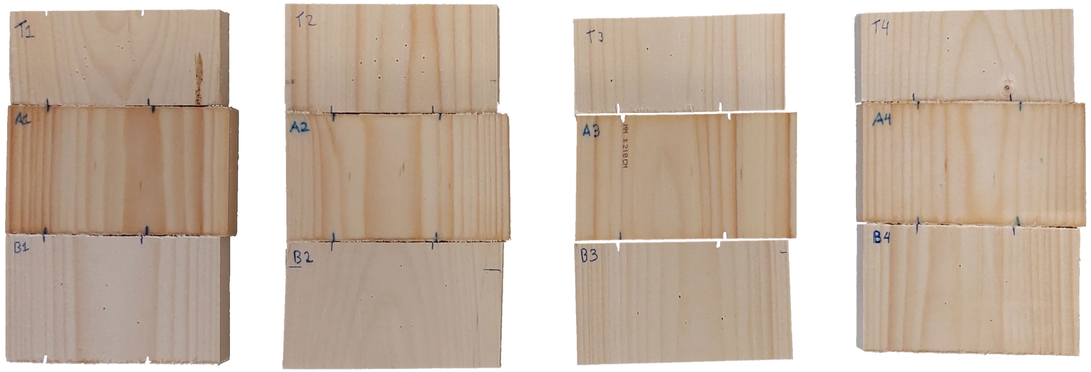
https://www.researchgate.net/publication/339169613_Inspiring_Responsive_Interior_Architecture_from_the_Inherent_Hygroscopic_Behavior_of_Pine_Cones/figures?lo=1

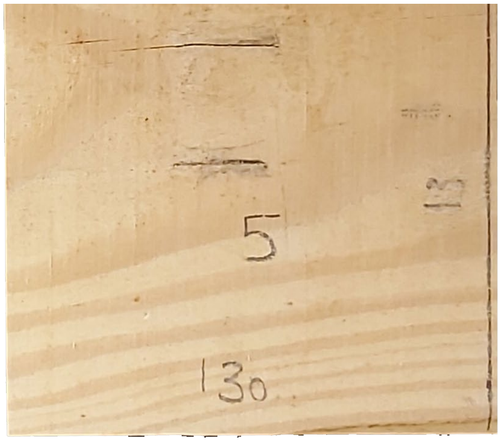
https://www.sciencedirect.com/science/article/pii/S0010448518300575


80 %
BONDING
40 %
SELF-SHAPING
10 %
LIMITS
40 %
FIXED
SQUINTED STOP
Based on the under squinted stop design, this zigzag pattern can slide on way.
SLIDING
When the RH decreases, the elements come closer to each other, resulting in a sliding movement.
FIXED
The RH increases again but the elements are fixed meaning a structural stable element.

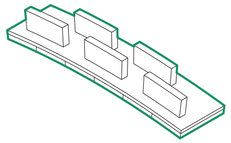
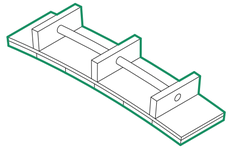
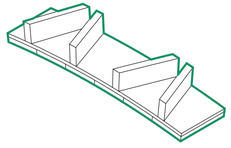
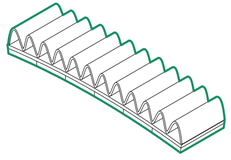
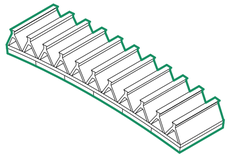
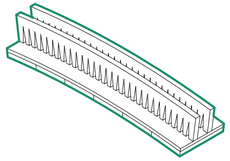
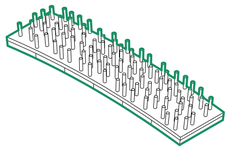




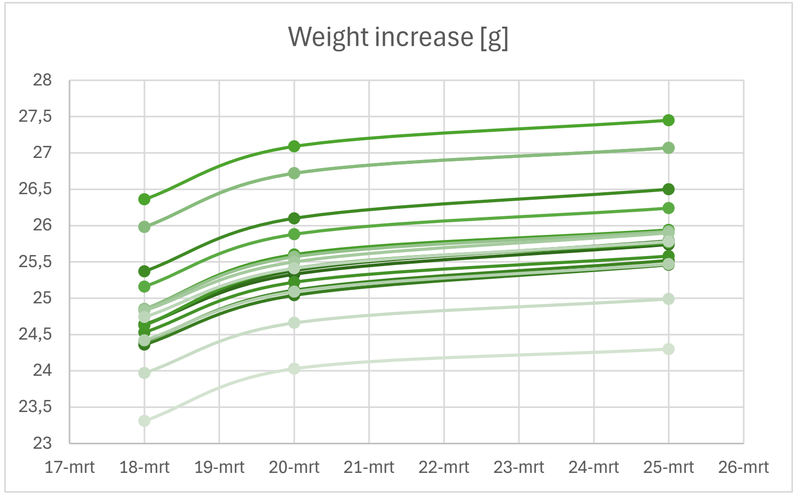

T1
A1
B1
T2
A2
B2
T3
A3
B3
T4
A4
B4

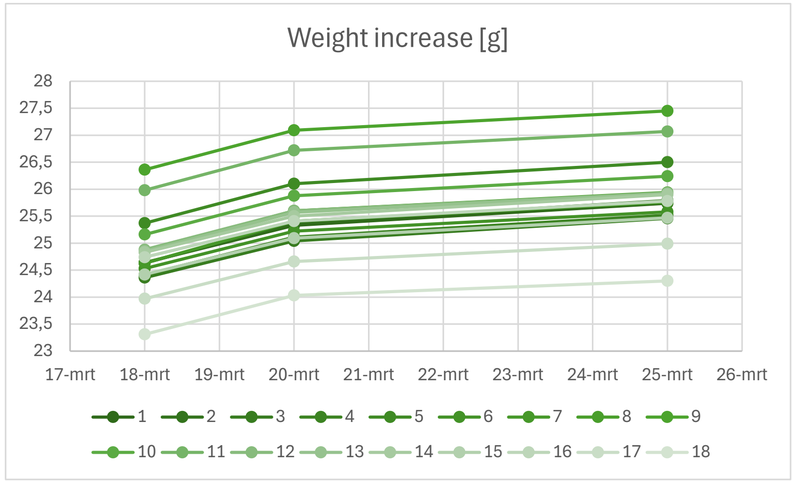

5
130



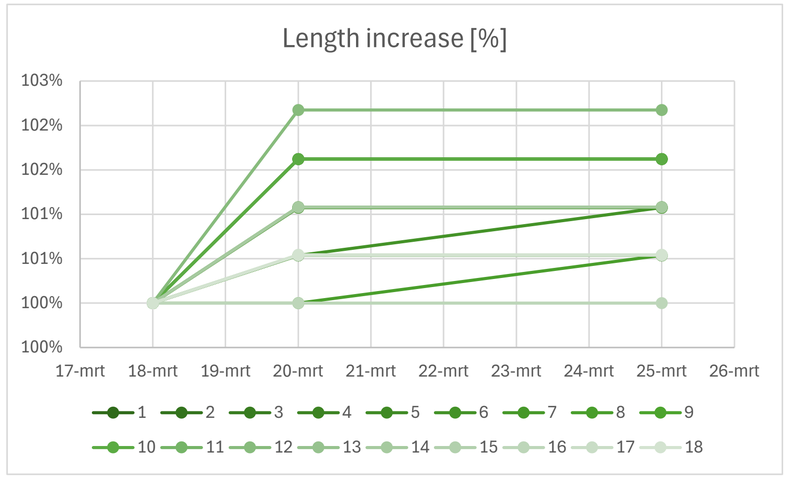
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
18-mrt	24,64	24,63	24,36	24,41	25,37	24,53	24,63	24,85	26,36	25,16	25,98	24,88	24,85	24,83	24,42	24,74	23,97	23,31
20-mrt	25,33	25,38	25,04	25,11	26,1	25,22	25,41	25,6	27,09	25,88	26,72	25,6	25,57	25,5	25,09	25,41	24,66	24,03
25-mrt	25,74	25,79	25,46	25,52	26,5	25,58	25,76	25,94	27,45	26,24	27,07	25,93	25,92	25,9	25,47	25,78	24,99	24,3

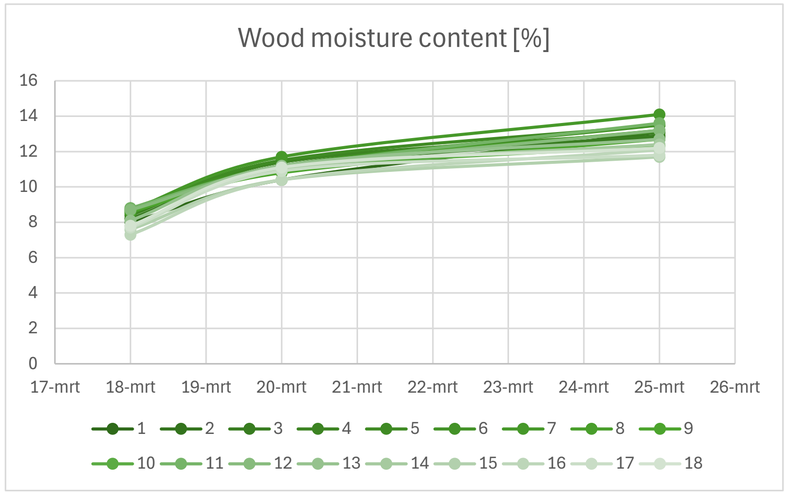




18-mrt	93	92,5	92,5	93	92,5	93	93	93	92,5	92,5	92,5	92	92,5	92,5	92,5	93	92,5	92
20-mrt	94	93,5	94	93,5	94	93,5	94	93	94	94	93,5	94	93	93,5	93	93	93	92,5
25-mrt	94	93,5	94	93,5	94	94	94	93,5	94	94	93,5	94	93	93,5	93	93	93	92,5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
18-mrt	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
20-mrt	101,08%	101,08%	101,62%	100,54%	101,62%	100,54%	101,08%	100,00%	101,62%	101,62%	101,08%	102,17%	100,54%	101,08%	100,54%	100,00%	100,54%	100,54%
25-mrt	101,08%	101,08%	101,62%	100,54%	101,62%	101,08%	101,08%	100,54%	101,62%	101,62%	101,08%	102,17%	100,54%	101,08%	100,54%	100,00%	100,54%	100,54%





	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
18-mrt	8	8,2	8,2	8,4	8,5	8,8	8,7	8,6	8,6	8,7	8,8	8,7	8,1	7,8	7,6	7,3	7,7	7,8
20-mrt	10,4	11,1	11,2	11,4	11,5	11,2	11,7	11,1	10,8	11	11,1	11	11,2	11	10,4	10,4	10,9	11,1
25-mrt	13,1	12,8	12,9	13,1	13,5	13,5	14,1	13,2	12,7	12,3	13,6	13,2	12,7	12,4	11,7	12,1	11,8	12,2

Conclusion

Discussion

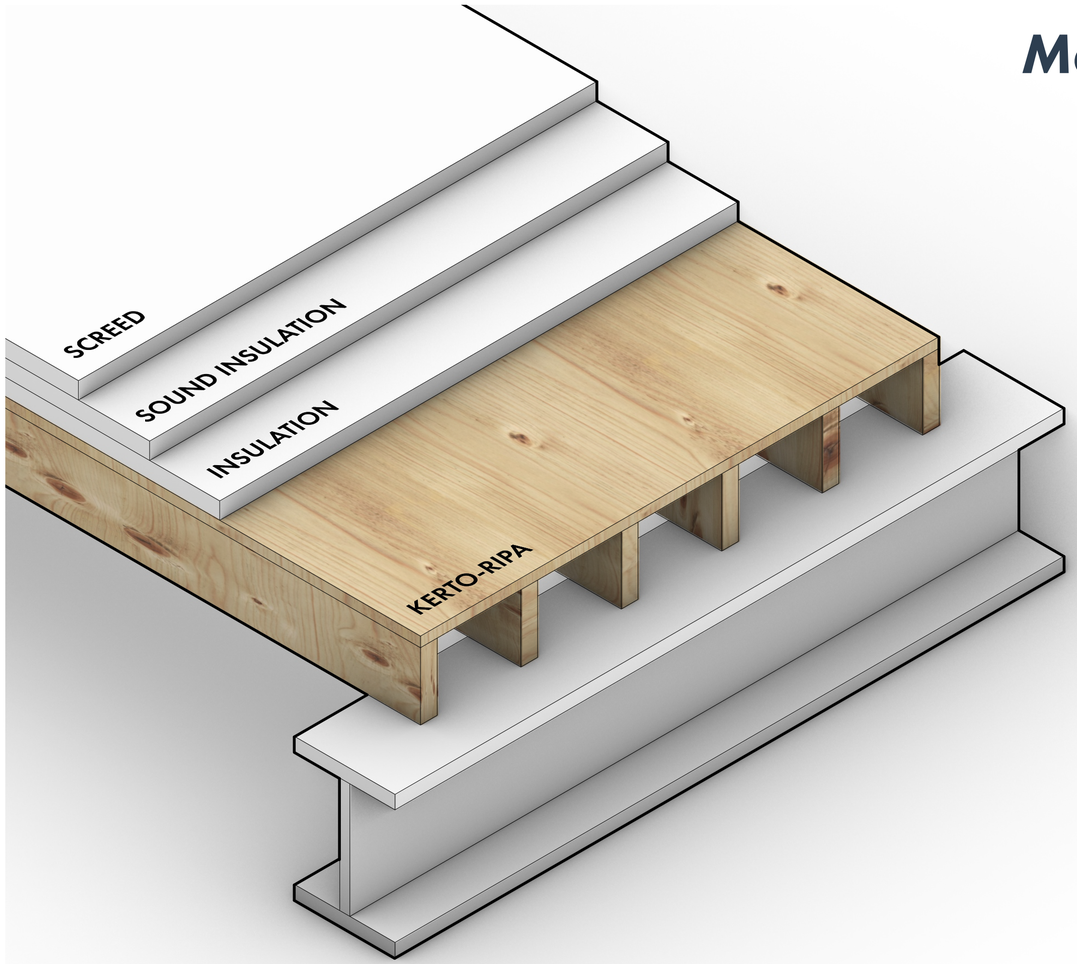
How does this new floor element **compare** to a standard boxfloor element (Kerto-ripa)?

Conclusion

Discussion

Conclusion

Discussion



Manufacturing
Material
Strength
Co2