P5 Presentation

Bio-based FRP structures:
A pedestrian bridge in Schiphol Logistics Park

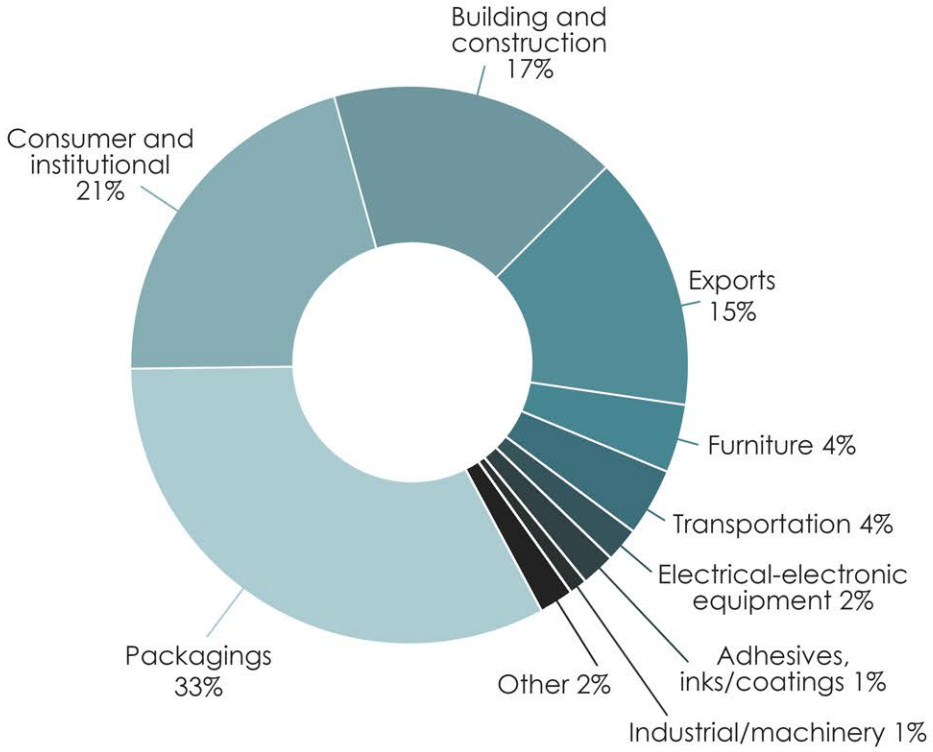
Rafail Gkaidatzis

1st mentor : ir.J. Smits
2nd mentor : ir. A.C. Bergsma

06 11 2014

Problem Definition

- plastic materials are part of our everyday life
- plastic industry ranks third in the world amongst all other industry
- majority of polymers are petroleum-based



source of heavy environmental pollution

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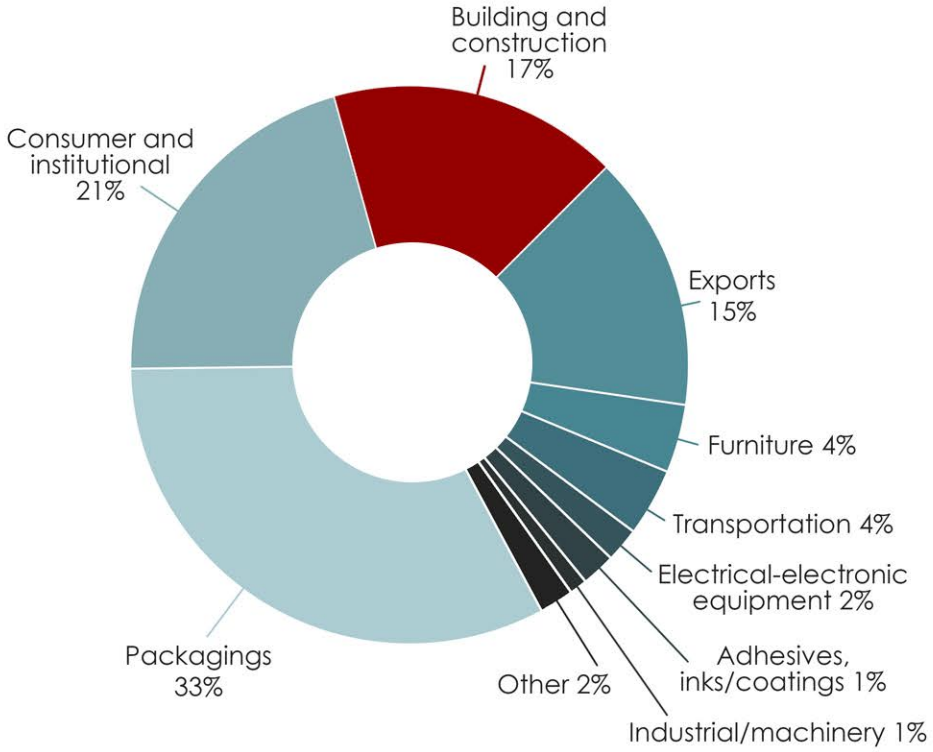

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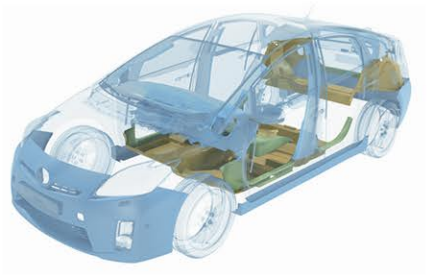
Problem definition

- eco-friendly plastics are emerging globally
- based on renewable raw materials, such as plant fibres or plant polymeric substances
- increased application in automotive industry, telecommunications, industrial design, packaging, medical science



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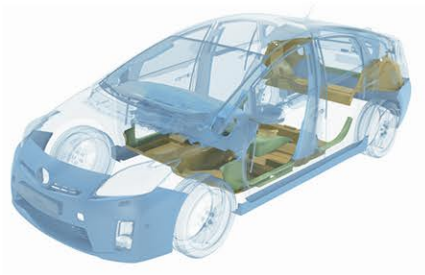
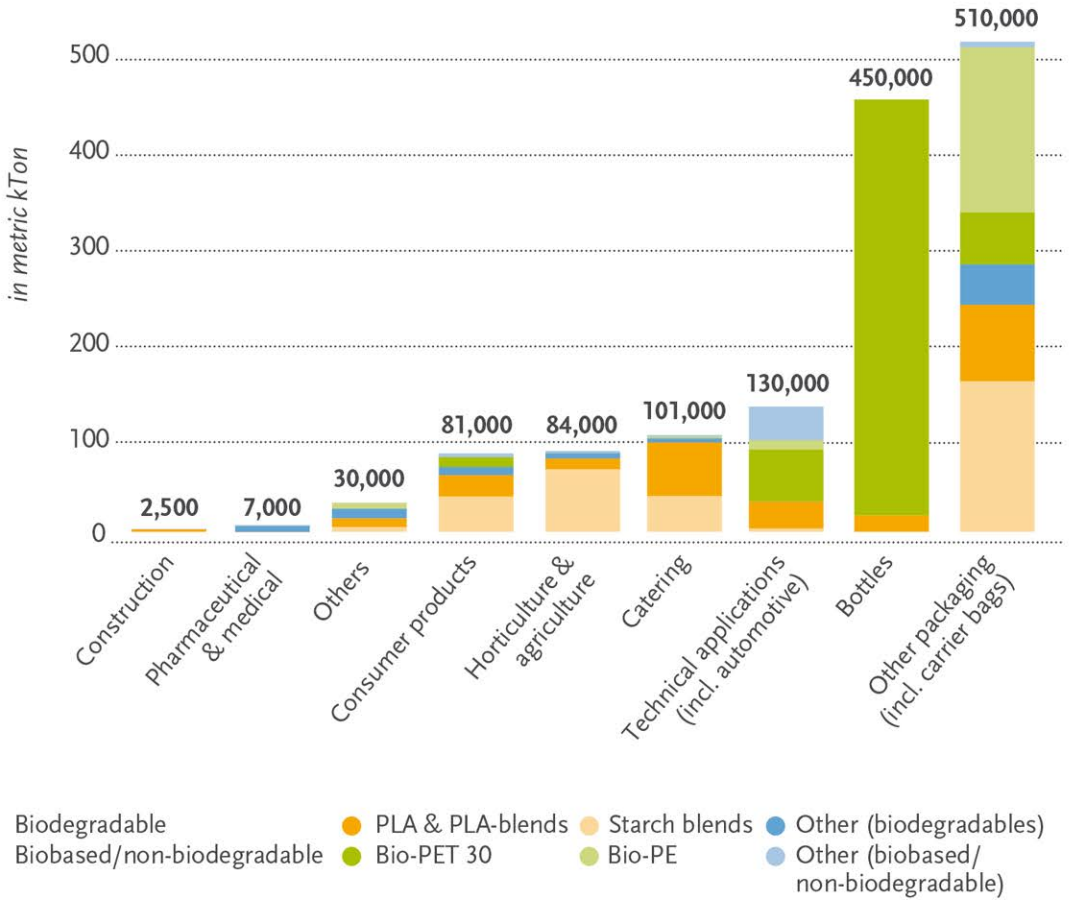


But in the building industry...

- bioplastics are in an **early stage of development**
- applications include : cladding components, insulation products, flooring, connections
- extremely **limited use in structural applications**

Global production capacities of bioplastics 2012 (by market segment)



Source: European Bioplastics | Institute for Bioplastics and Biocomposites (December 2013)

Goal of the study

- prove that biocomposites have comparable properties with conventional composites
- contribute towards the establishment of biocomposites in construction

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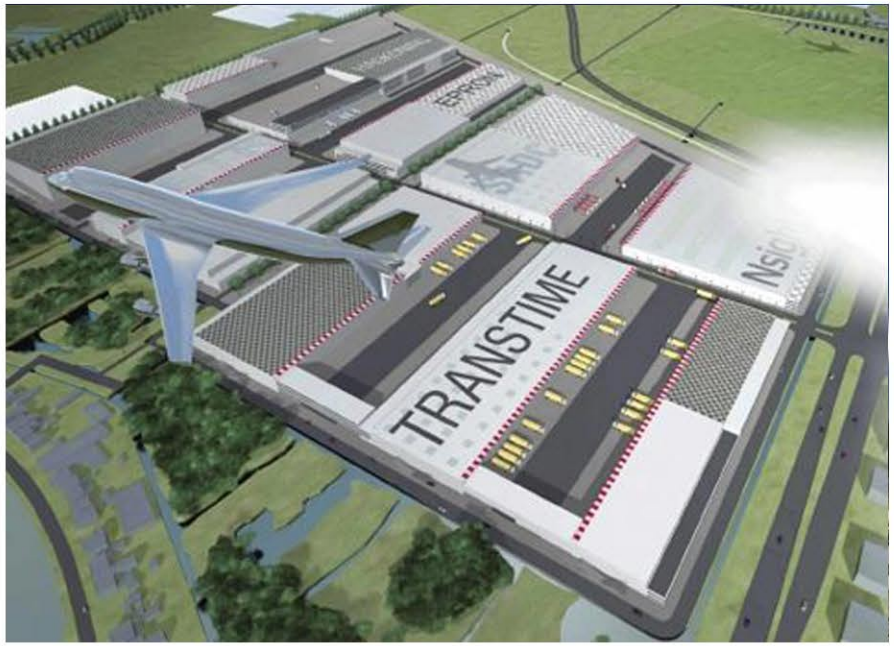
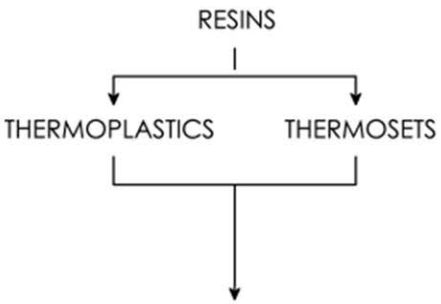
Bio-based composite pedestrian bridge

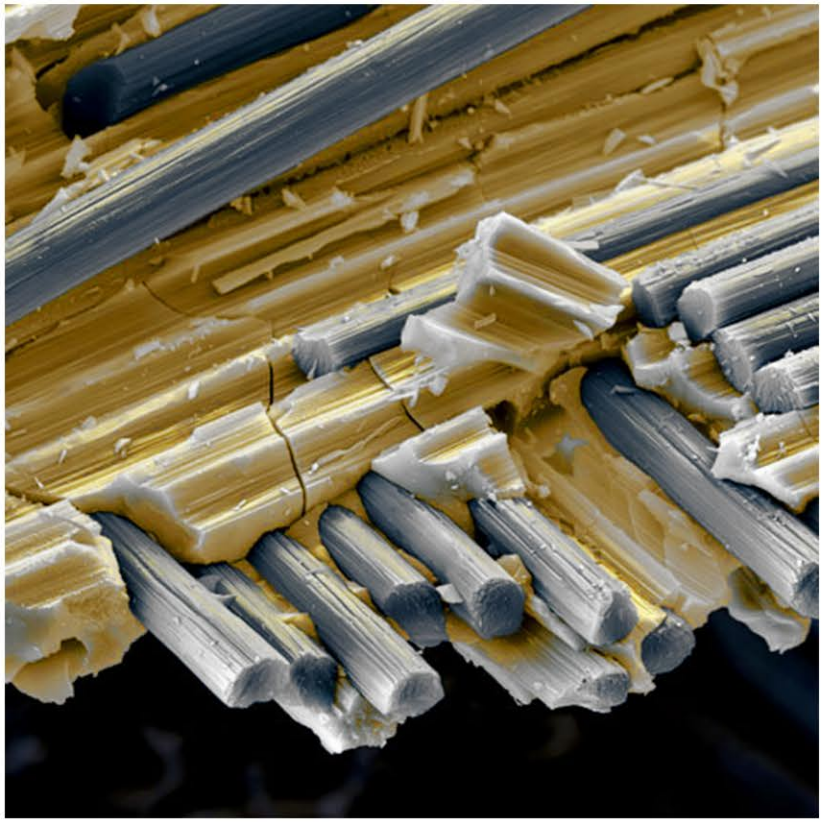


Goal of the study

- research whether biocomposites have comparable properties with conventional composites
- contribute towards the establishment of biocomposites in construction

Composites





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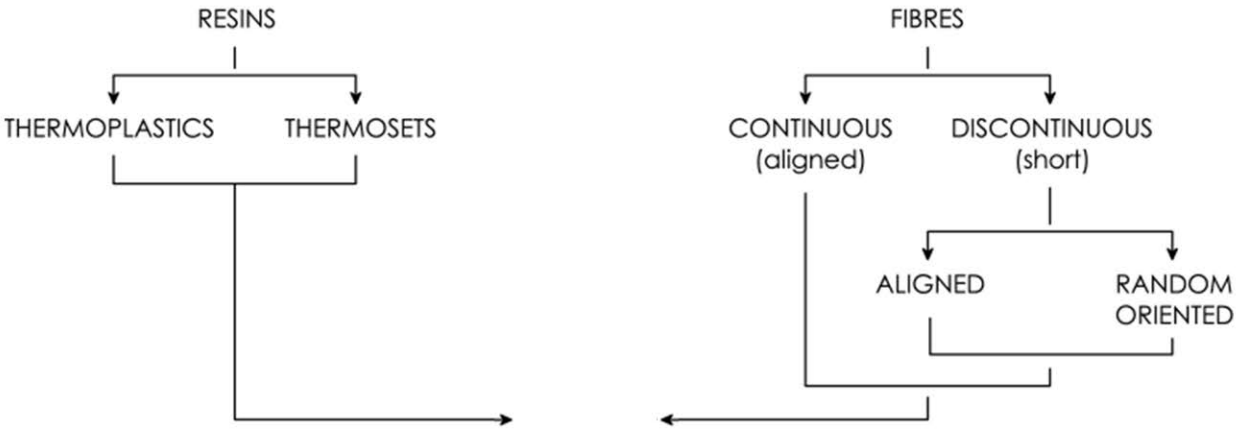

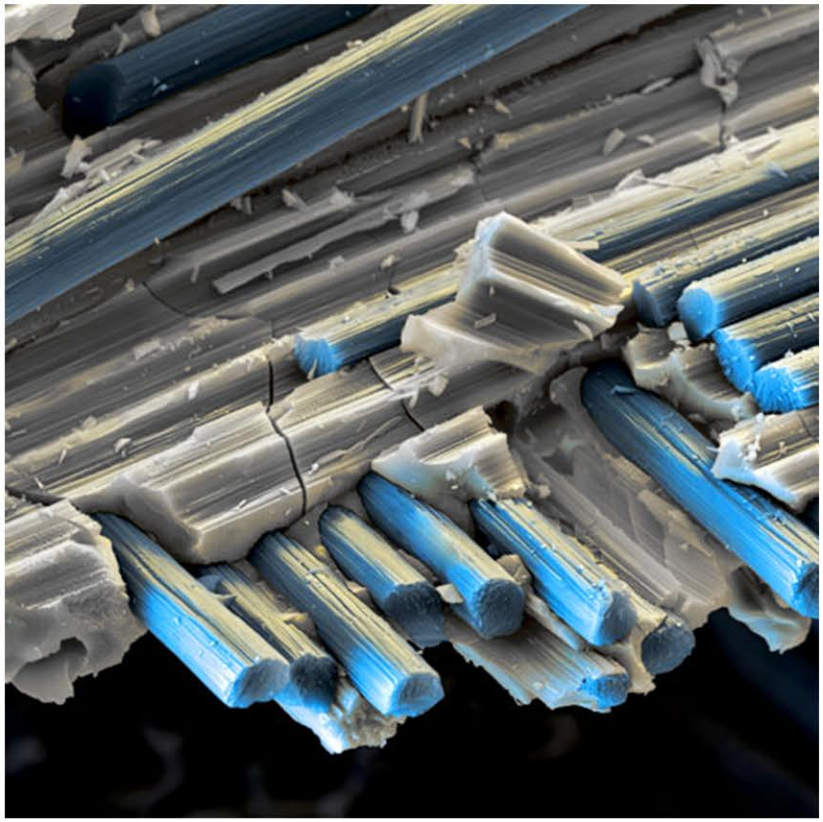

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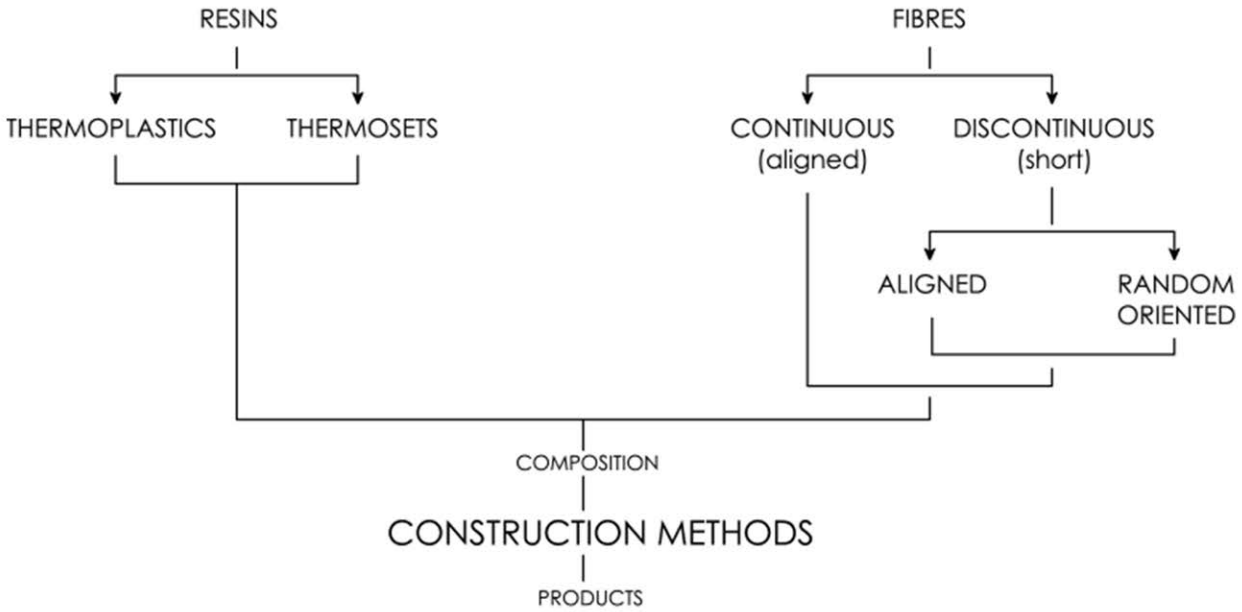

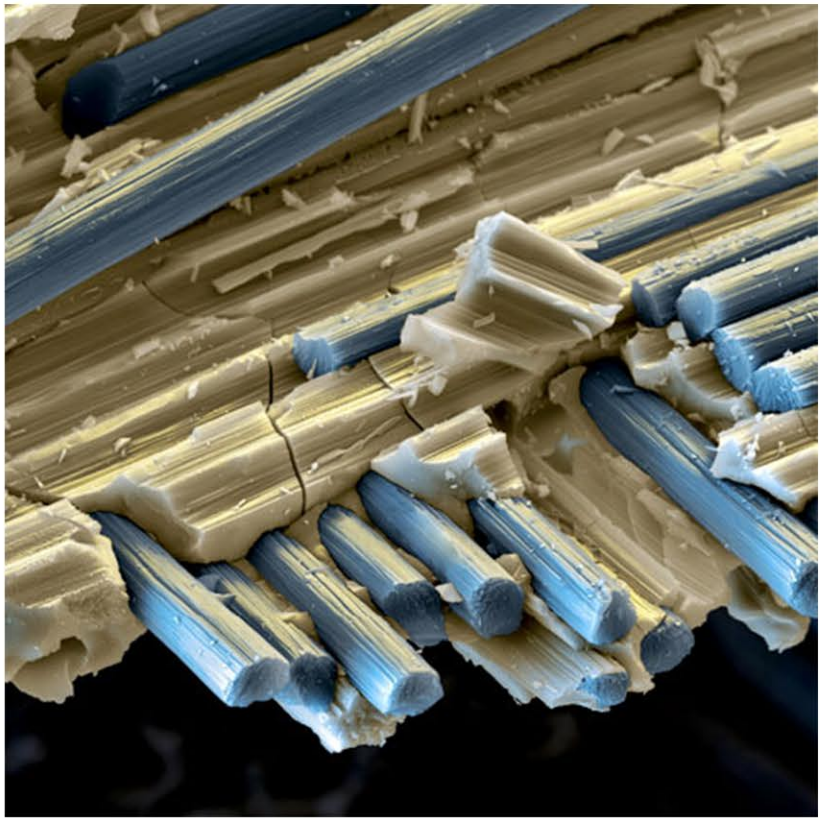

Research on plant fibres

- fibres
  - naturally occurring
    - plant
      - Flax
      - Hemp
      - Jute
      - Sisal
      - Ramie
      - Cotton
    - animal
      - Silk
      - Wool
      - Futhers
  - man-made
    - inorganic | mineral
      - Glass
      - Carbon
      - Basalt
      - Ceramic
    - organic
      - Polyethylene (PE)
      - Polyamide (PA)
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      - Polyacrilonitrile (PAN)
      - Polytetrafluoroethylene (PTFE)
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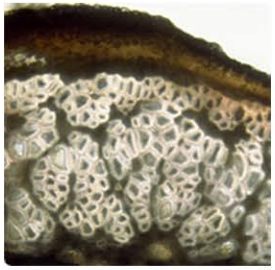


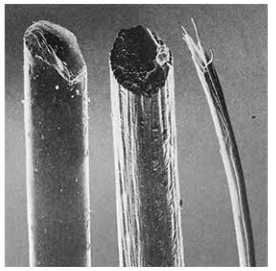
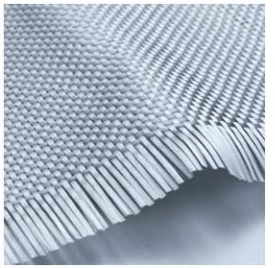
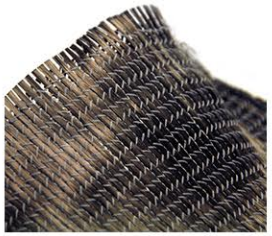

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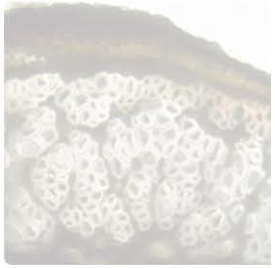


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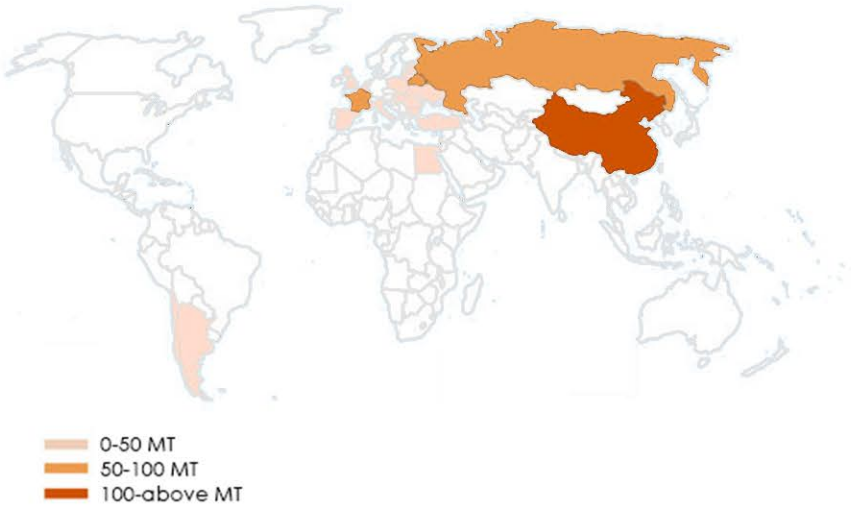
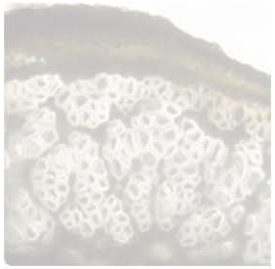


- temperate climate zone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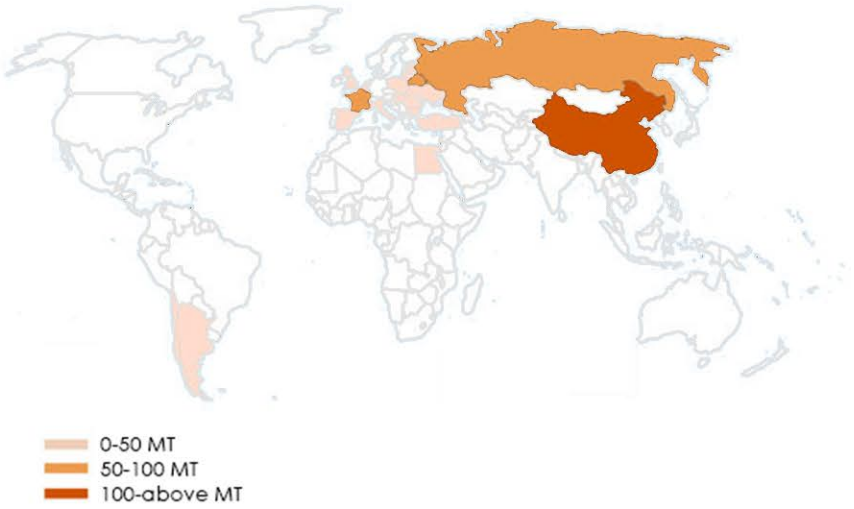
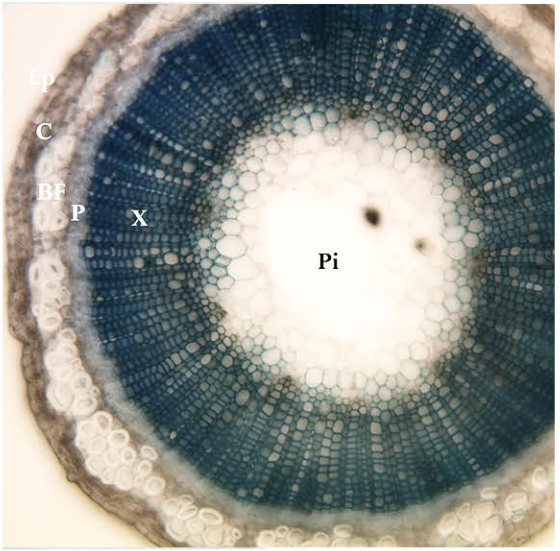
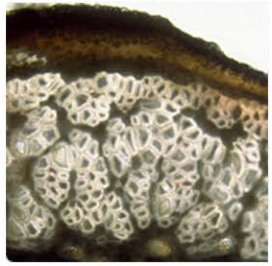
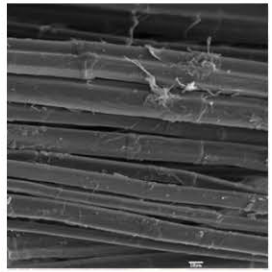


- temperate climate zone
- bast fibre category (long fibres)







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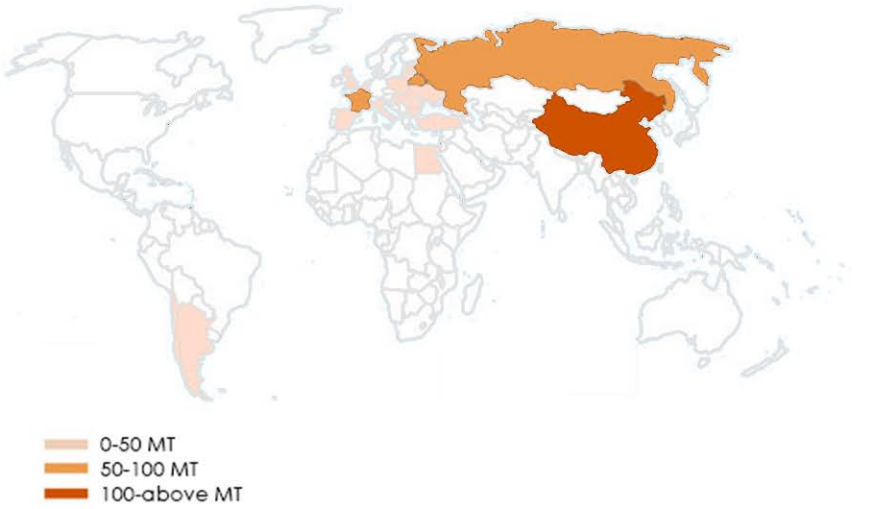
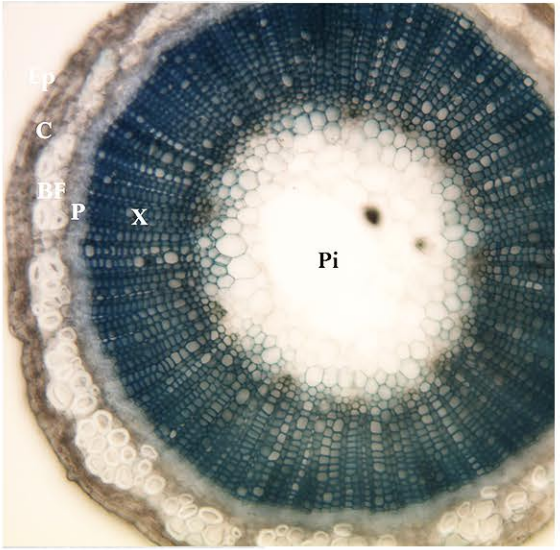
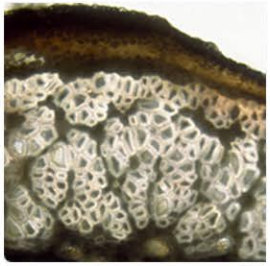
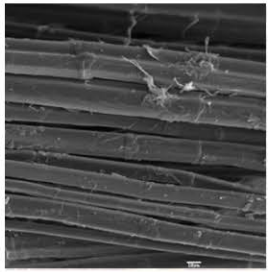


- temperate climate zone
- bast fibre category (long fibres)
- fibre extracted from outer skin of dry stalks







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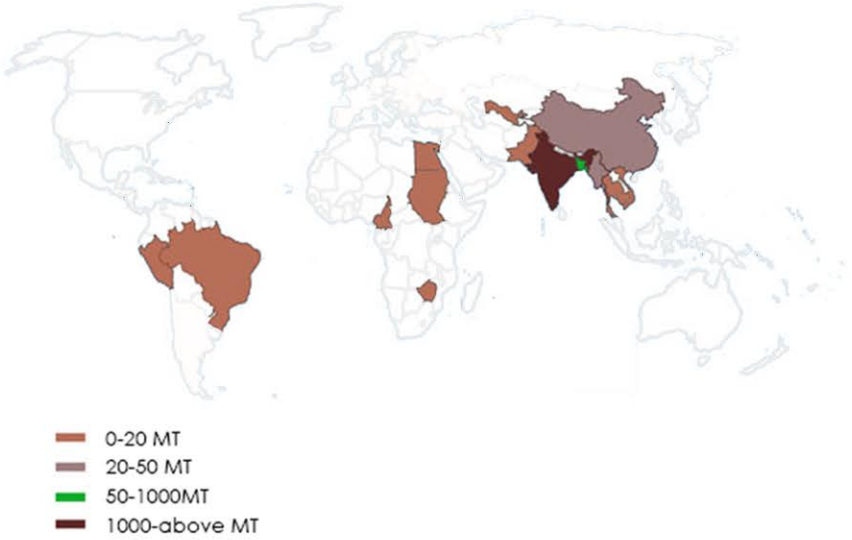
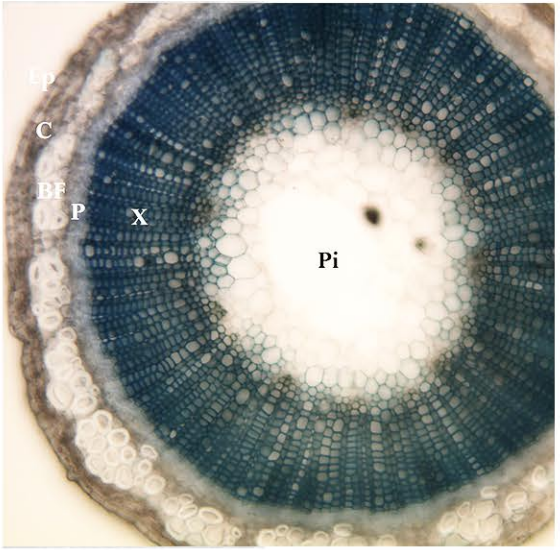
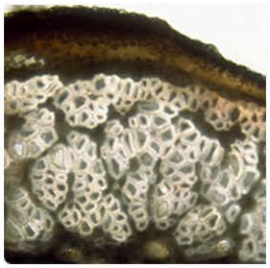
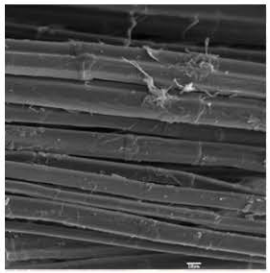


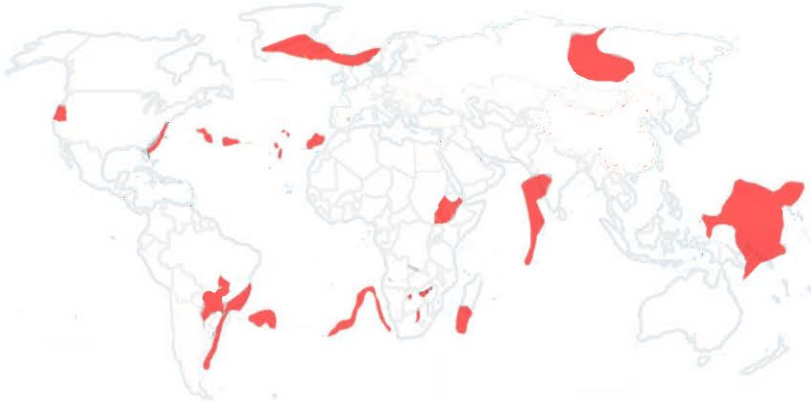
- tropical climate zone (humid-warm conditions)
- bast fibre category (long fibres)
- fibre extracted from outer skin of dry stalks



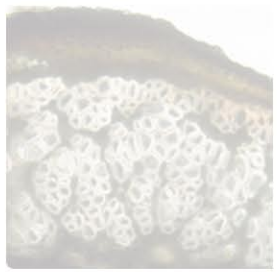




Research on artificial fibres



- type of volcanic rock



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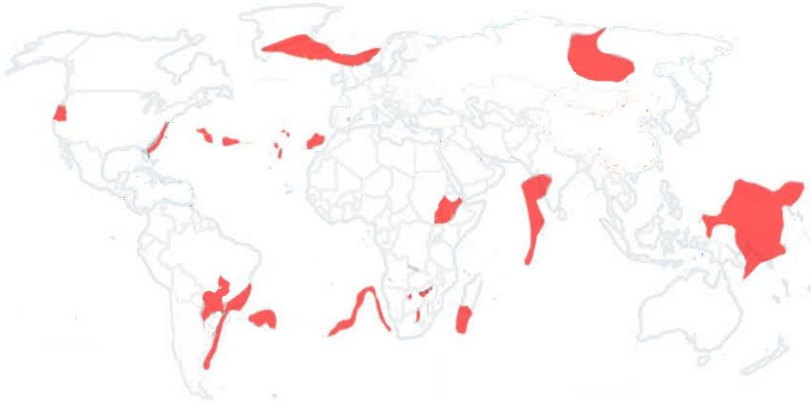

- type of volcanic rock
- most common rock on earths crust

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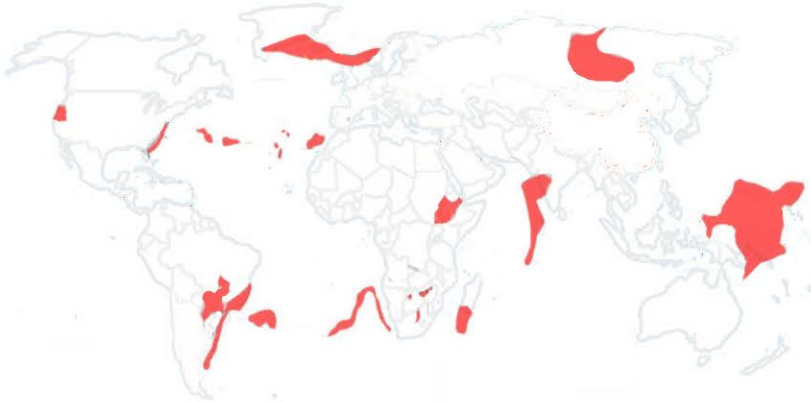
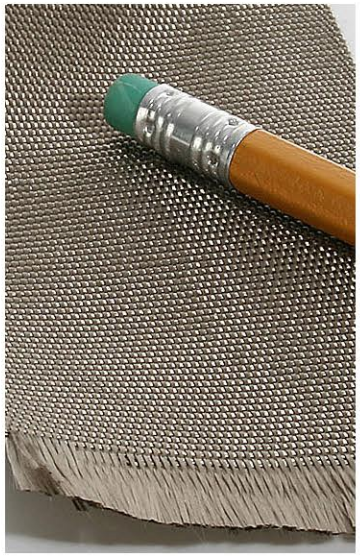
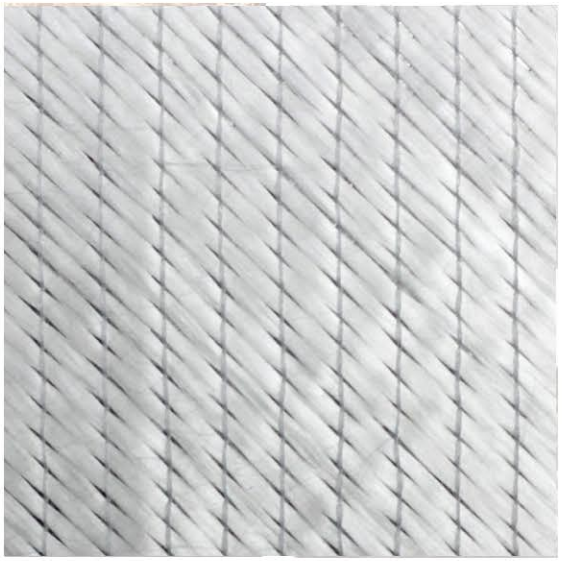


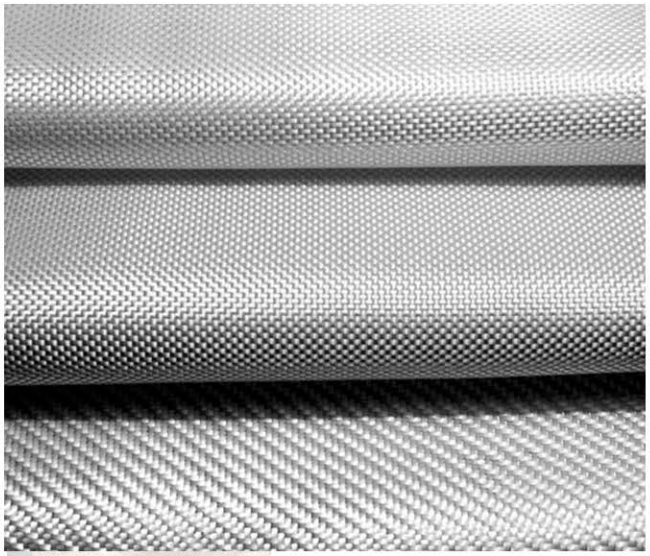
- type of volcanic rock
- most common rock on earths crust
- extracted by typical mining activity

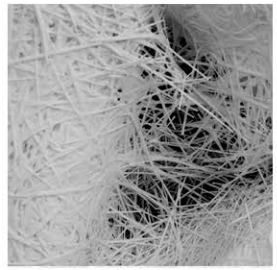


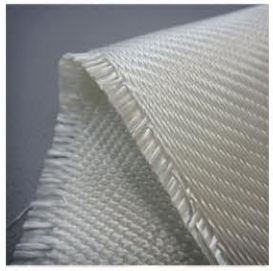
Research on artificial fibres

- consists of sand and other particles (Kaolin, Limestone, Colemanite)
- easy and abundant availability of raw materials
- highly used in composites









Mechanical properties | Durability | Cost

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MECHANICAL PROPERTIES

DENSITY
STRENGTH
STIFFNESS

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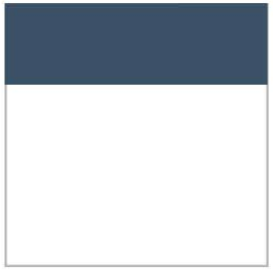

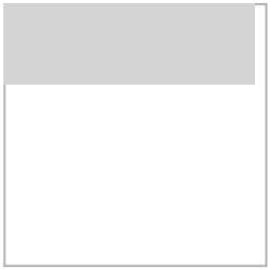

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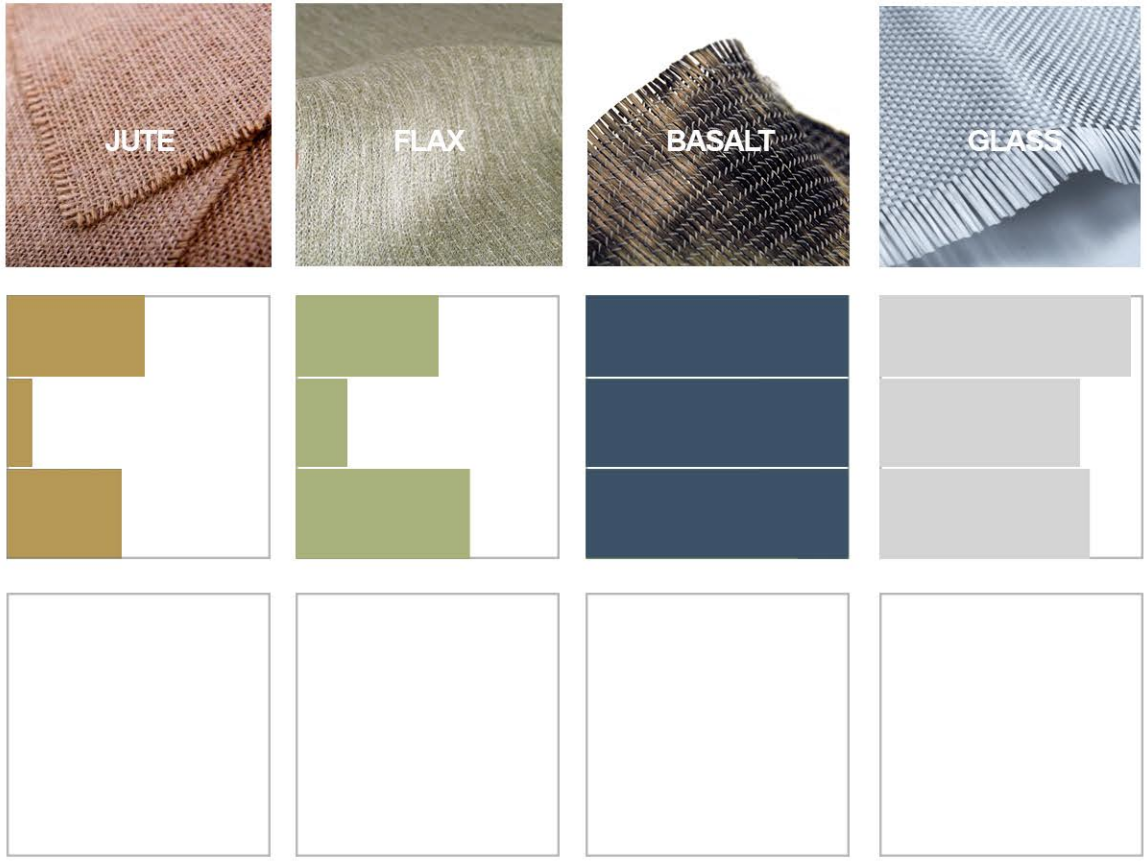

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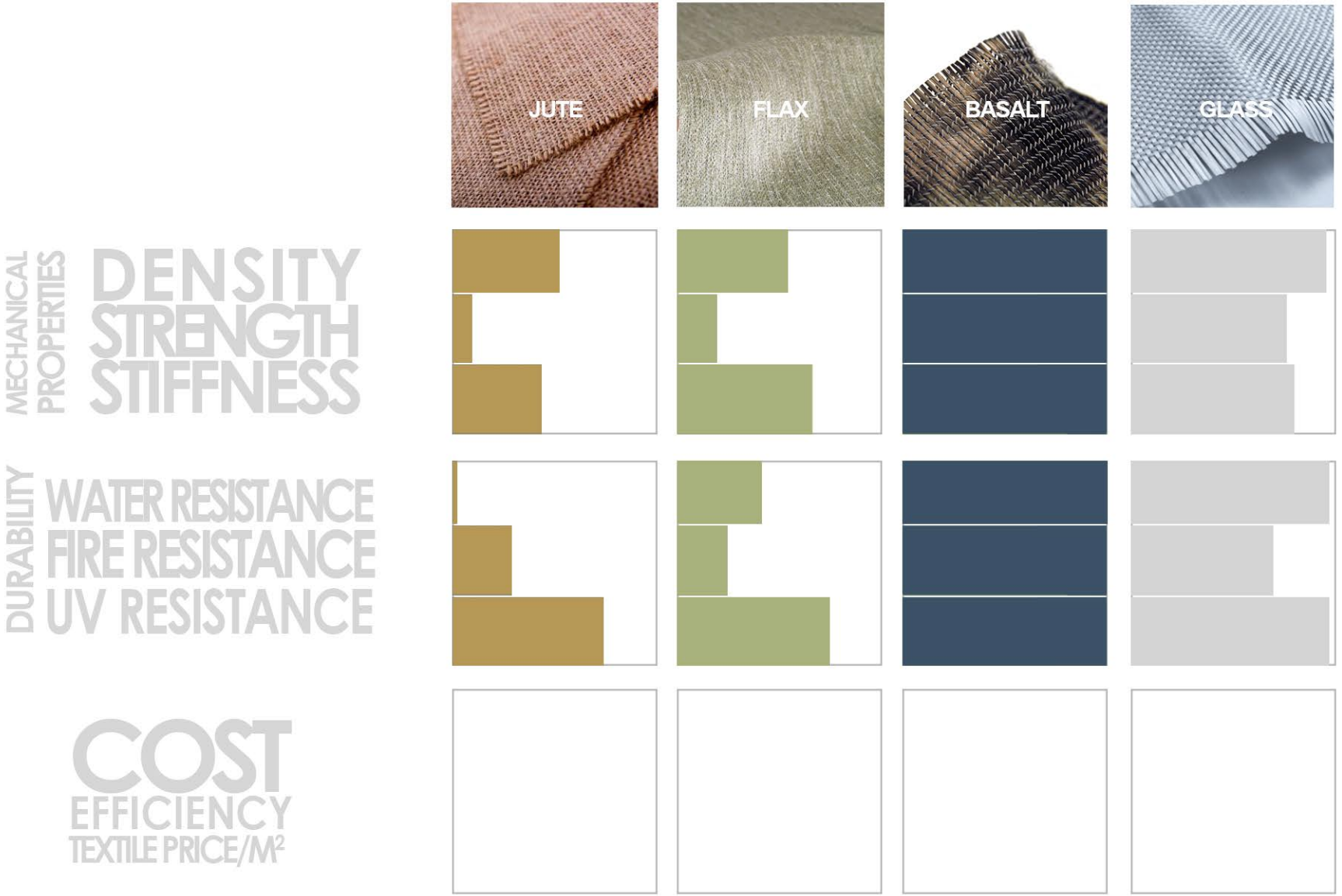

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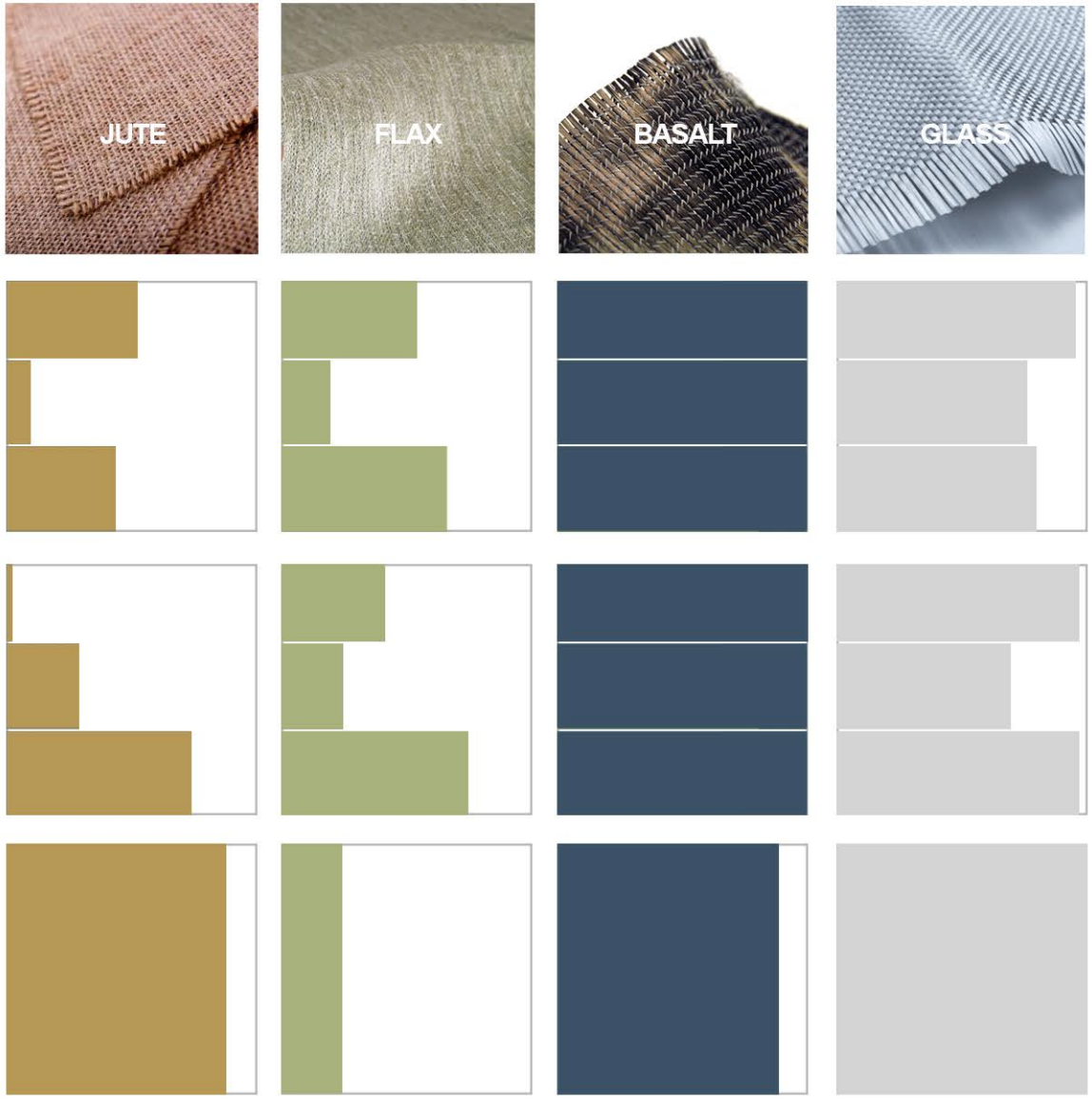

Life Cycle Assessment

Environmental assessment method

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ENVIRONMENTAL IMPACT ➡ FIBRE PRODUCTION ⬅ ENERGY CONSUMPTION

Life Cycle Assessment

Environmental assessment method

ENVIRONMENTAL IMPACT ← FIBRE PRODUCTION ← ENERGY CONSUMPTION

8

ENVIRONMENTAL IMPACT CLASSIFICATION FACTORS

Life Cycle Assessment

Environmental assessment method

ENVIRONMENTAL IMPACT ← FIBRE PRODUCTION ← ENERGY CONSUMPTION

ACIDIFICATION

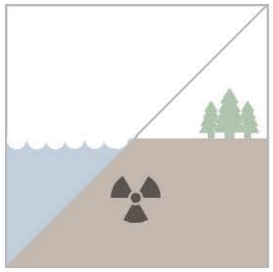
Life Cycle Assessment

Environmental assessment method

ENVIRONMENTAL IMPACT ← FIBRE PRODUCTION → ENERGY CONSUMPTION

ACIDIFICATION

AQUATIC TOXICITY
ECOTOXICITY



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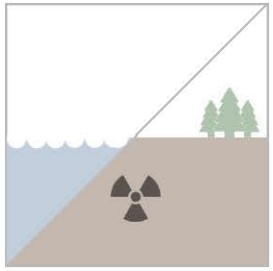
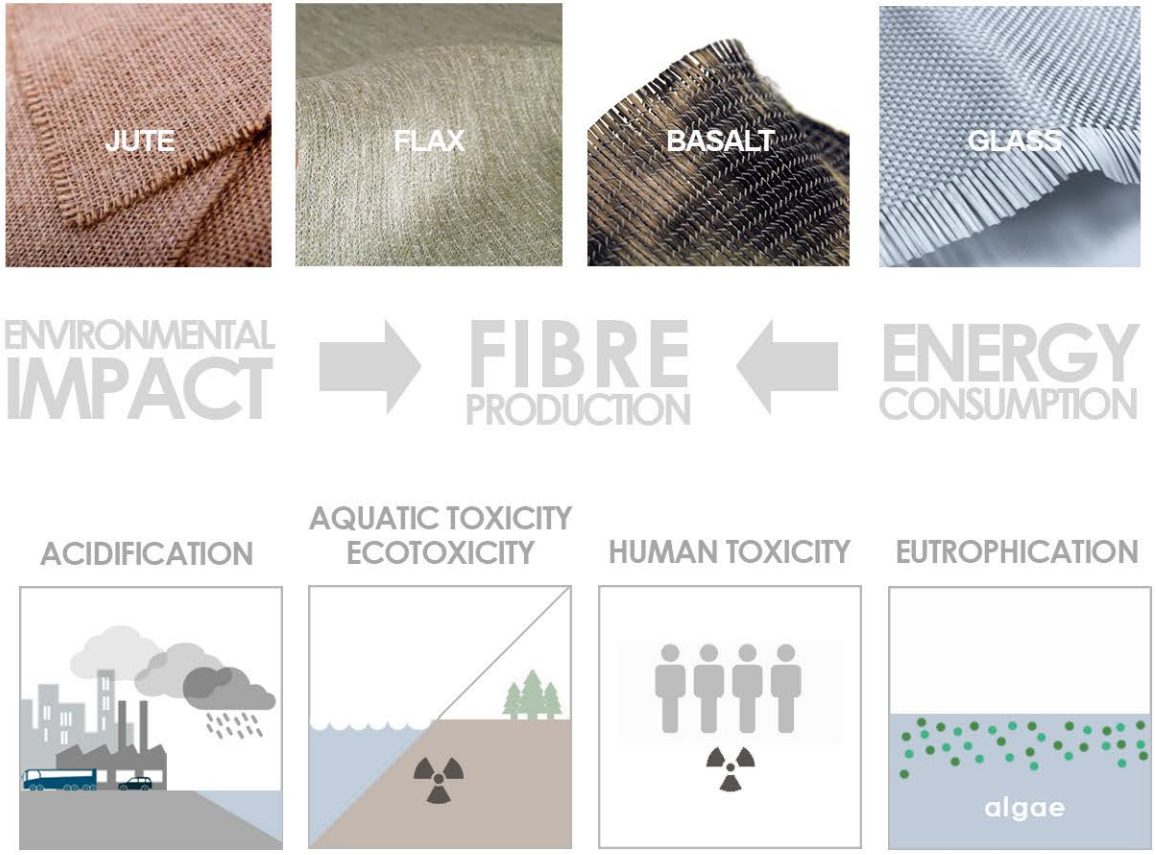


HUMAN TOXICITY

Life Cycle Assessment

Environmental assessment method



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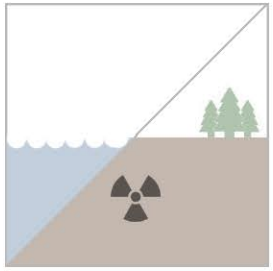
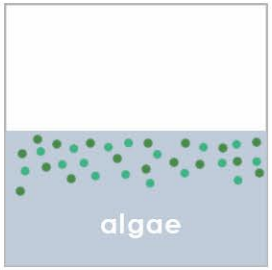


HUMAN TOXICITY

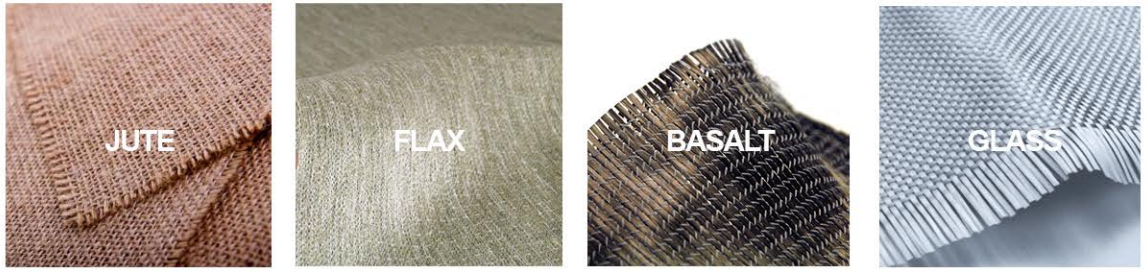
EUTROPHICATION



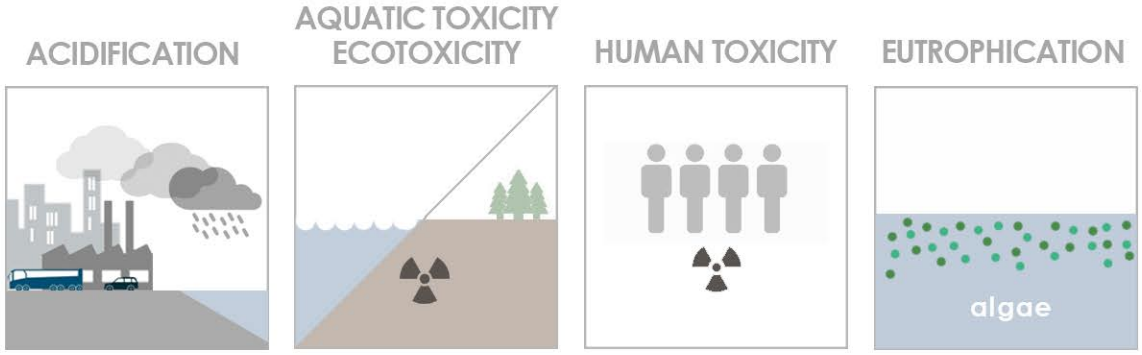
GLOBAL WARMING

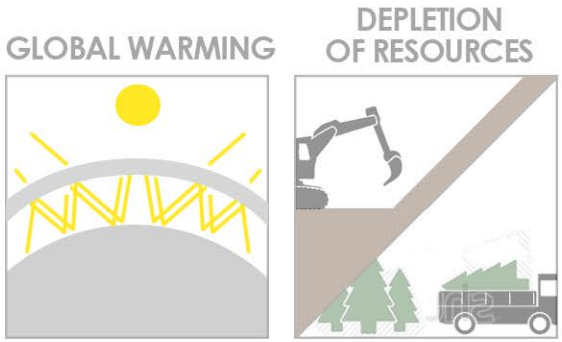
Life Cycle Assessment

Environmental assessment method



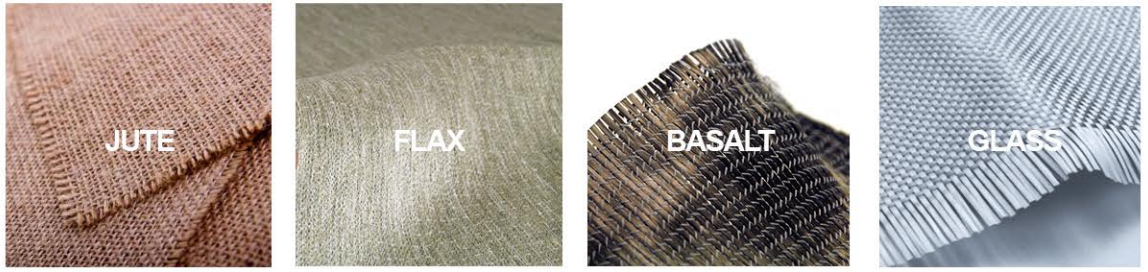
ENVIRONMENTAL IMPACT ← FIBRE PRODUCTION ← ENERGY CONSUMPTION



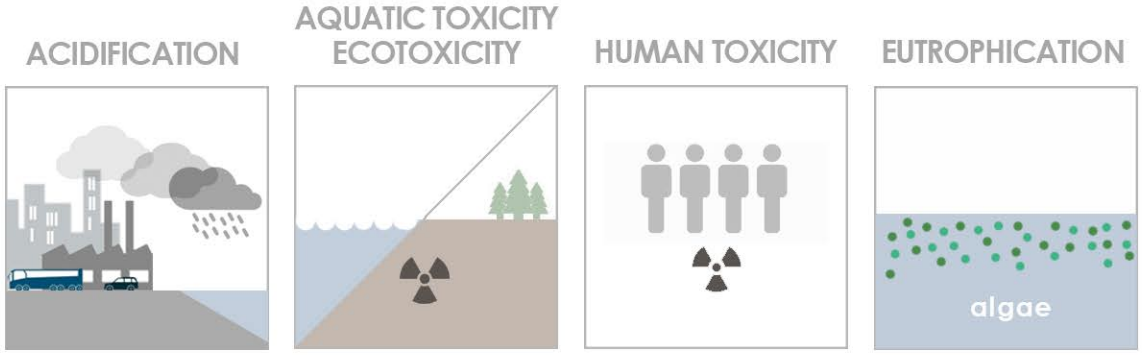


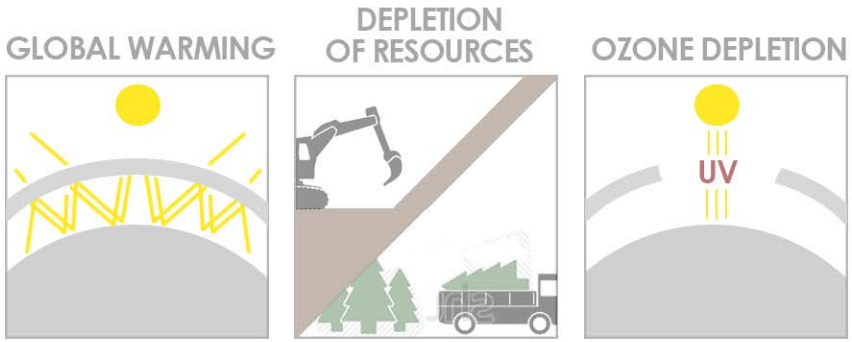
Life Cycle Assessment

Environmental assessment method



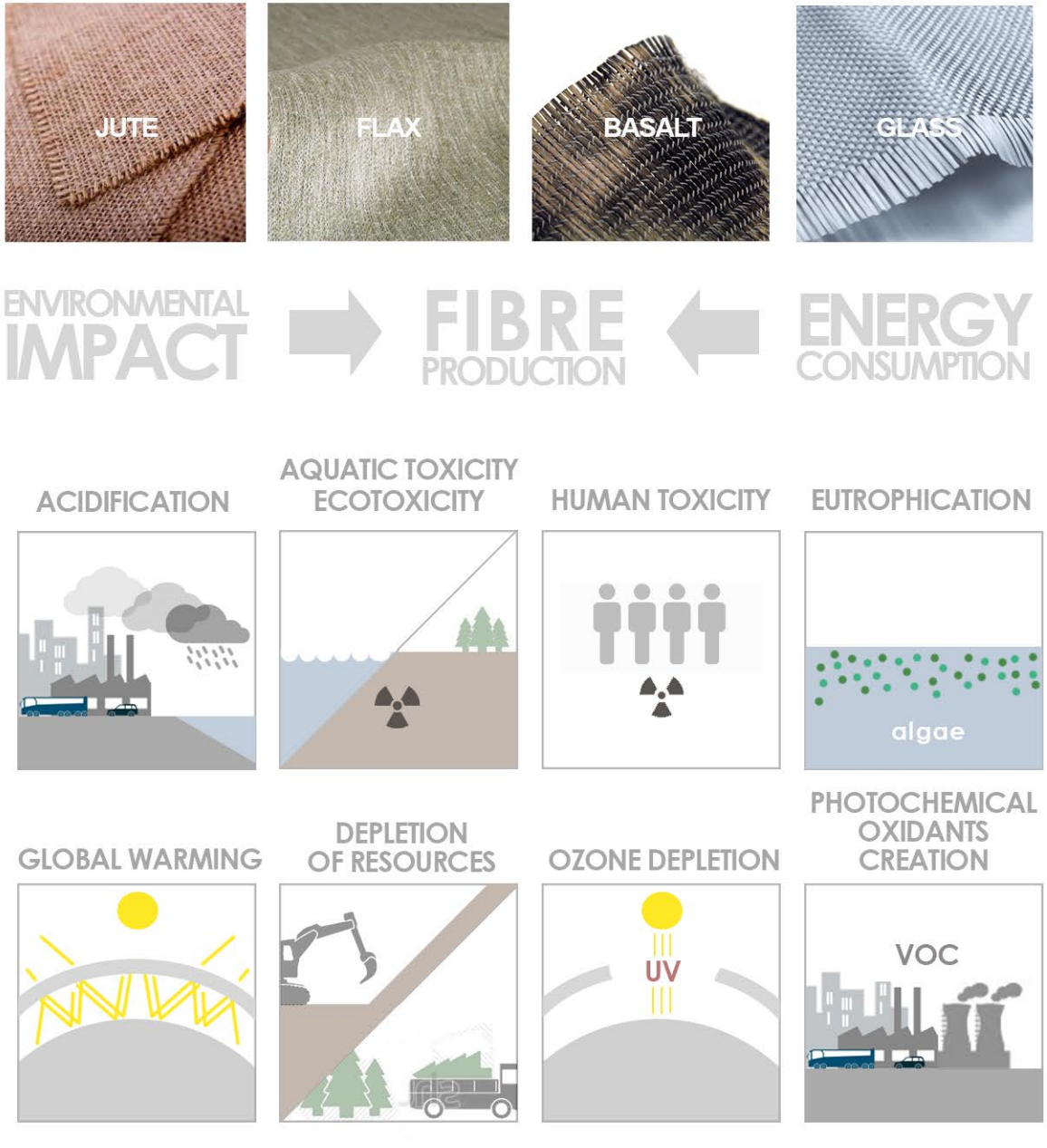
ENVIRONMENTAL IMPACT ← FIBRE PRODUCTION → ENERGY CONSUMPTION





Life Cycle Assessment

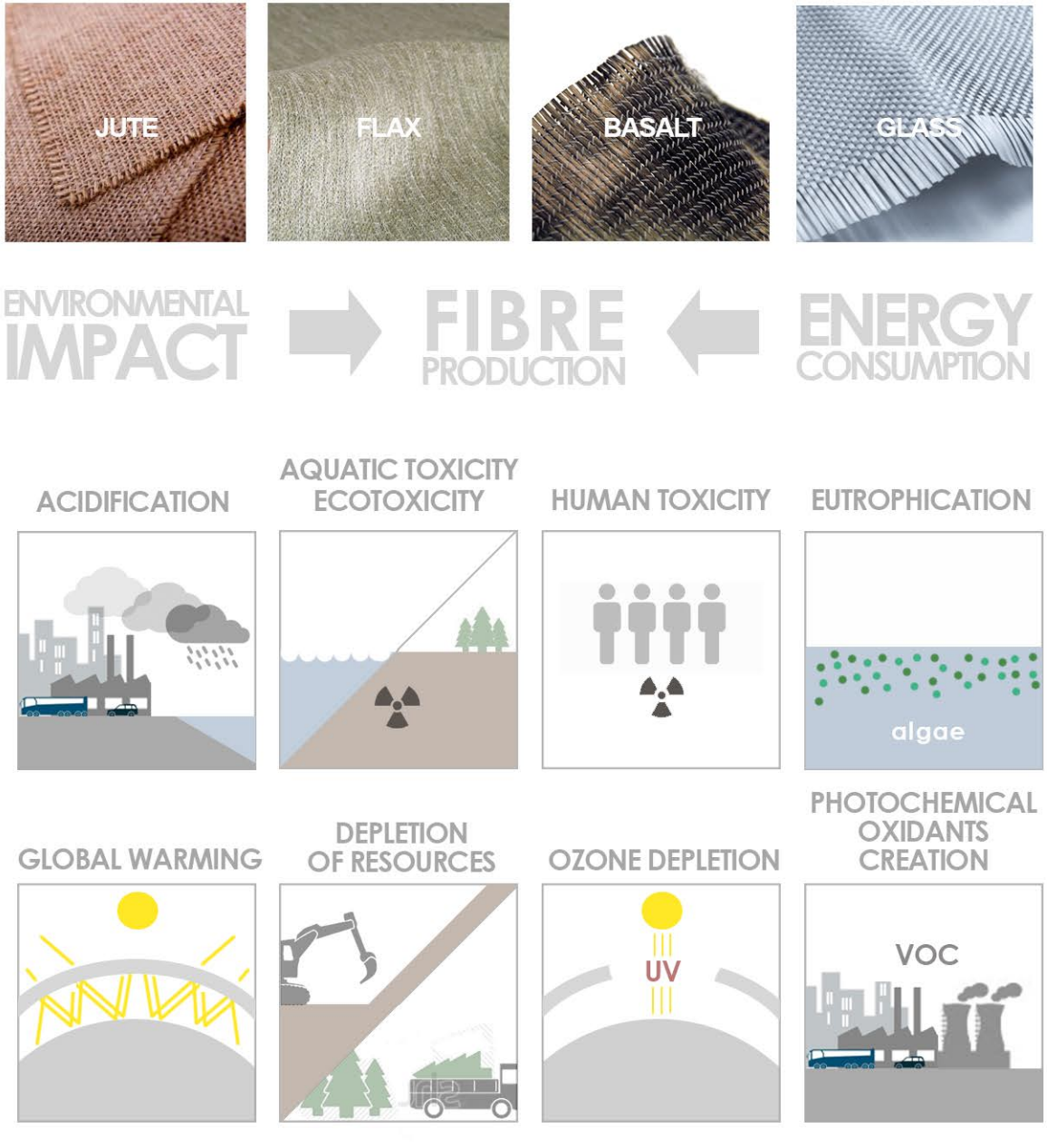
Environmental assessment method



Life Cycle Assessment

Environmental assessment method

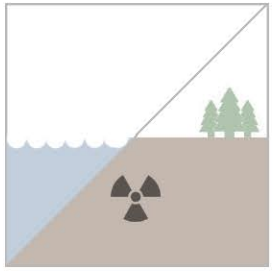
Sources:
Existing research and LCAs
Databases



Life Cycle Assessment

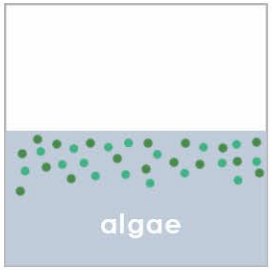
ACIDIFICATION

AQUATIC TOXICITY
ECOTOXICITY

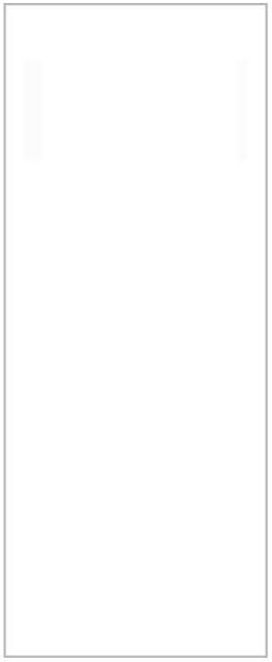


HUMAN TOXICITY

EUTROPHICATION



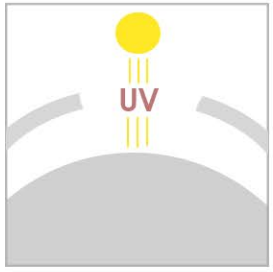
ENERGY
CONSUMPTION



GLOBAL WARMING

DEPLETION
OF RESOURCES

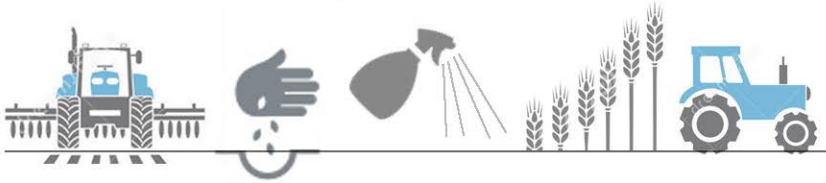
OZONE DEPLETION



PHOTOCHEMICAL
OXIDANTS
CREATION

Life Cycle Assessment

agricultural



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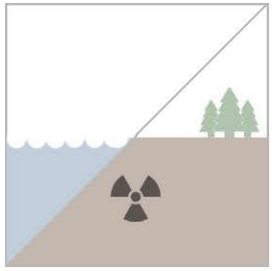

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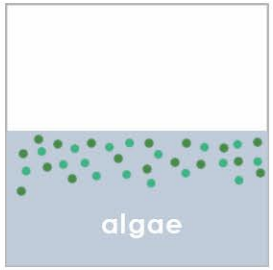
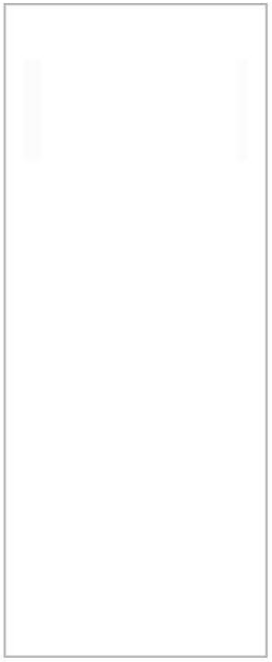


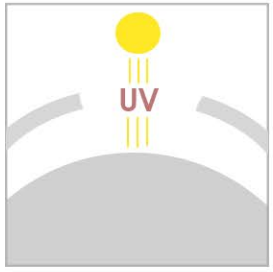
ENERGY
CONSUMPTION



GLOBAL WARMING

DEPLETION
OF RESOURCES

OZONE DEPLETION

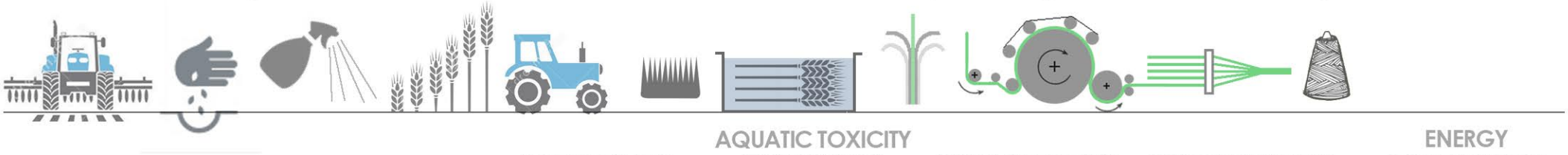


PHOTOCHEMICAL
OXIDANTS
CREATION

Life Cycle Assessment

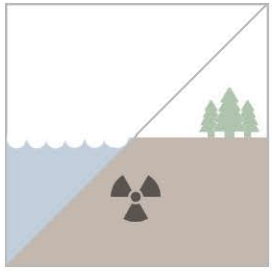
agricultural

fibre processing



ACIDIFICATION

AQUATIC TOXICITY
ECOTOXICITY



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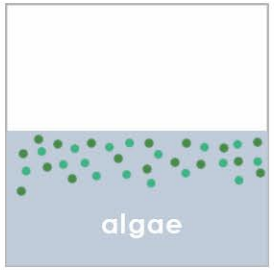
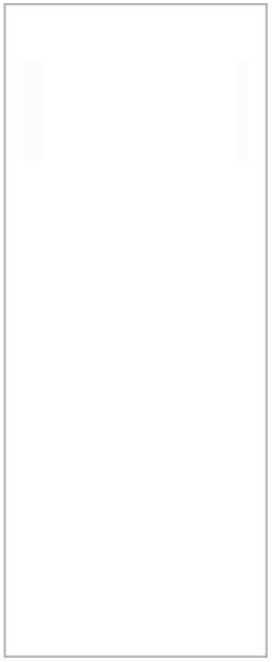


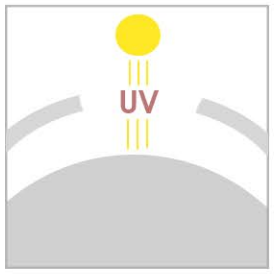
ENERGY
CONSUMPTION



GLOBAL WARMING

DEPLETION
OF RESOURCES

OZONE DEPLETION

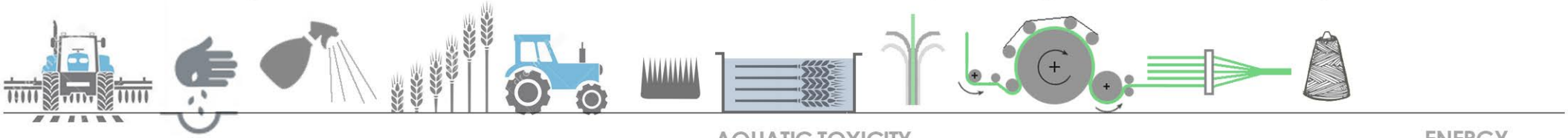


PHOTOCHEMICAL
OXIDANTS
CREATION

Life Cycle Assessment

agricultural

fibre processing



ACIDIFICATION

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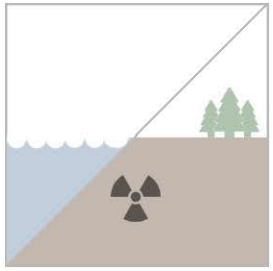
ECOTOXICITY



HUMAN TOXICITY

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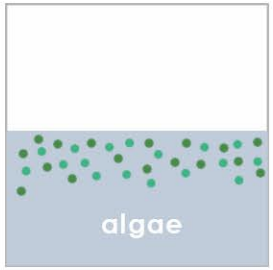
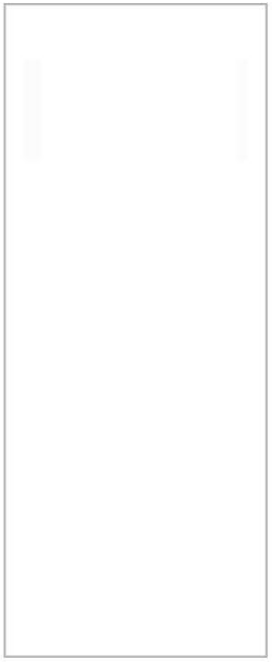


ENERGY
CONSUMPTION



GLOBAL WARMING

DEPLETION
OF RESOURCES

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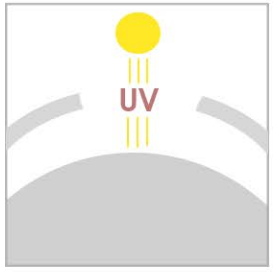
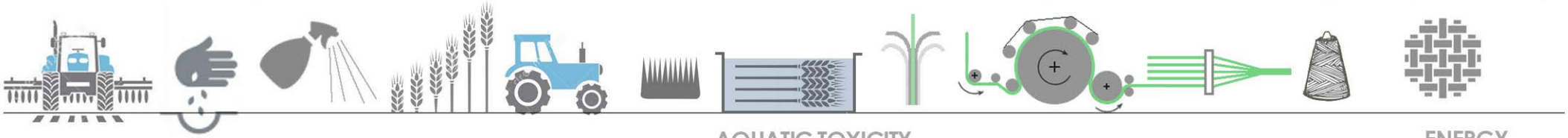


PHOTOCHEMICAL
OXIDANTS
CREATION

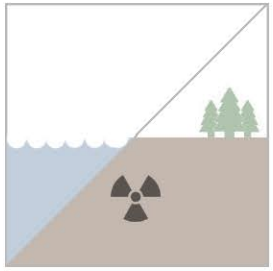
Life Cycle Assessment

agricultural | fibre processing | fabric processing



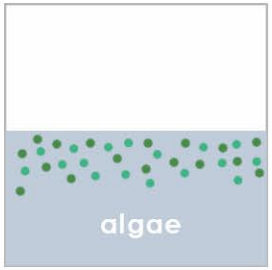
ACIDIFICATION

AQUATIC TOXICITY
ECOTOXICITY

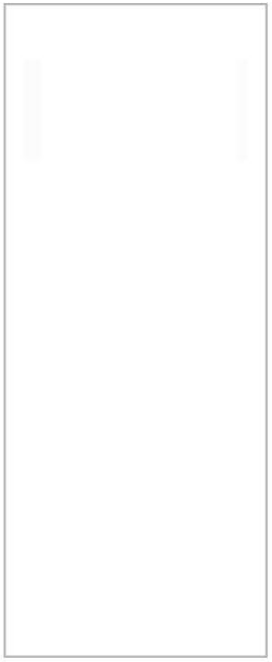


HUMAN TOXICITY

EUTROPHICATION



ENERGY
CONSUMPTION



GLOBAL WARMING

DEPLETION
OF RESOURCES

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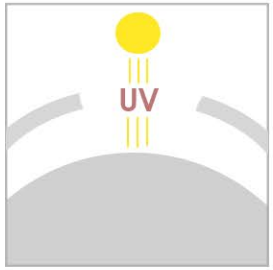
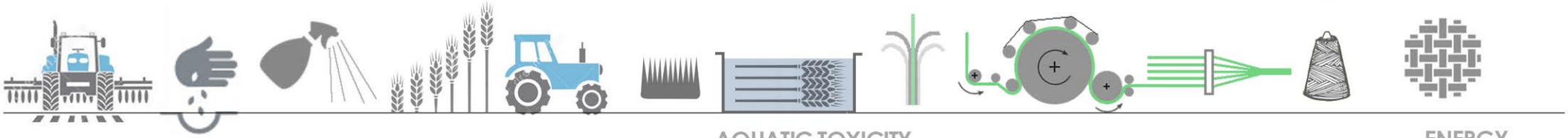
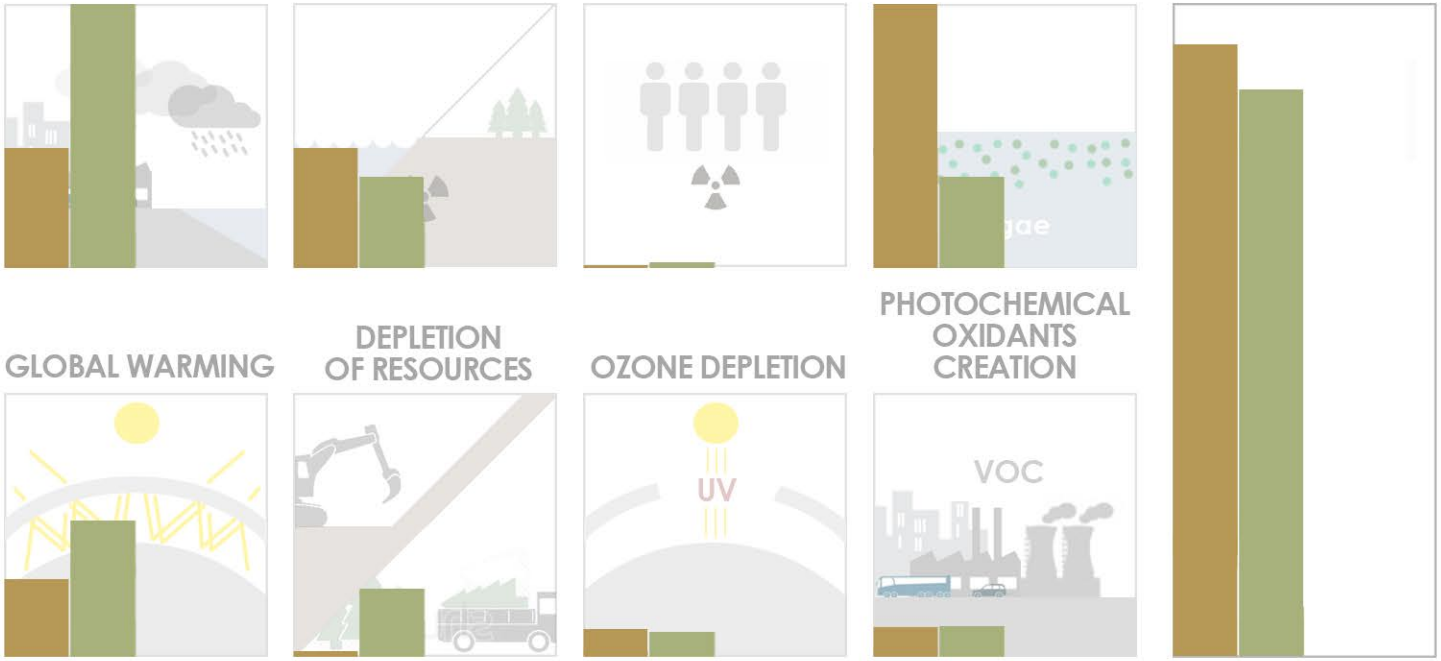


PHOTOCHEMICAL
OXIDANTS
CREATION

Life Cycle Assessment

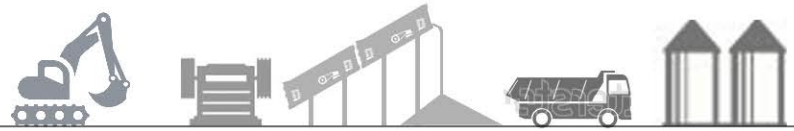
agricultural | fibre processing | fabric processing

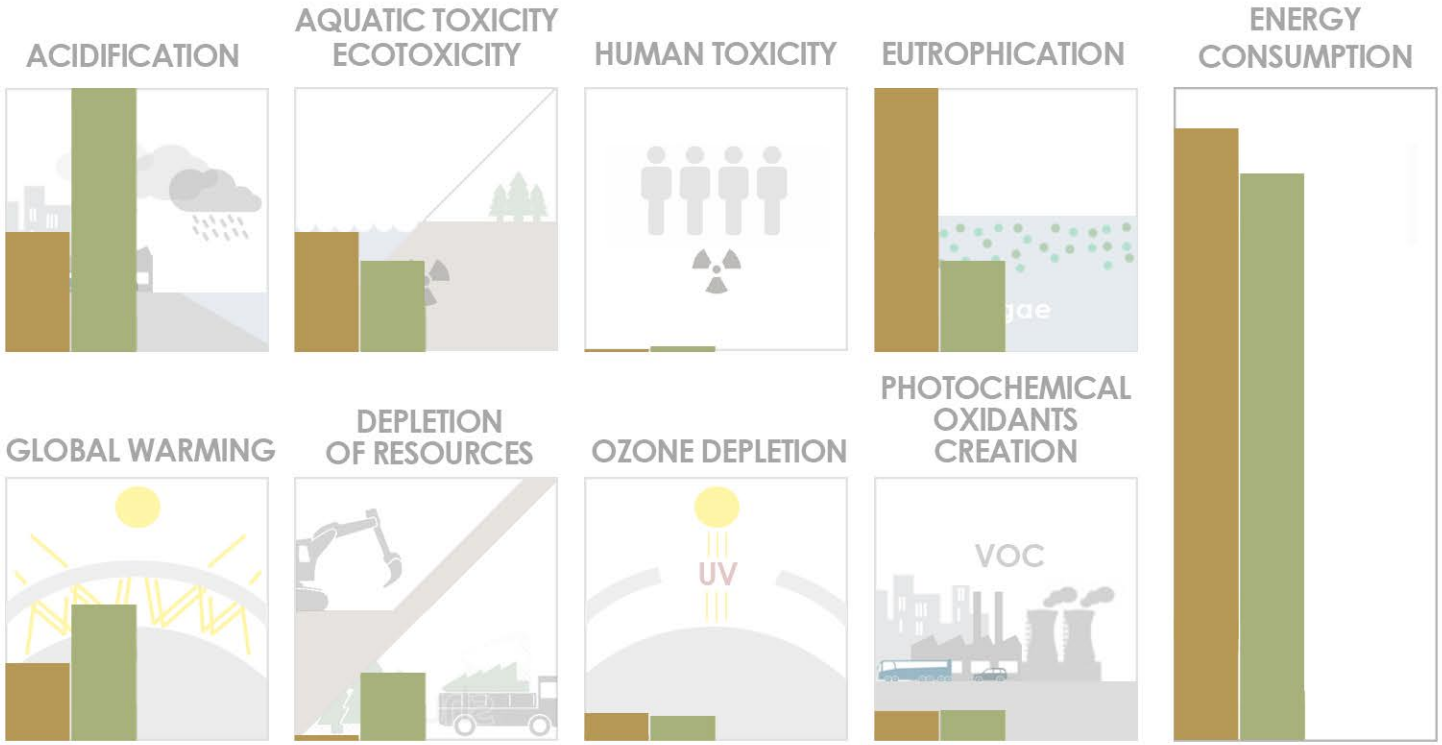




Life Cycle Assessment

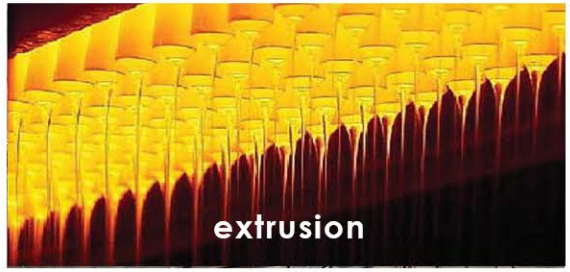
extraction

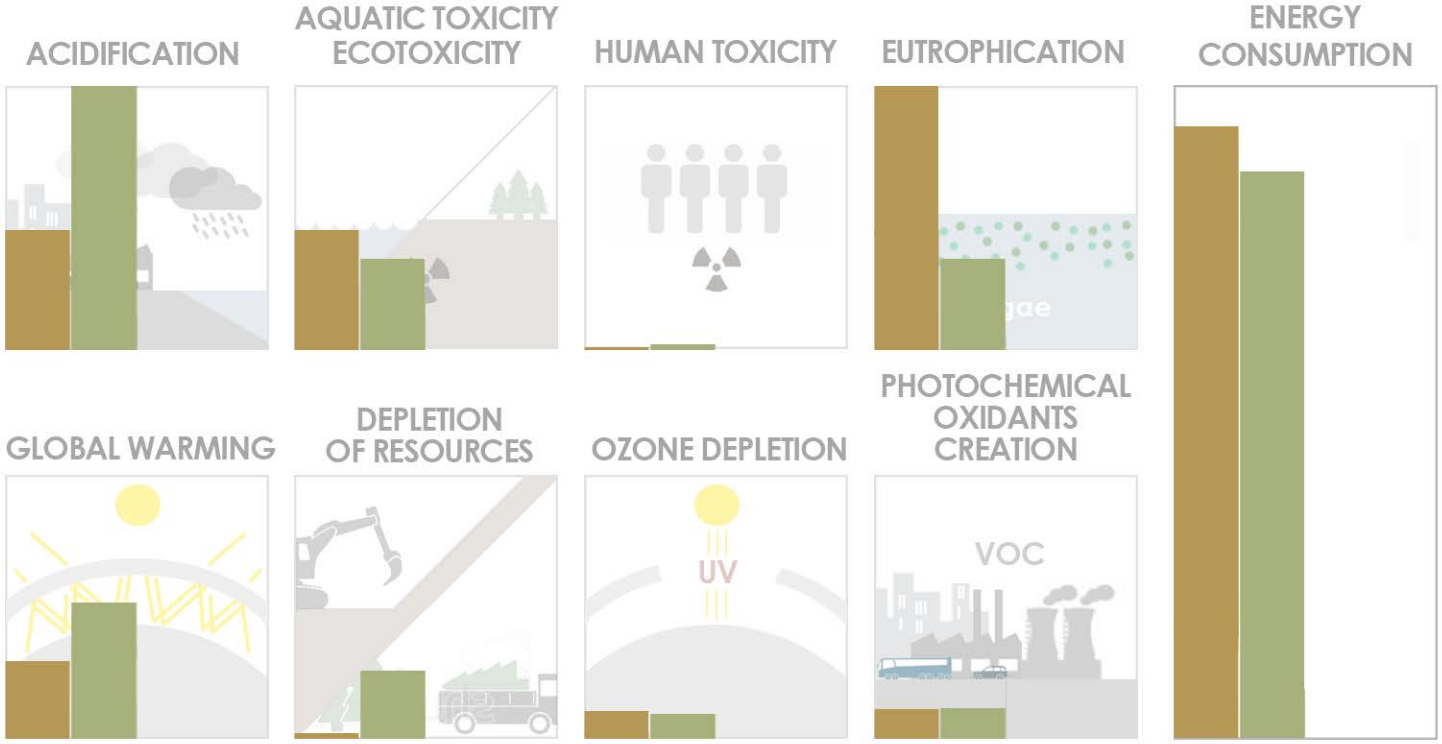




Life Cycle Assessment

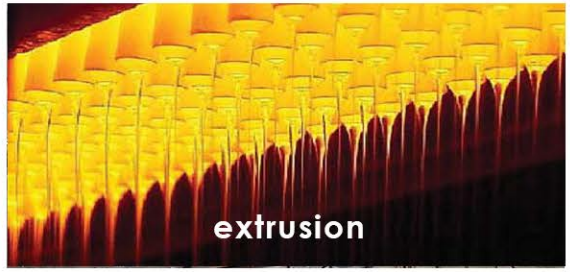
extraction — fibre processing

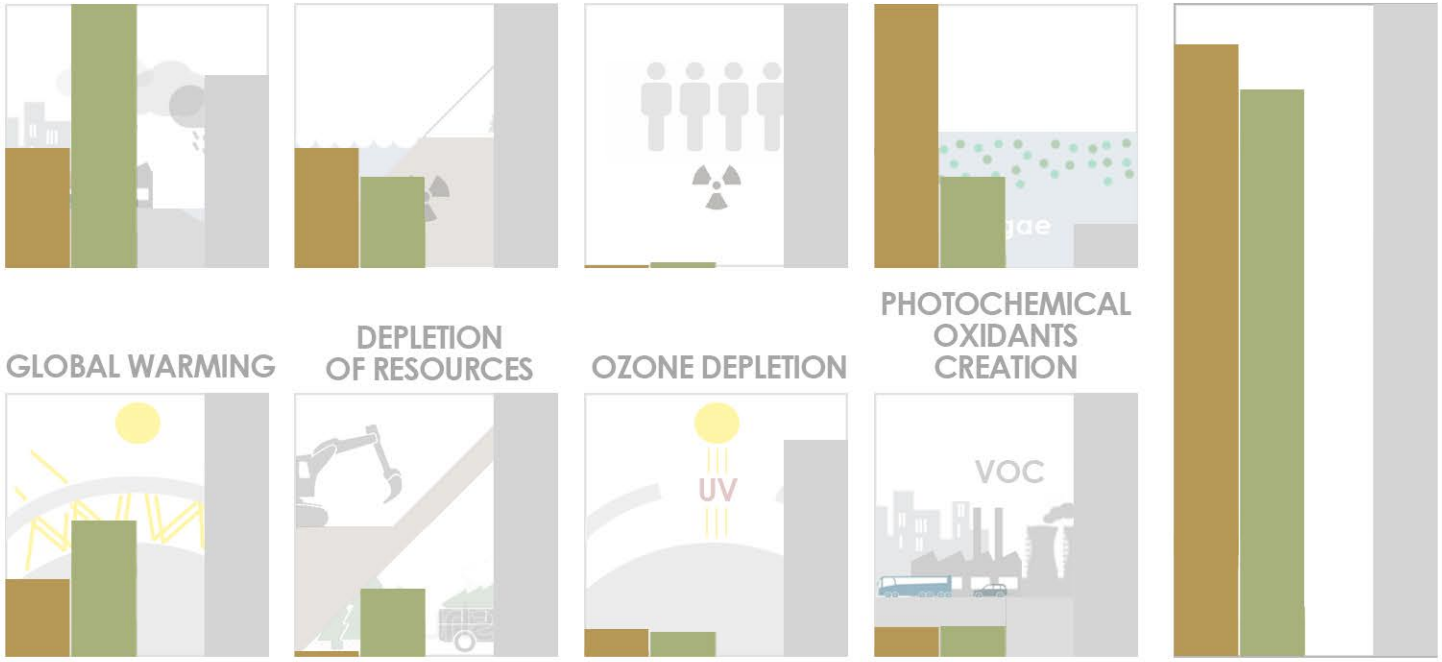




Life Cycle Assessment

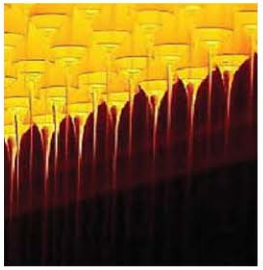
extraction — fibre processing — fabric processing

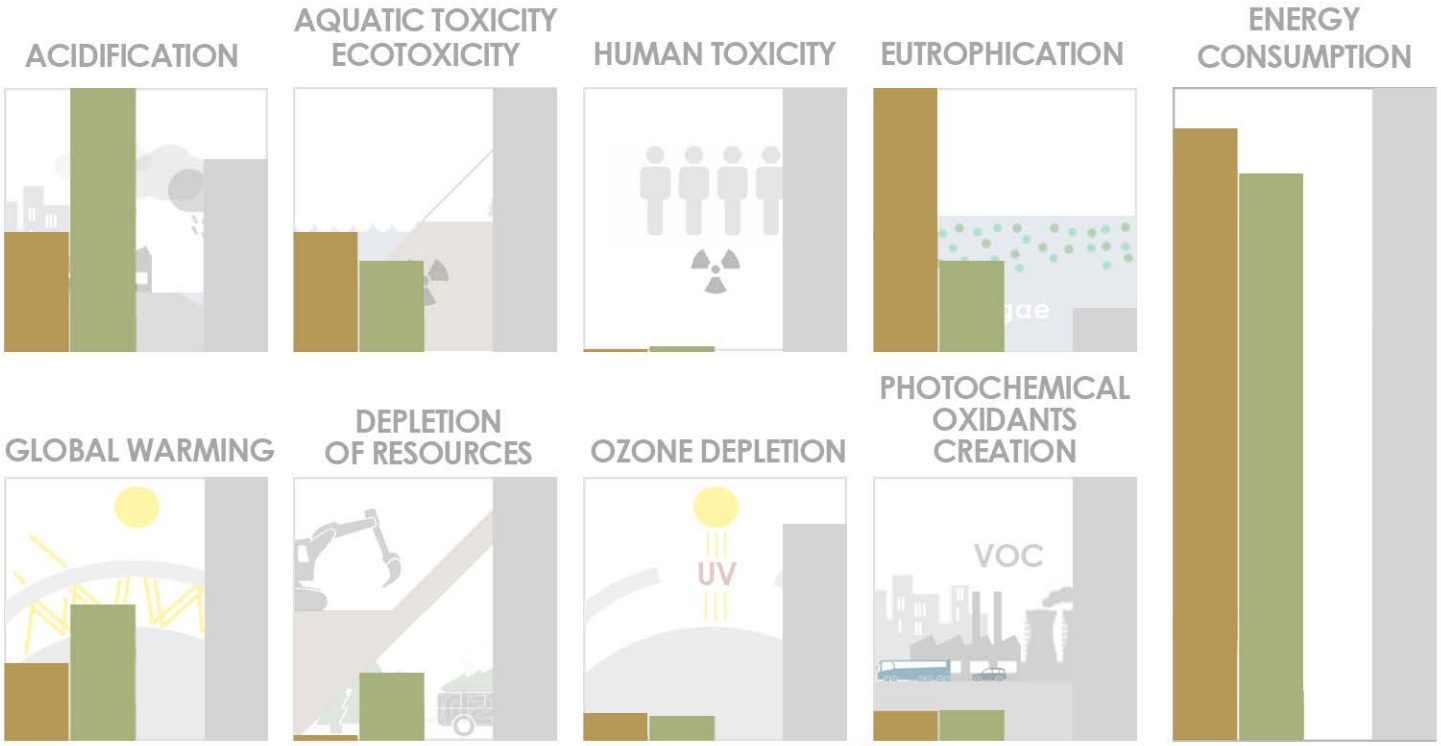




Life Cycle Assessment

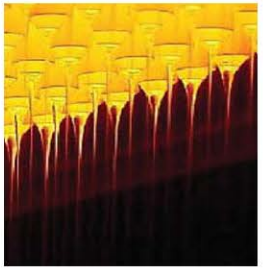

extraction — fibre processing — fabric processing

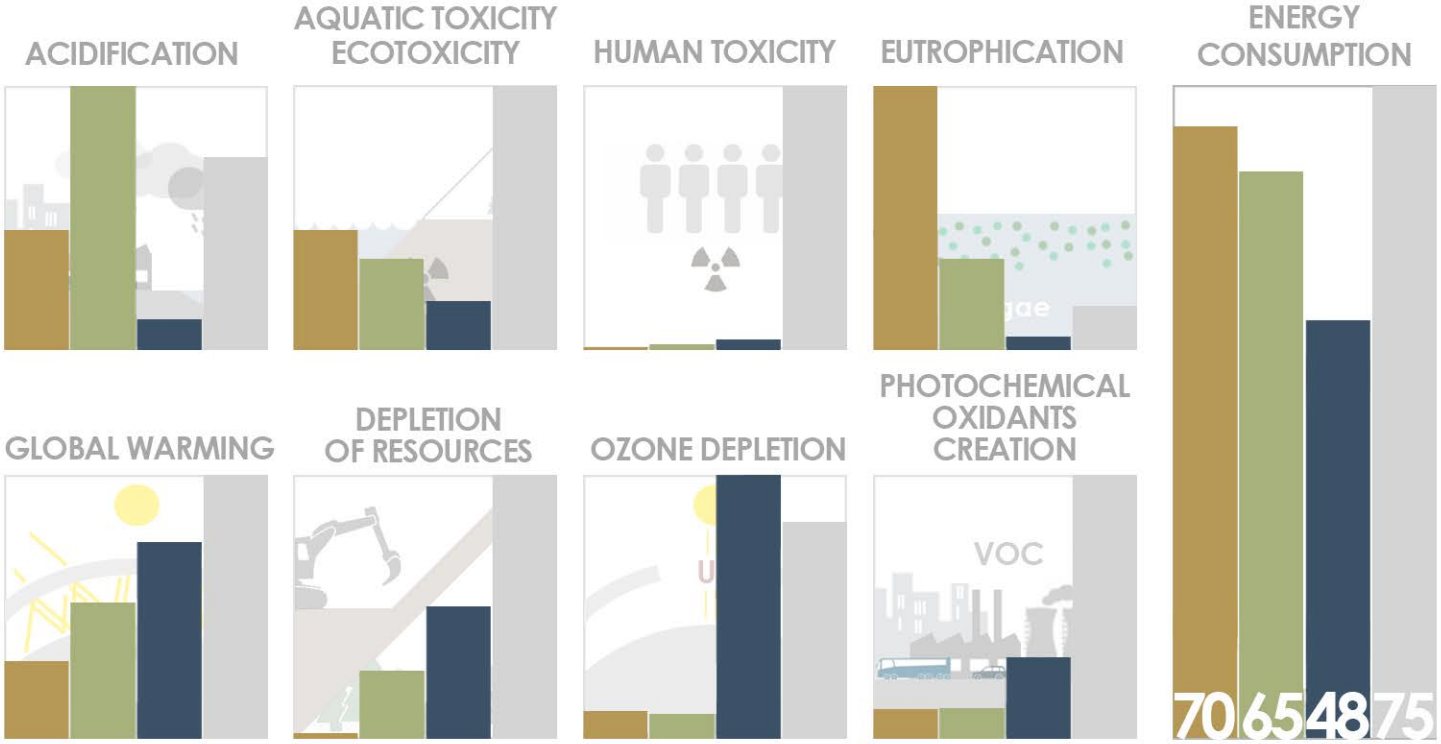






Life Cycle Assessment


extraction — fibre processing — fabric processing




Rafail Gkaidatzis | 06-11-2014

TU Delft Delft University of Technology

Research on bio-resins

Bio-polymers are generally classified into:

BIODEGRADABLE

DURABLE

Research on bio-resins

Bio-polymers are generally classified into:

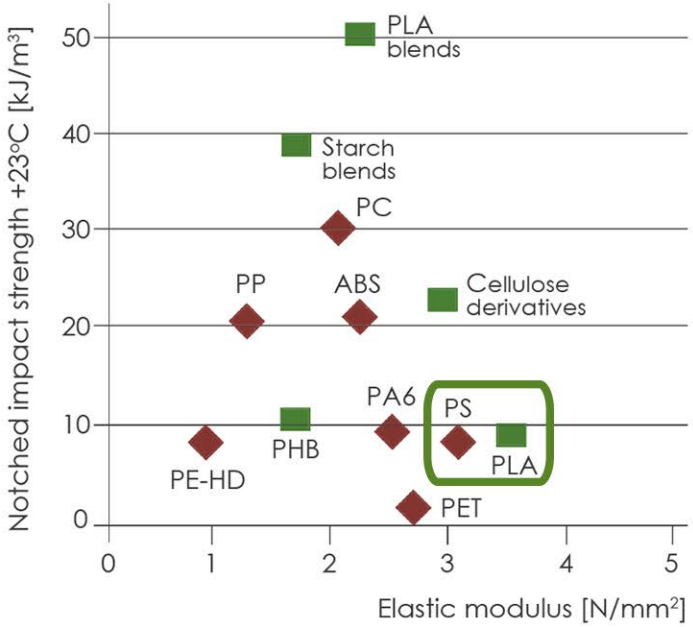
BIODEGRADABLE

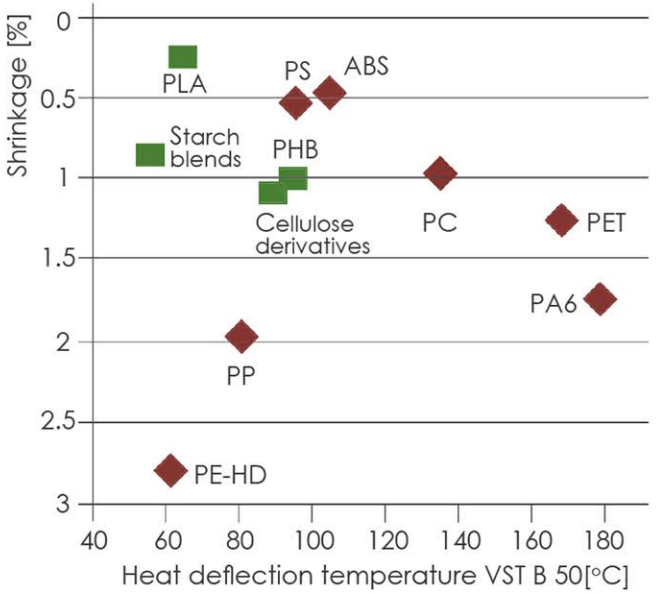
DURABLE

100% bio-based polymers produced exclusively by natural substances such as starch or cellulose (PLA, PHB) :

- characterized by high moisture absorption
- brittle behaviour
- sensitivity to high temperatures
- under developement

Properties	Tensile strength (MPa)	E-modulus (GPa)	Elongation at failure (%)	Moisture absorption (%) per 24h
PLA	48-60	3.45-3.85	2-6	0.5-1
PHB	40	1.8	4	3-5
CA	21-31	1.66-1.74	32.5-35.4	1.7-3.7
TPS	16-22	0.24-1.5	10-80	5-10
PP	19.7-80	1.5-2	52-232	0.01-0.09
PET	55-60	2-2.7	28-320	0.1-0.2
PC	43-66	1.5-2.6	92-200	0.13-0.15
PS	20-56	3-3.5	1,2-50	0.005-0.01





TU Delft Delft University of Technology

Research on bio-resins

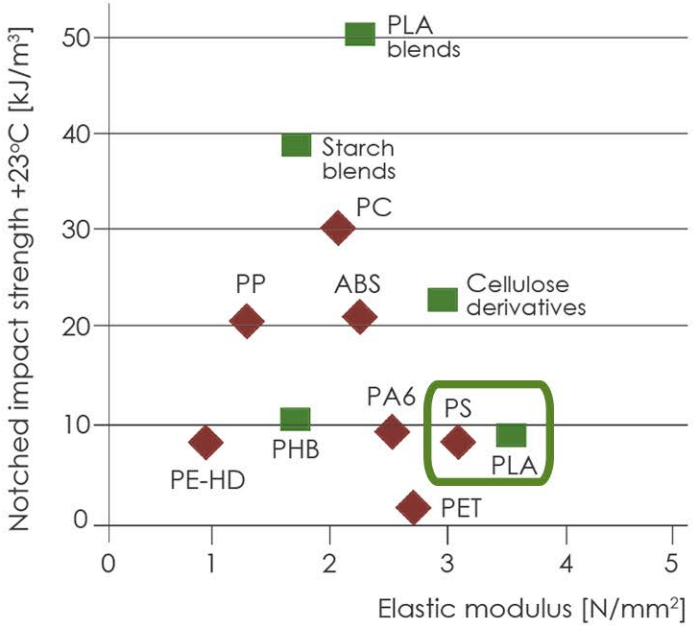
Bio-polymers are generally classified into:

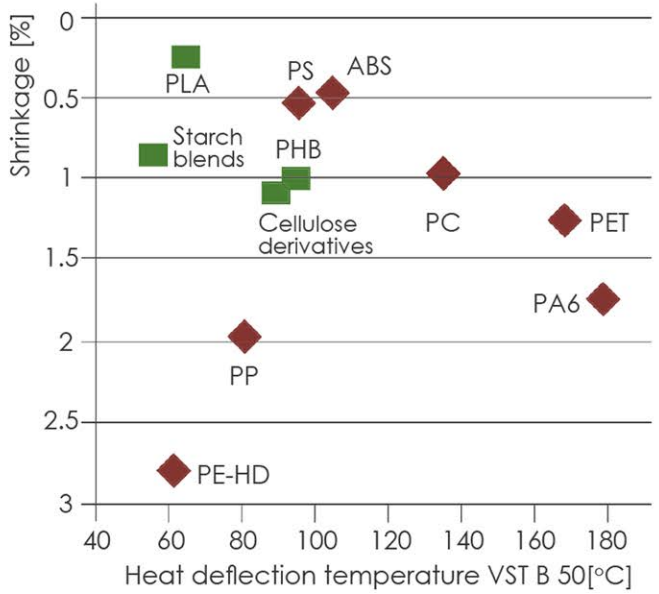
~~BIODEGRADABLE~~

DURABLE

suitable for temporary applications

and **not for loadbearing** structural applications





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PET	55-60	2-2.7	28-320	0.1-0.2
PC	43-66	1.5-2.6	92-200	0.13-0.15
PS	20-56	3-3.5	1,2-50	0.005-0.01

Research on bio-resins

Bio-polymers are generally classified into:

BIODEGRADABLE

DURABLE

Durable bio-polymers is a next generations after biodegradable polymers:

- maximizing the content of renewable raw materials
- achieve a long-lasting functionality (fillers and additives to inhibit degradability and reduce brittleness)
- based on vegetable oil (biodiesel)

Research on bio-resins

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- based on vegetable oil (biodiesel)

FURAN

- 100% bio-based thermoset resin derived from renewable resources
- Produced from pentose sugars and furfuryl alcohol which is created from agricultural wastes (corn cobs, sugar canes)
- Compatible with natural fibres and basalt

Core materials

Core materials

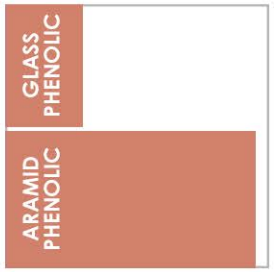
ENERGY CONSUMPTION

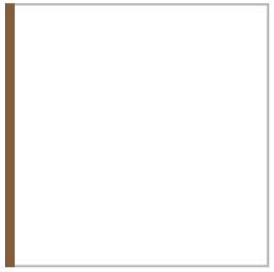
ENVIRONMENTAL IMPACT

Core materials

ENERGY CONSUMPTION

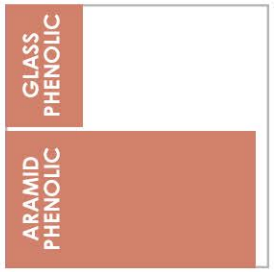
ENVIRONMENTAL IMPACT

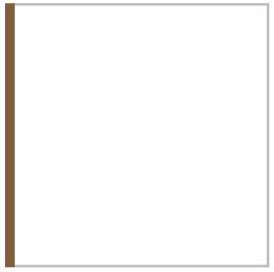




Core materials

ENERGY CONSUMPTION





ENVIRONMENTAL IMPACT

FOAM BLOWING AGENTS (CFCs, HCFCs)

OZONE DEPLETION
GLOBAL WARMING
TOXICITY
PHOTOCHEMICAL OXIDANTS

OZONE DEPLETION
GLOBAL WARMING
TOXICITY
PHOTOCHEMICAL OXIDANTS
DEPLETION OF RESOURCES

DEPLETION OF RESOURCES
GLOBAL WARMING
OZONE DEPLETION
PHOTOCHEMICAL OXIDANTS
ACIDIFICATION

LOW IMPACT

RENEWABLE RESOURCE = FAST GROWTH

NON-TOXIC

NO AGRICULTURAL ACTIVITY = NOT A "CROP" WOOD

NO FERTILIZING

Research on manufacturing processes

Research on manufacturing processes

Manual lay-up processes

Hand lay-up

Vacuum/pressure bag

Autoclave molding

Research on manufacturing processes

Manual lay-up processes

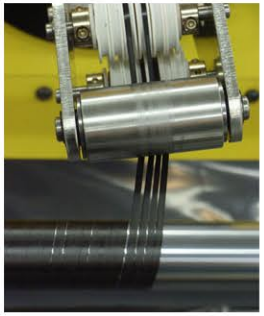
Hand lay-up

Vacuum/pressure bag

Autoclave molding

Automatic lay-up processes

Automated tape placement (ATP)



Filament winding

Research on manufacturing processes

Manual lay-up processes

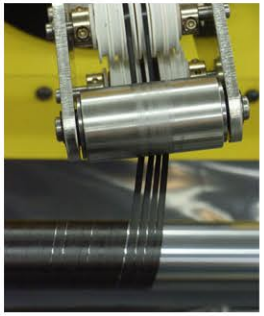
Hand lay-up

Vacuum/pressure bag

Autoclave molding

Automatic lay-up processes

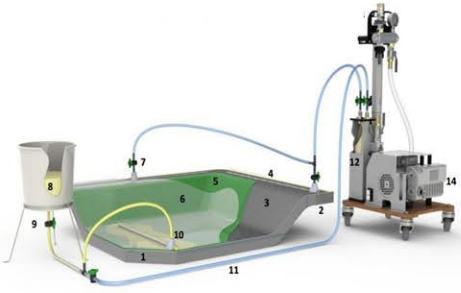
Automated tape placement (ATP)



Filament winding

Resin transfer processes

Resin transfer molding (RTM)



Vacuum assisted RTM

Resin film infusion (RFI)

Research on manufacturing processes

Manual lay-up processes

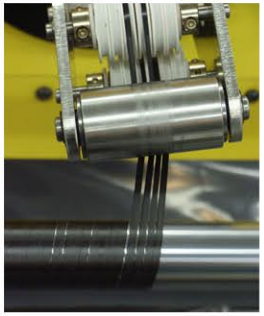
Hand lay-up

Vacuum/pressure bag

Autoclave molding

Automatic lay-up processes

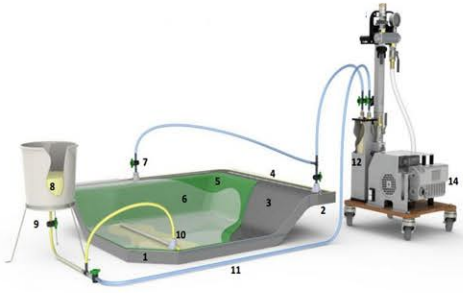
Automated tape placement (ATP)



Filament winding

Resin transfer processes

Resin transfer molding (RTM)



Vacuum assisted RTM

Resin film infusion (RFI)

Continuous processes

Pultrusion

Continuous laminating

Research on manufacturing processes

Manual lay-up processes

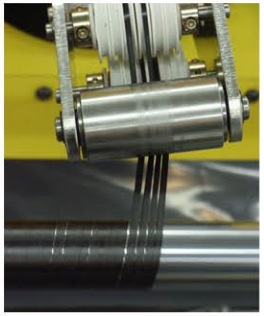
Hand lay-up

Vacuum/pressure bag

Autoclave molding

Automatic lay-up processes

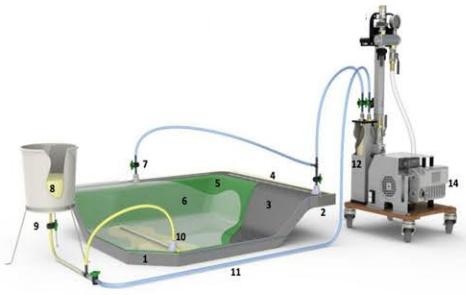
Automated tape placement (ATP)



Filament winding

Resin transfer processes

Resin transfer molding (RTM)



Vacuum assisted RTM

Resin film infusion (RFI)

Continuous processes

Pultrusion

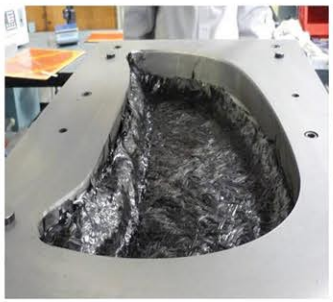
Continuous laminating

Spraying processes

Spray-up

Centrifugal molding

Compression molding processes



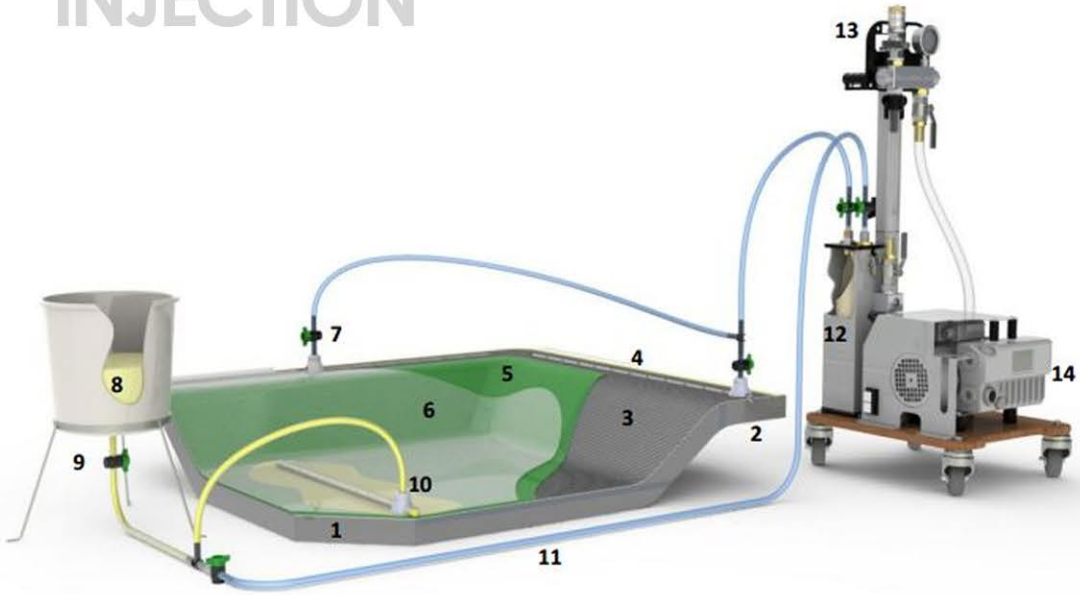
BMC molding

SMC molding

Cold press molding

Thermoforming

VACUUM INJECTION



Process steps

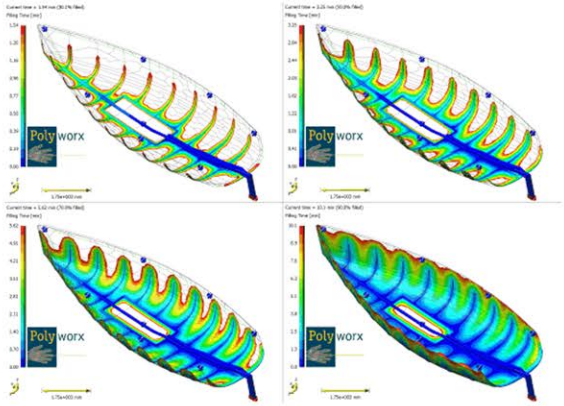
1. lamination of dry reinforcement and additional layers on mold
2. the laminate is sealed airtight on the mold by a flexible bag
3. injection of resin from a tube inside the laminate
3. extraction of air from the laminate by a vacuum pump

Advantages

- economic process
- small butch sizes and not mass productions
- good component quality
- mold costs can be lower (low-cost, disposable materials)
- low chemical emissions (closed mold process) / clean process

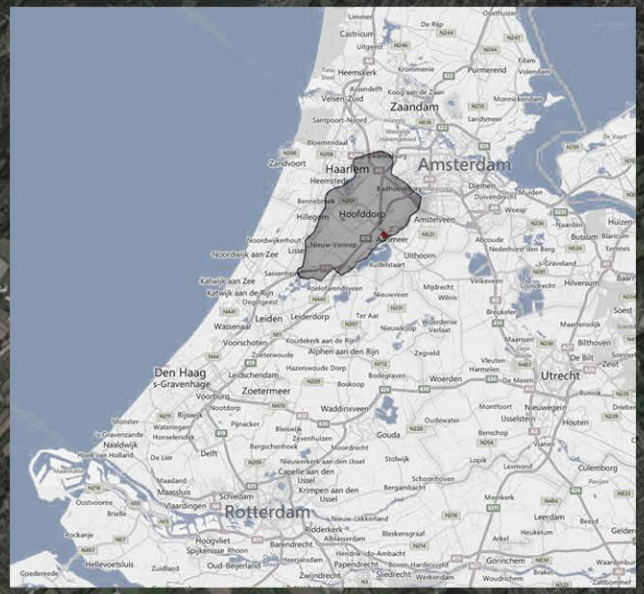
Disadvantages

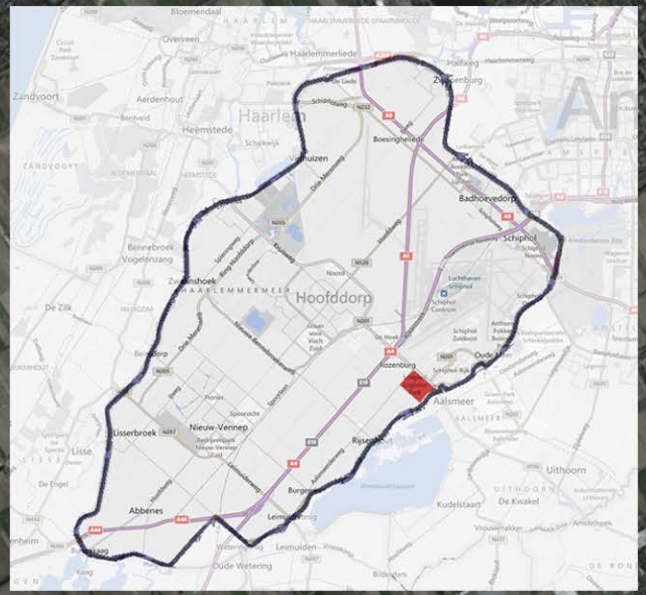
- only one ''good'' surface with smooth finish is obtained



DESIGN

Schiphol Logistics Park





Schiphol Logistics Park

Rafail Gkaidatzis | 06-11-2014

TU Delft Delft University of Technology

Schiphol Logistics Park

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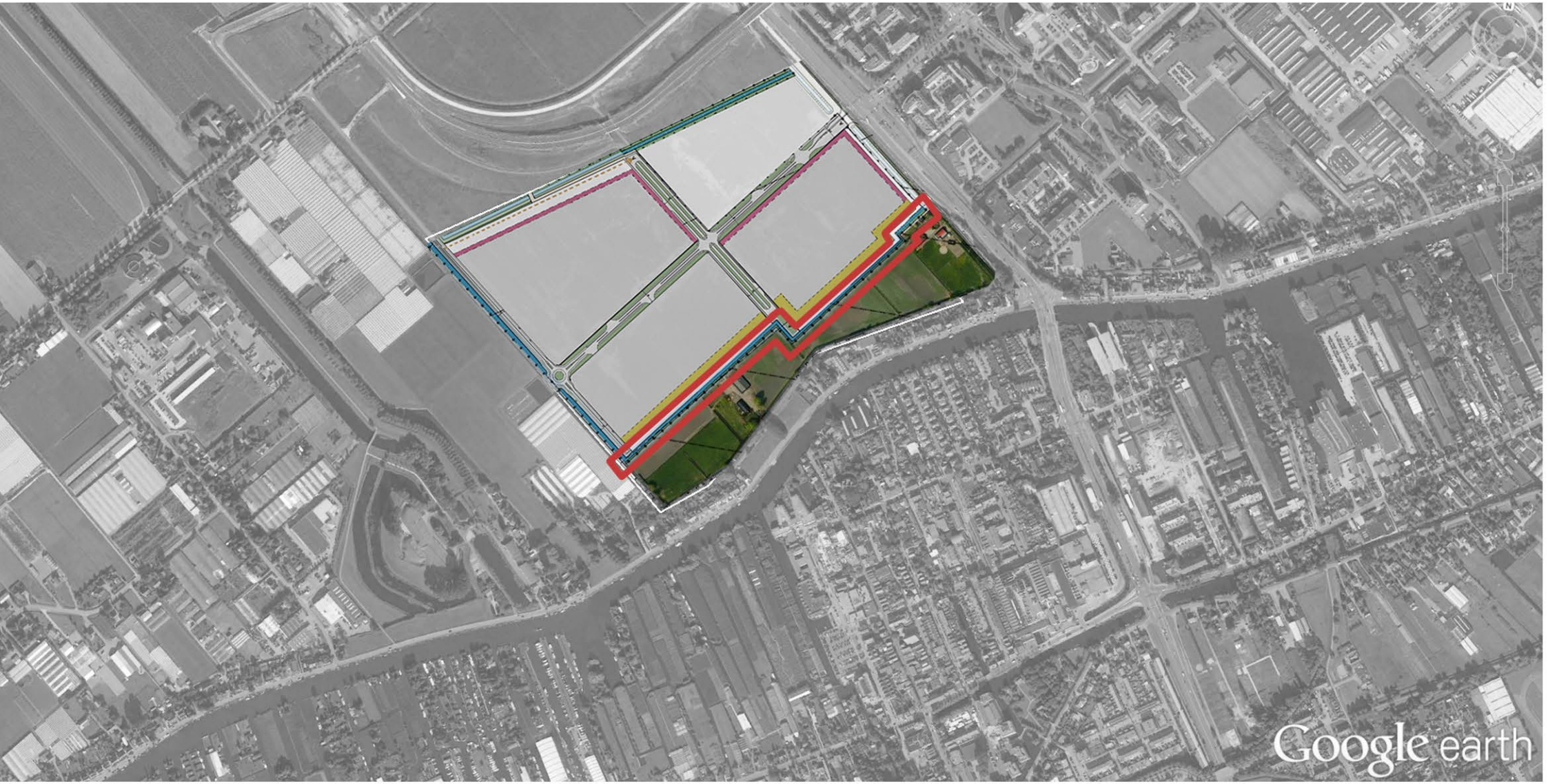
Schiphol Logistics Park



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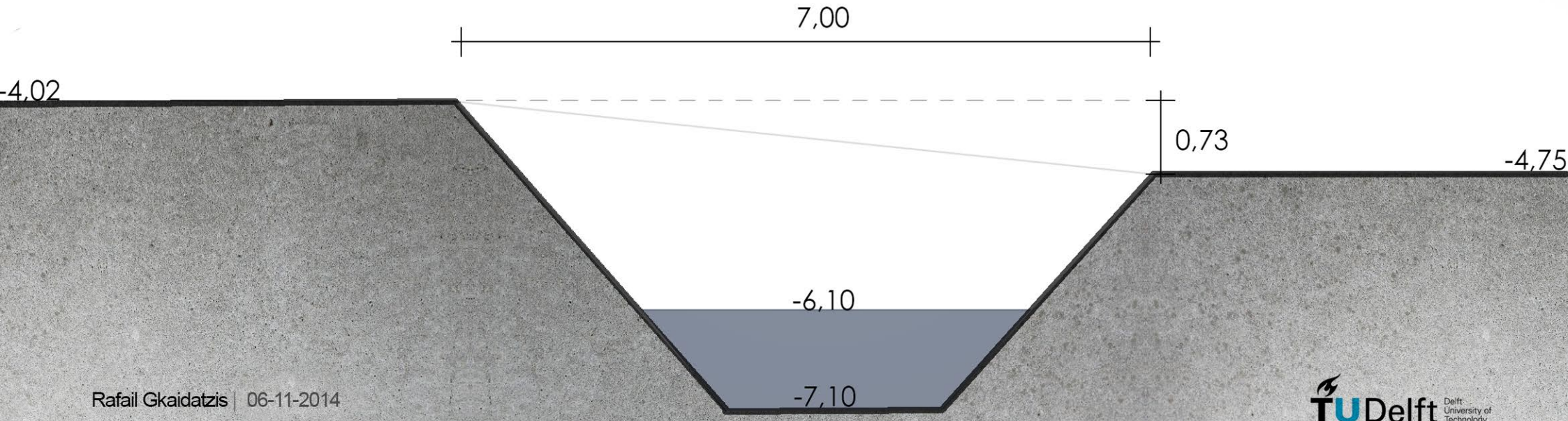
TU Delft Delft University of Technology

Site analysis



Design guidelines of bio-based bridge

Design guidelines of bio-based bridge

1

Cost efficiency

- economic production method for a single unit
- low cost and simple moldmaking

Design guidelines of bio-based bridge

1

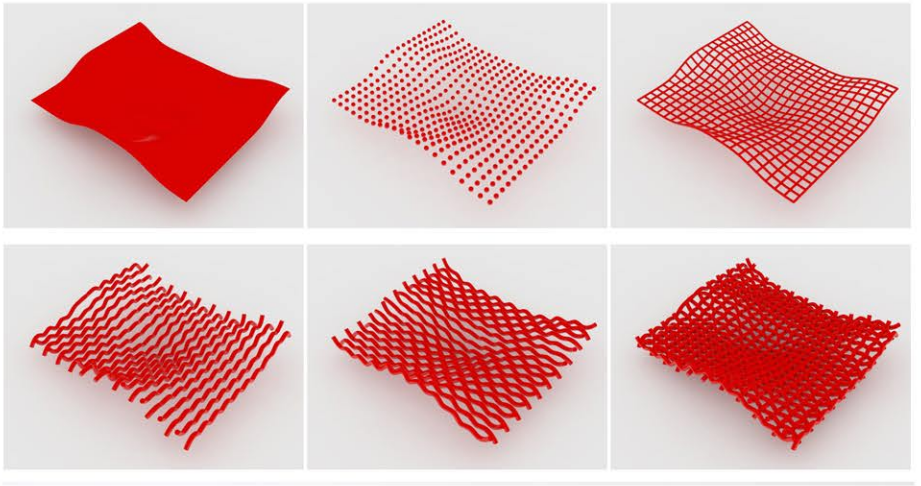
Cost efficiency

- economic production method for a single unit
- low cost and simple moldmaking

2

Structural efficiency

- optimized geometry
- optimized composite structure (laminate, fibre orientations)



Design guidelines of bio-based bridge

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- low cost and simple moldmaking

2

Structural efficiency

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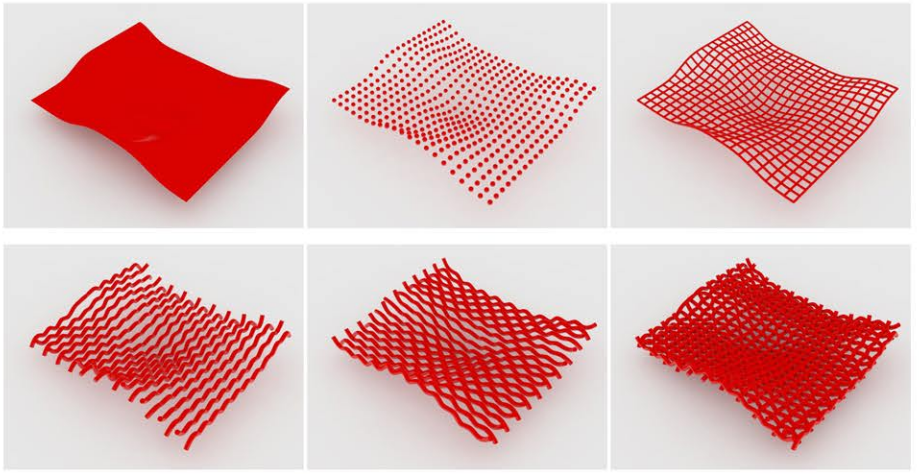


3

Design aesthetics

- reflection of the plasticity of molded plastic

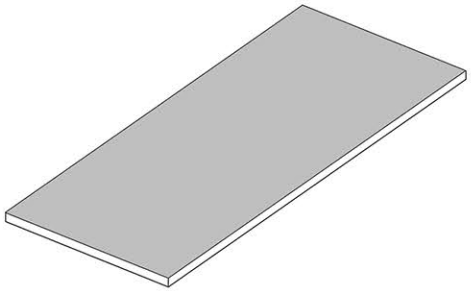
Design concept

COST EFFICIENCY

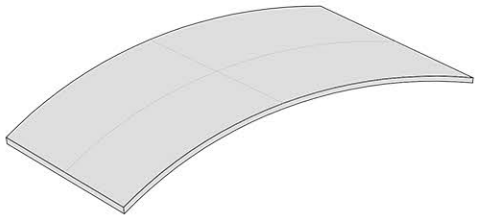
flat or slightly curved surfaces

use of existing molds

use of low-cost material



vacuum table



Design concept

COST EFFICIENCY

flat or slightly curved surfaces

use of existing molds

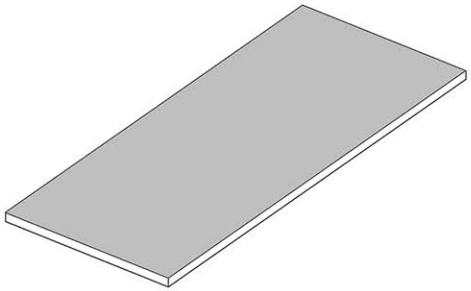
use of low-cost material

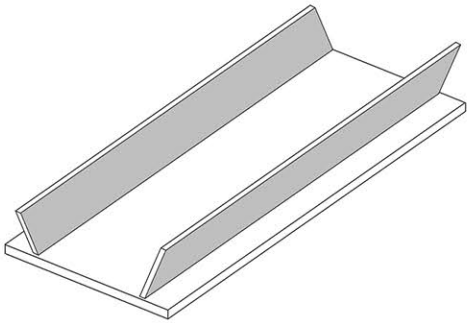
U shaped beam

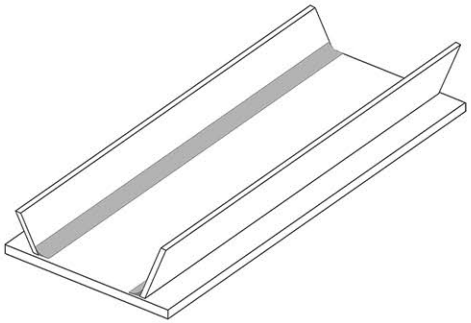
structurally used parapets
continuity of fibres

curved corners

STRUCTURAL EFFICIENCY



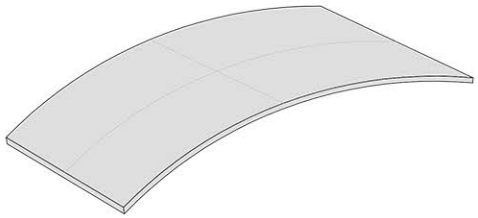


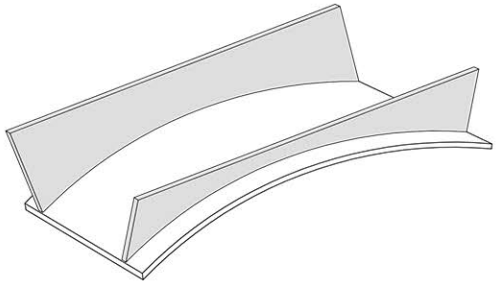


vacuum table

flat side boards
(balsa wood,mdf)

curved foam corners





Design concept

COST EFFICIENCY

flat or slightly curved surfaces

use of existing molds

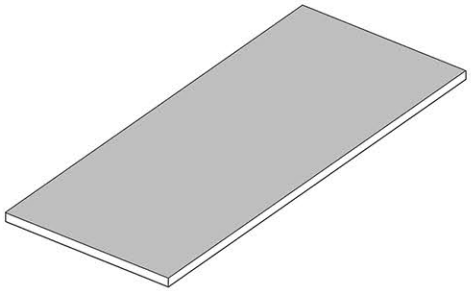
use of low-cost material

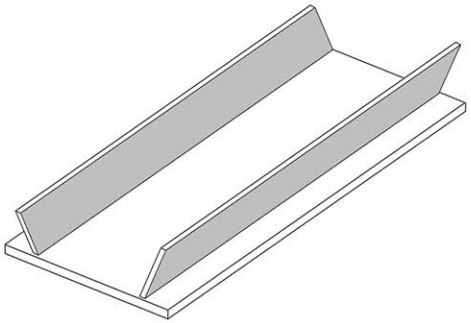
U shaped beam

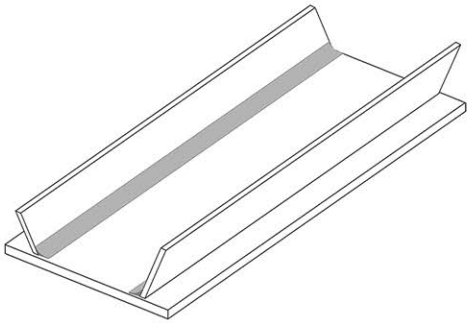
structurally used parapets
continuity of fibres

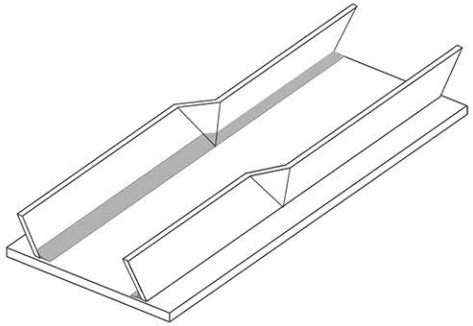
curved corners

STRUCTURAL EFFICIENCY







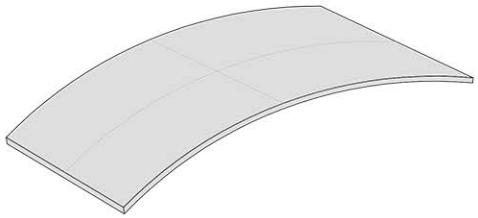


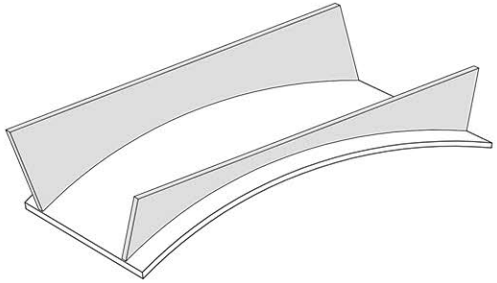
vacuum table

flat side boards
(balsa wood,mdf)

curved foam corners

alternative





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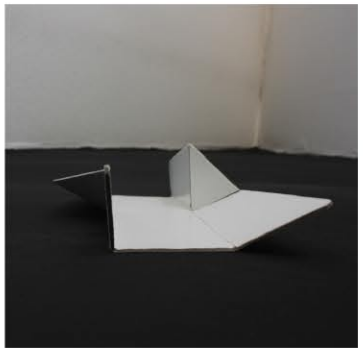
Design research





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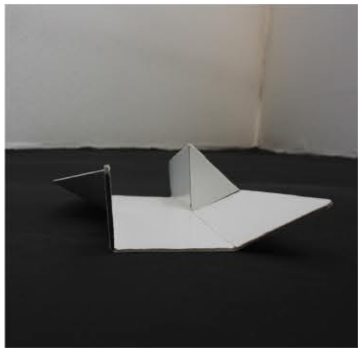

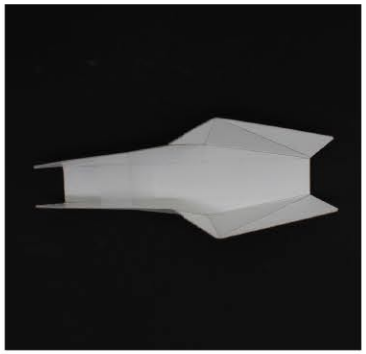
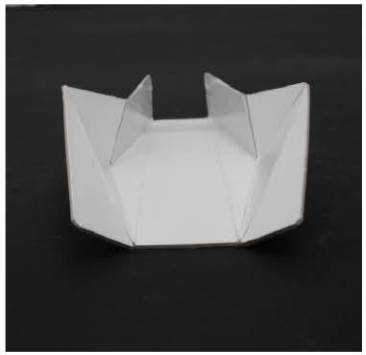

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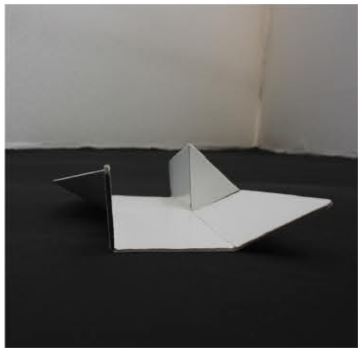

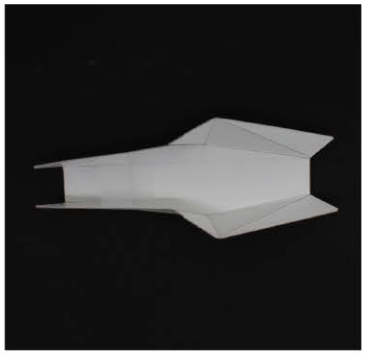
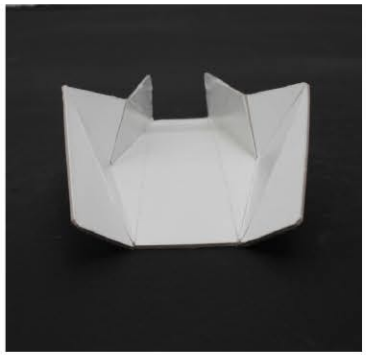

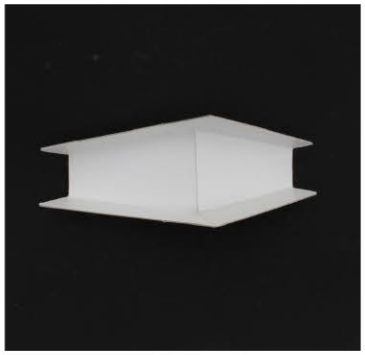

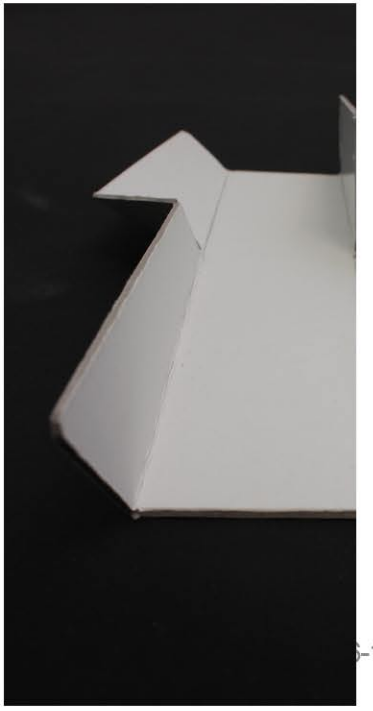

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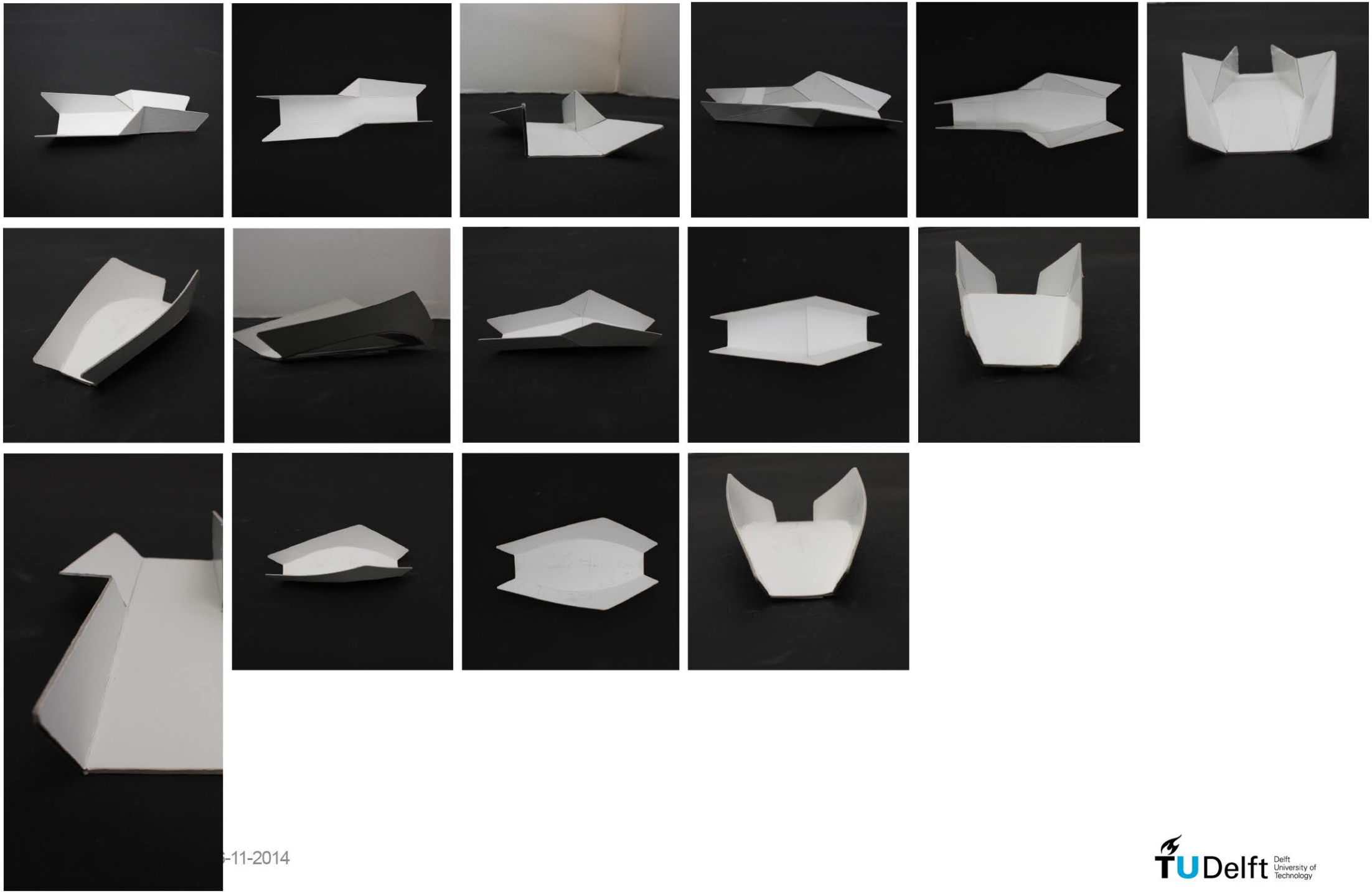

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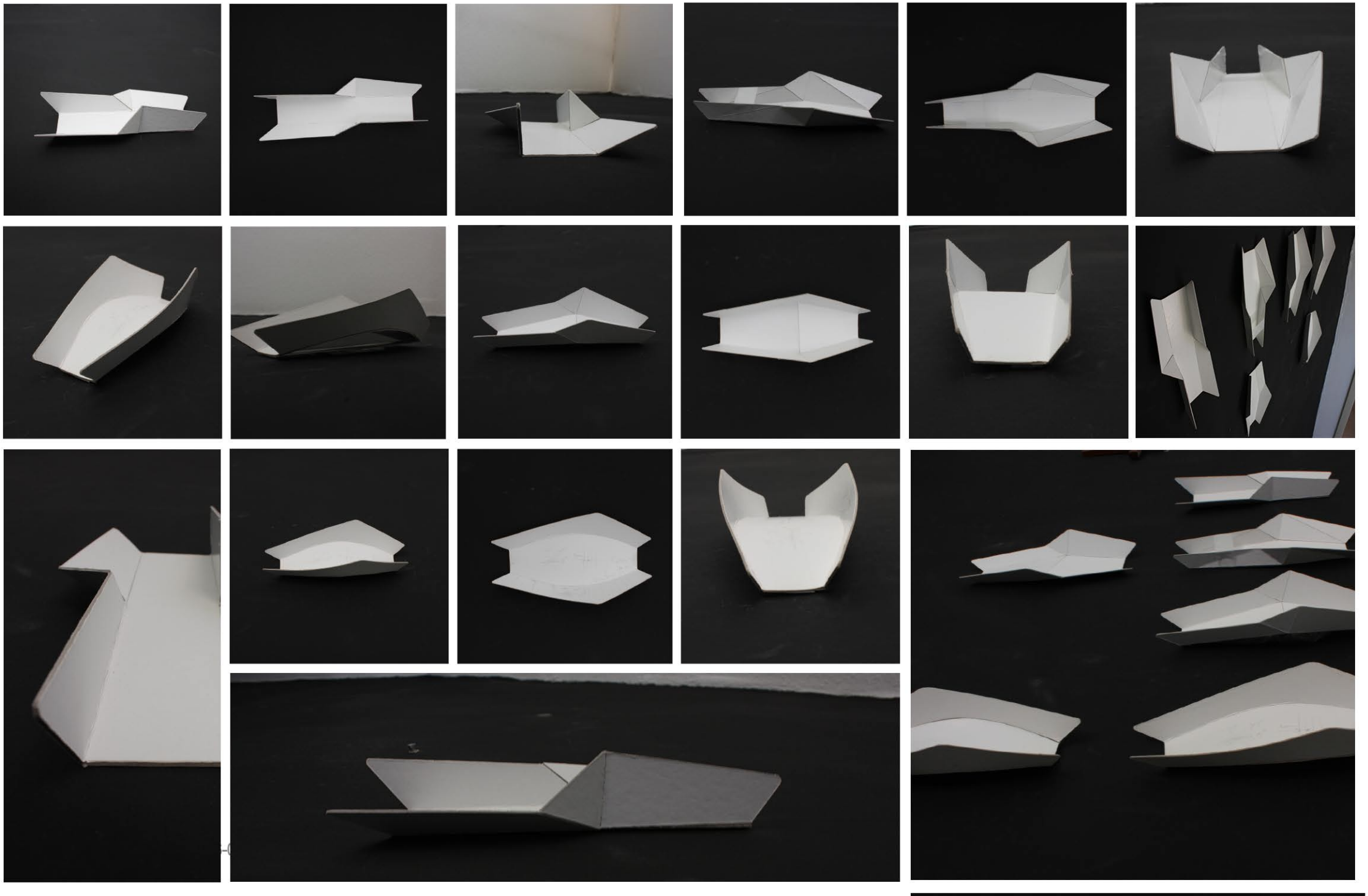

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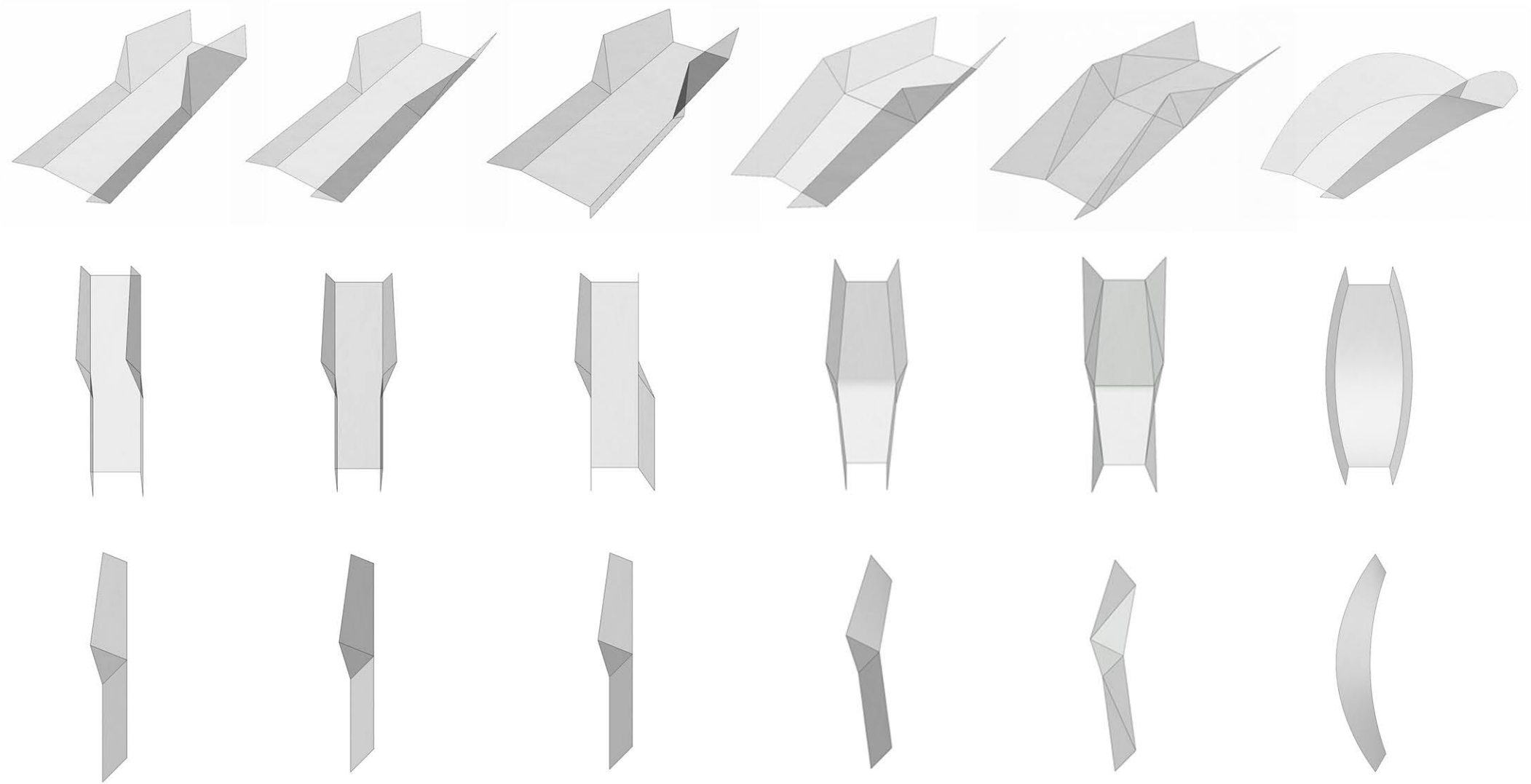
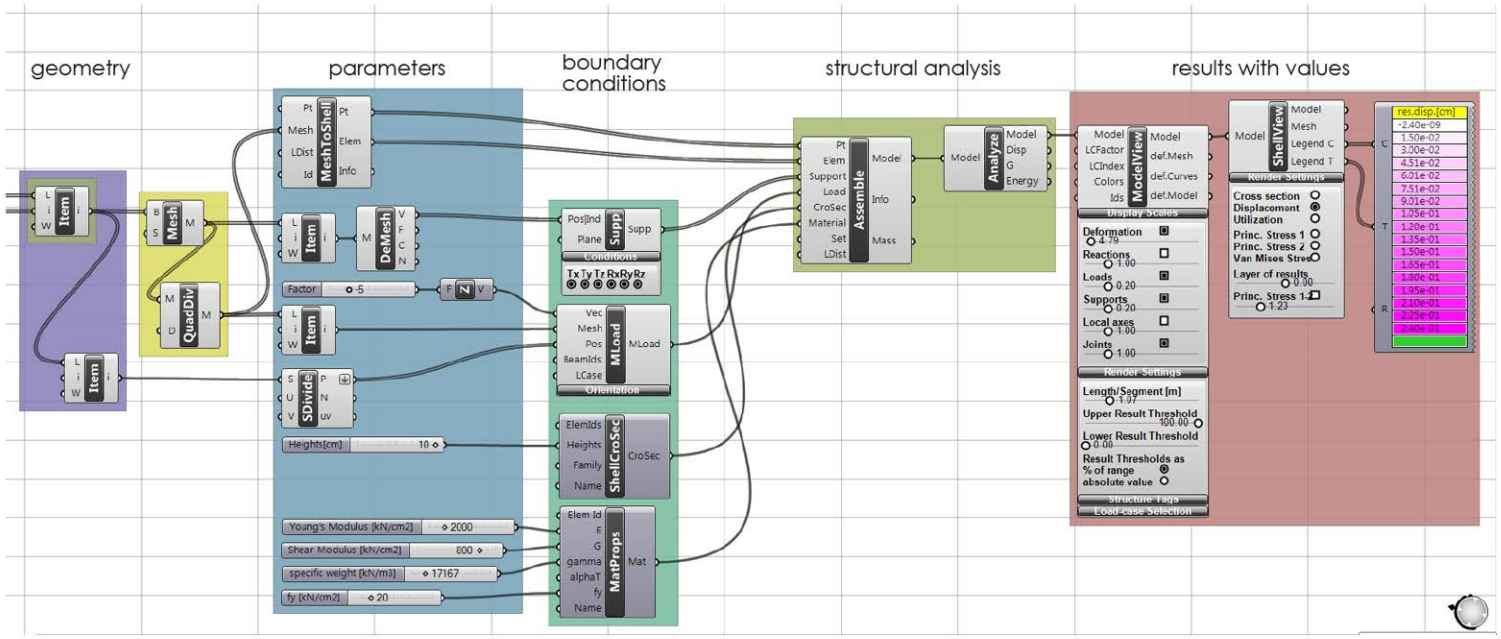
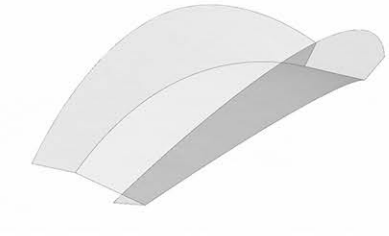


Design research

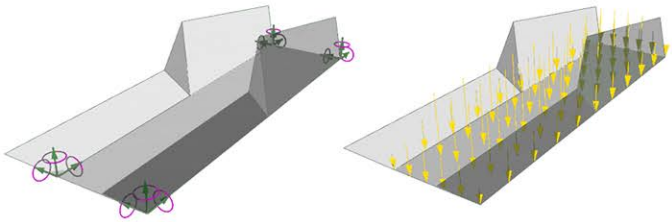
Structural testing (stiffness)





Boundary Conditions

- Supports
- Loads
- Cross section
- Material mechanical prop.



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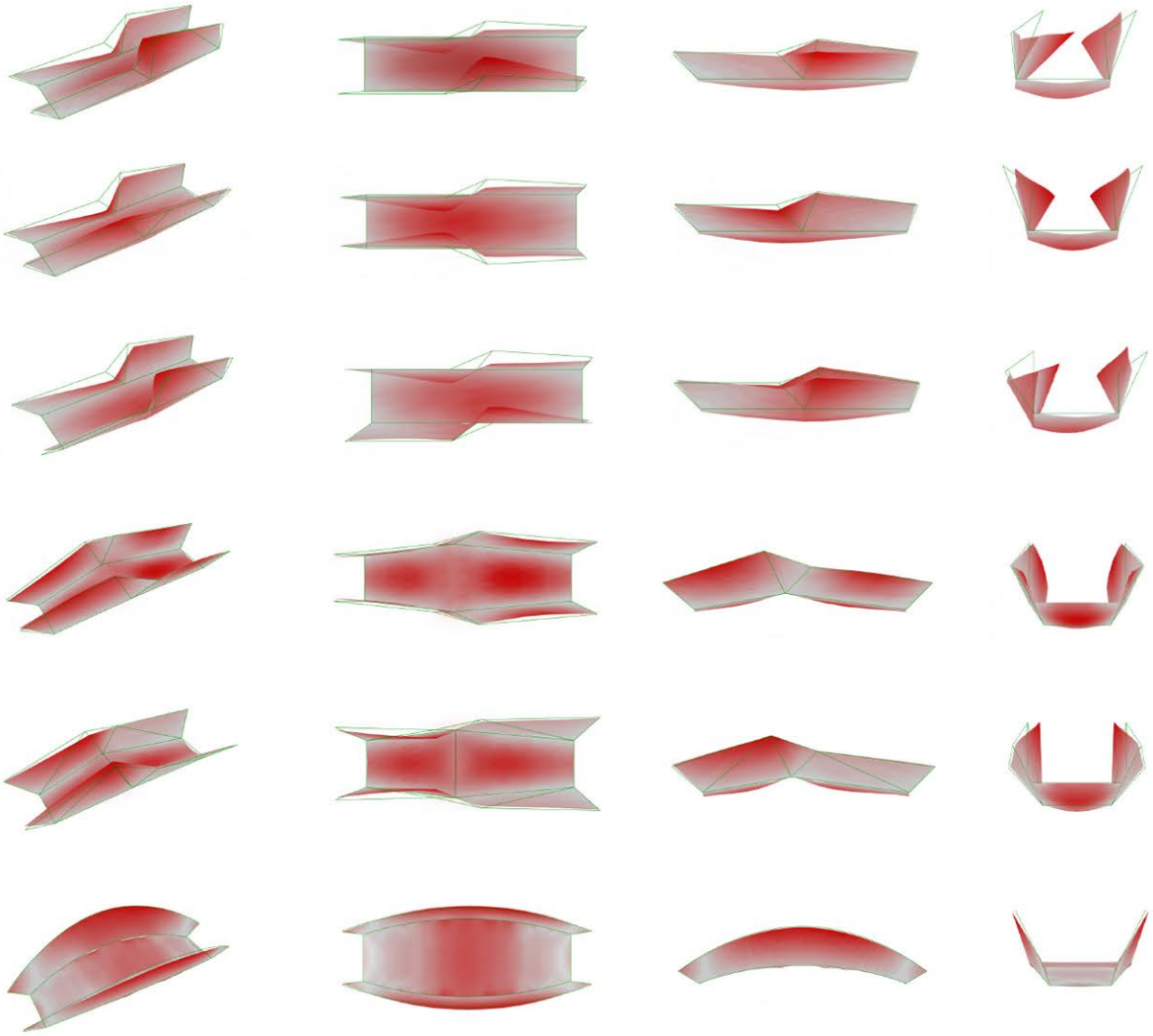
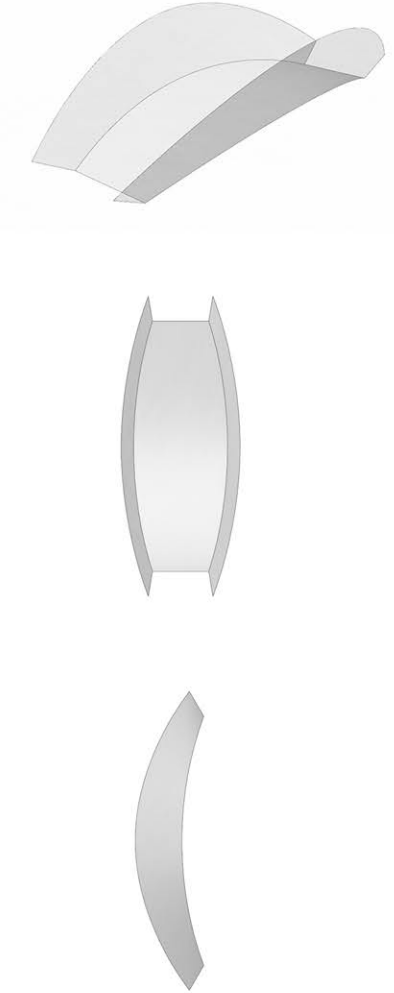
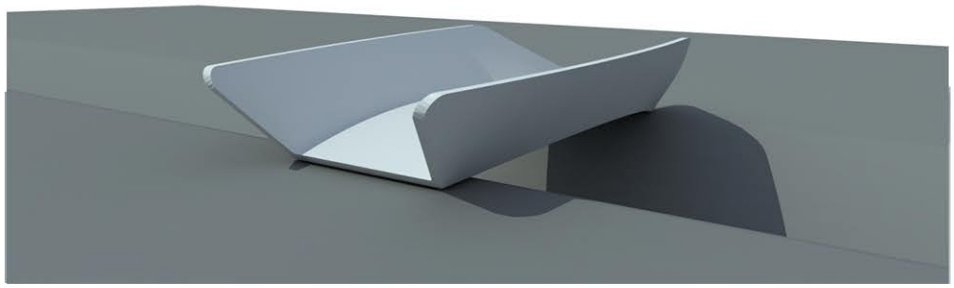
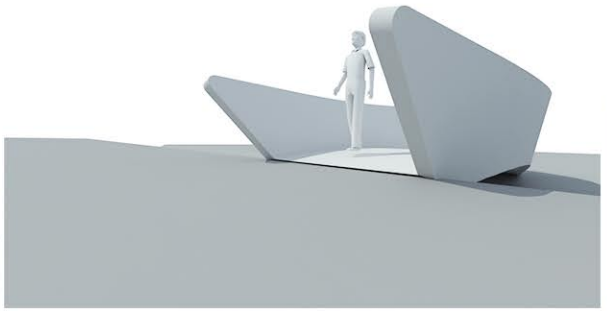
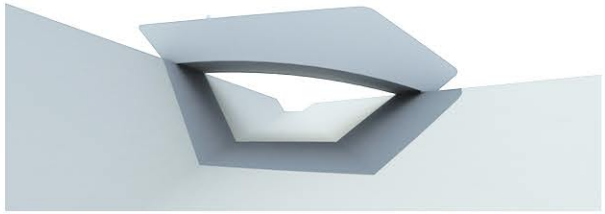


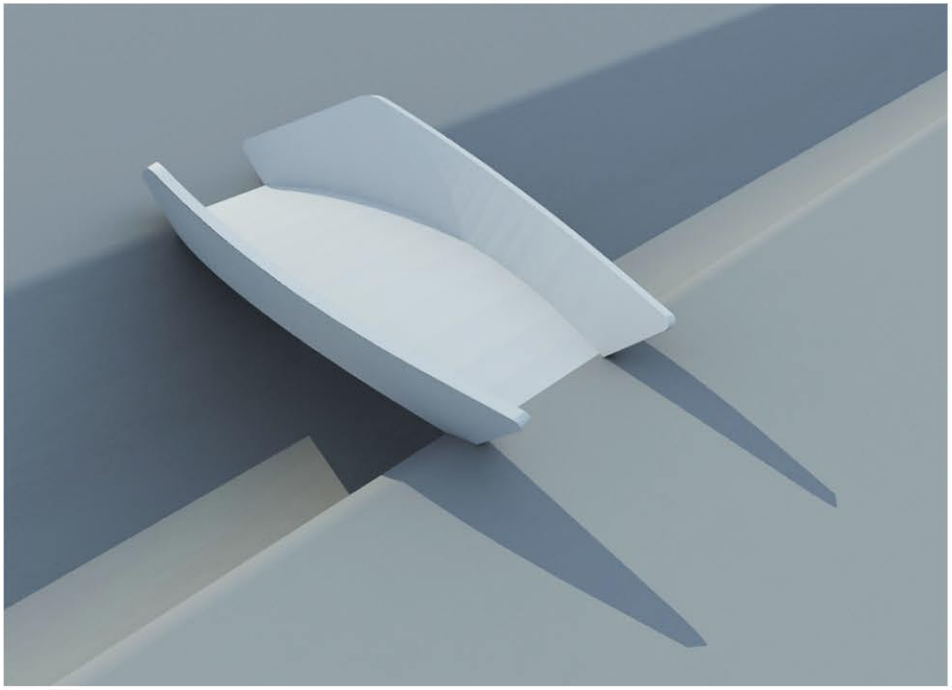


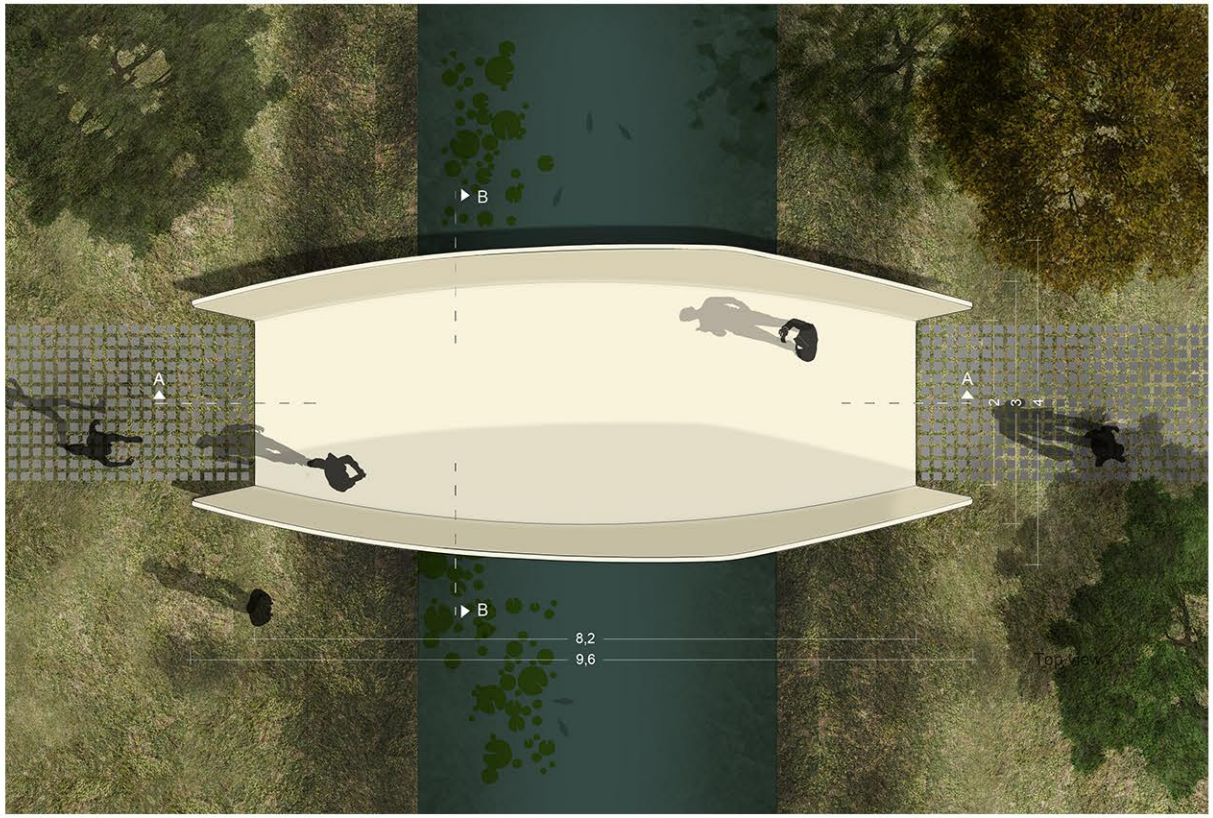
Design











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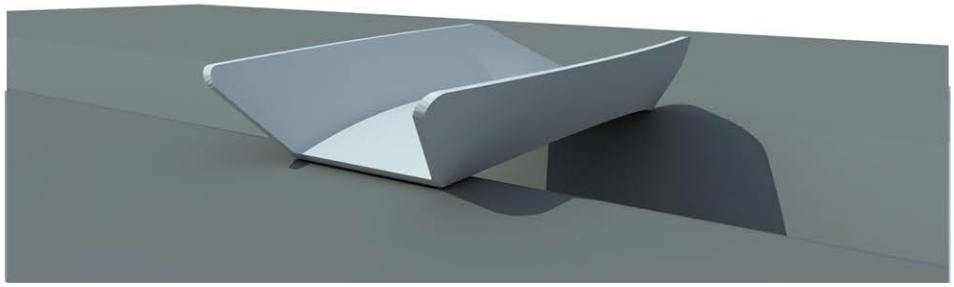

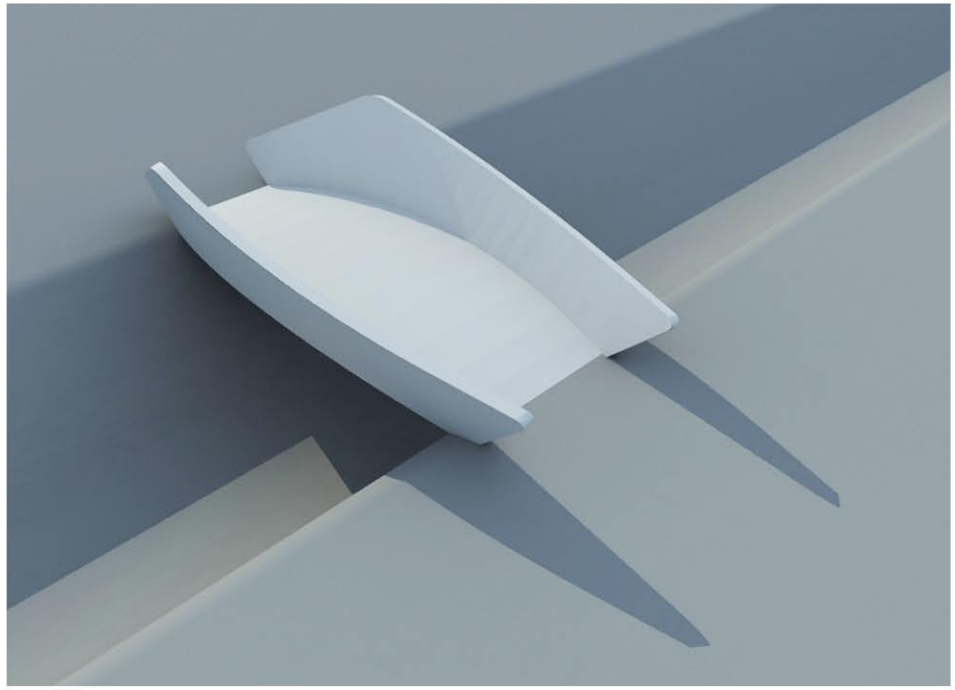

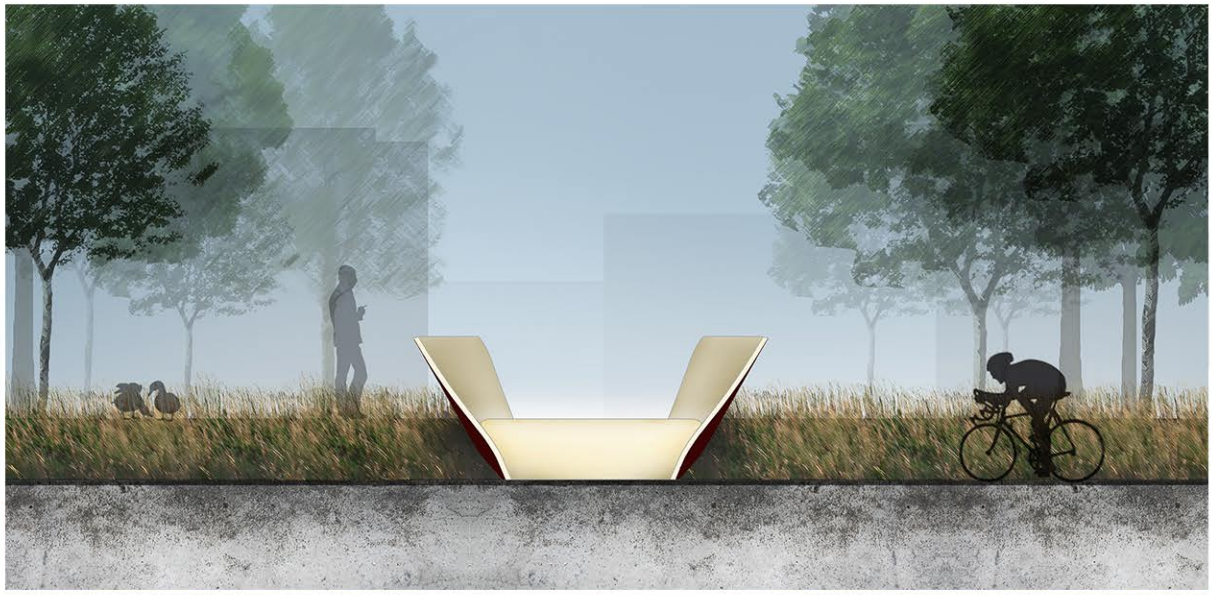

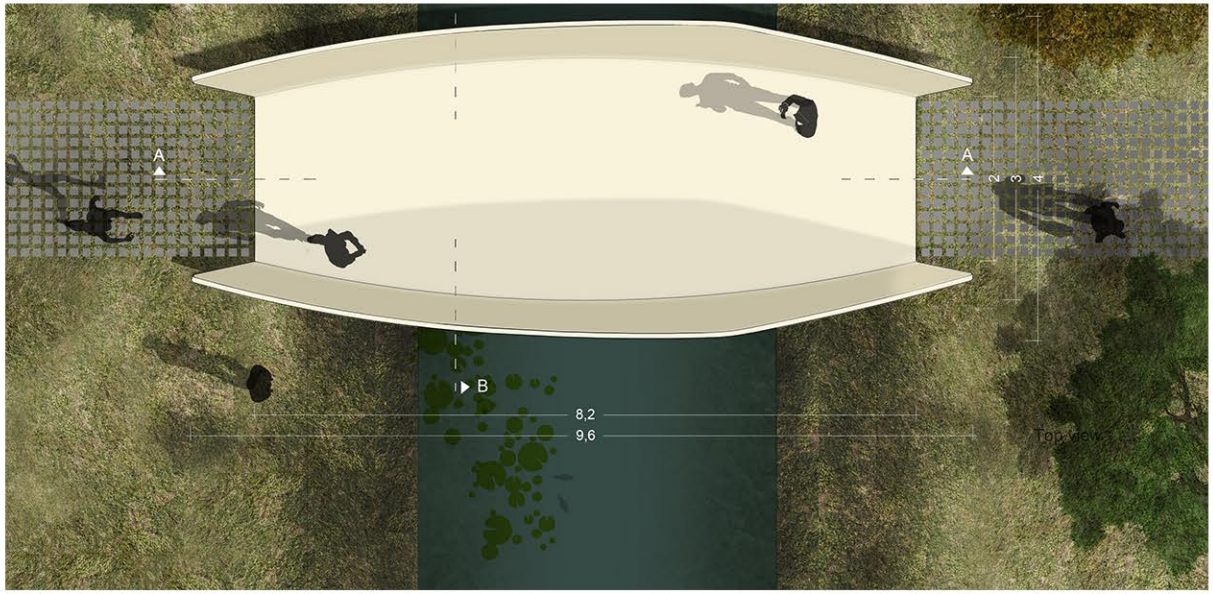

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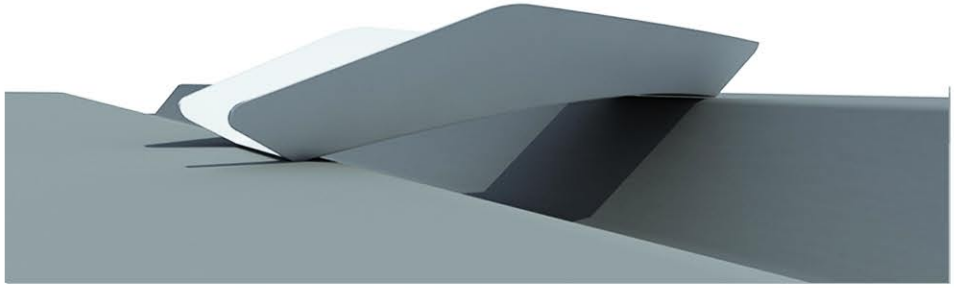

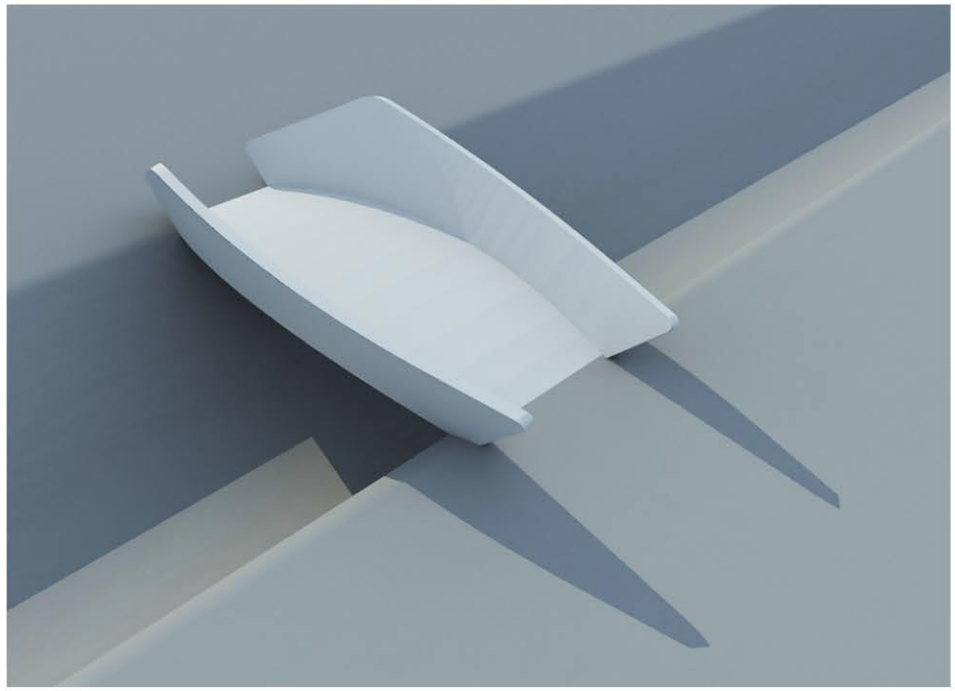

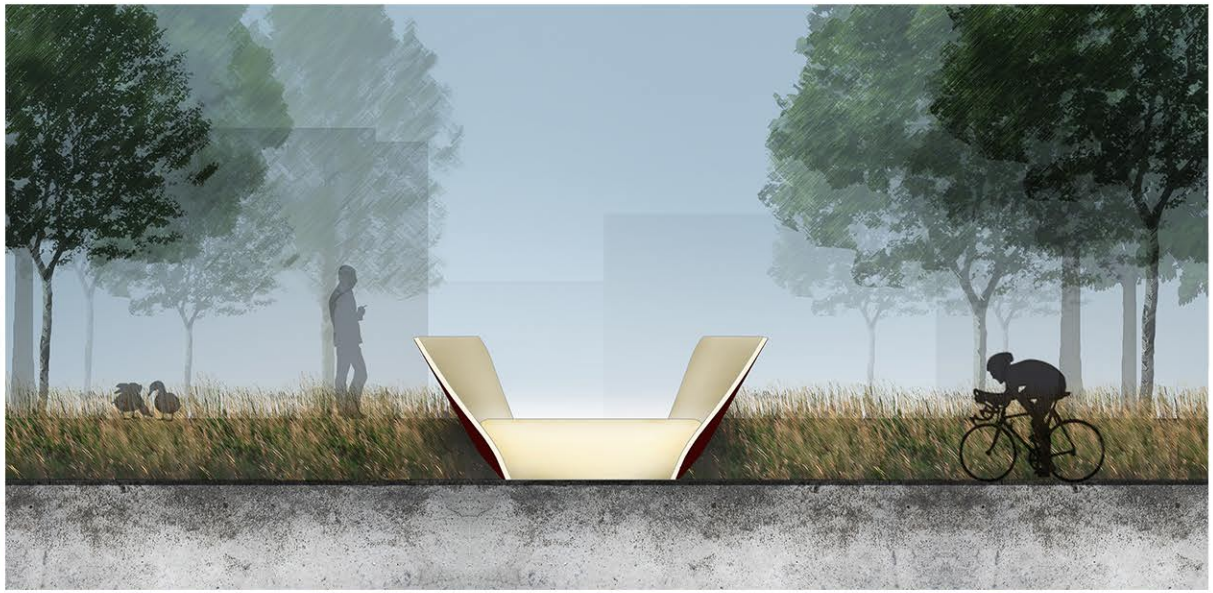

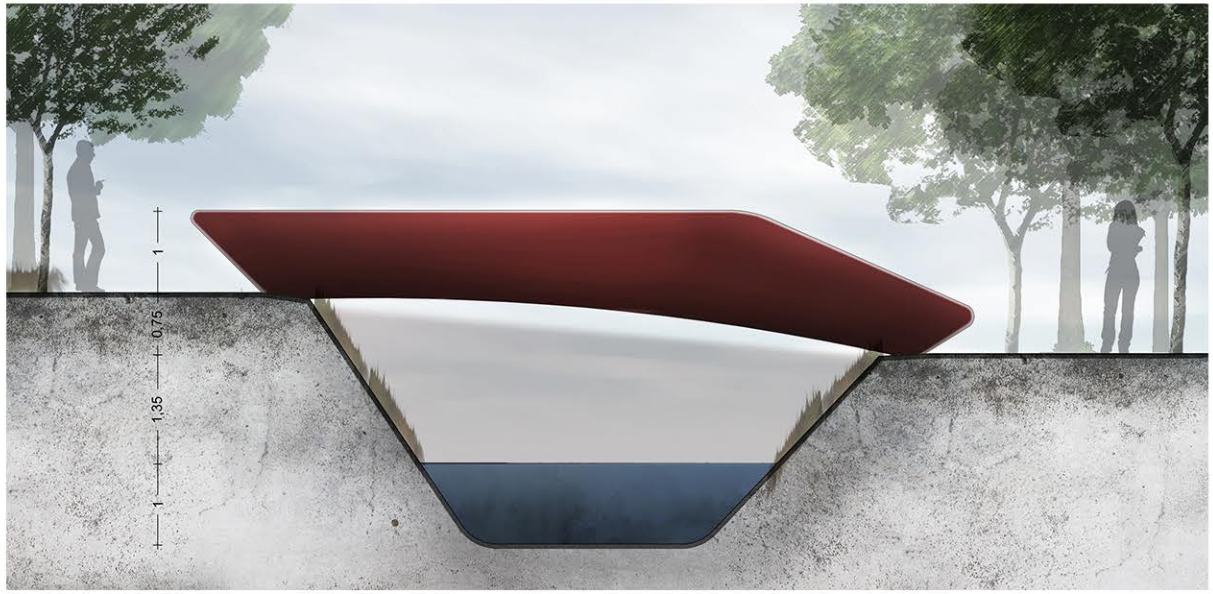

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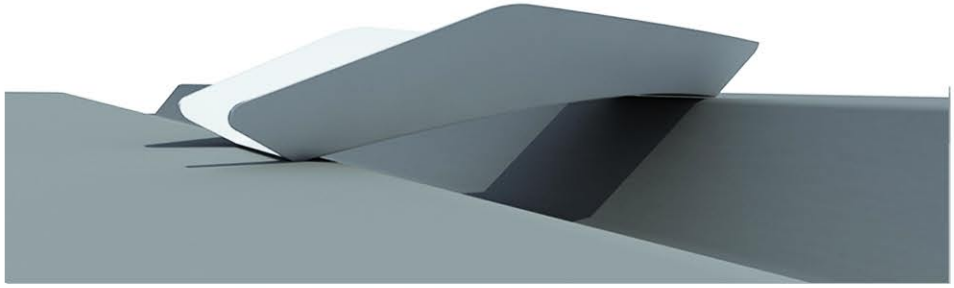
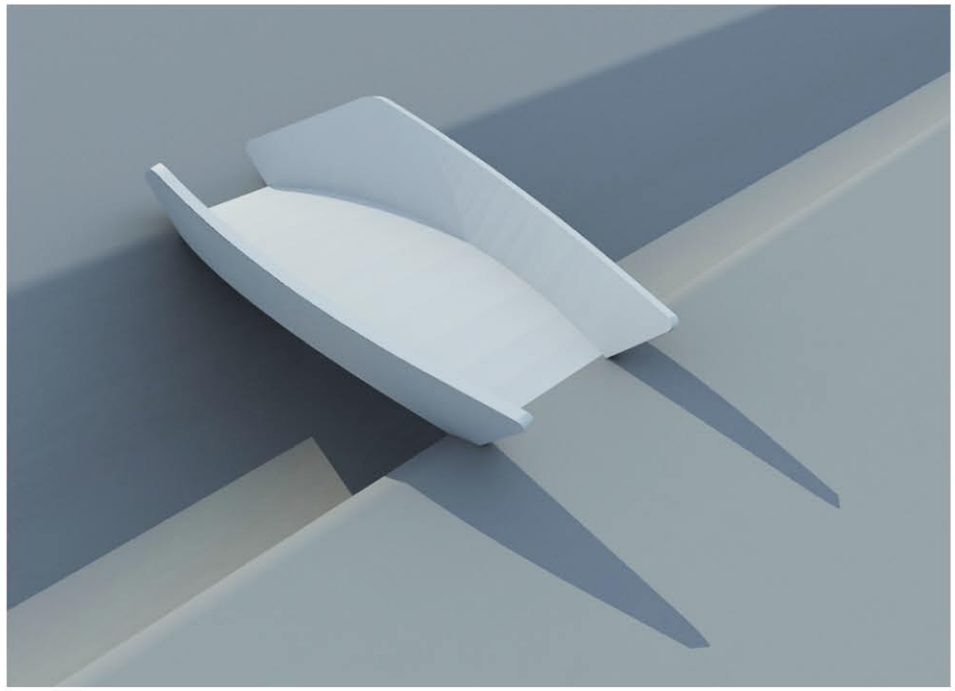
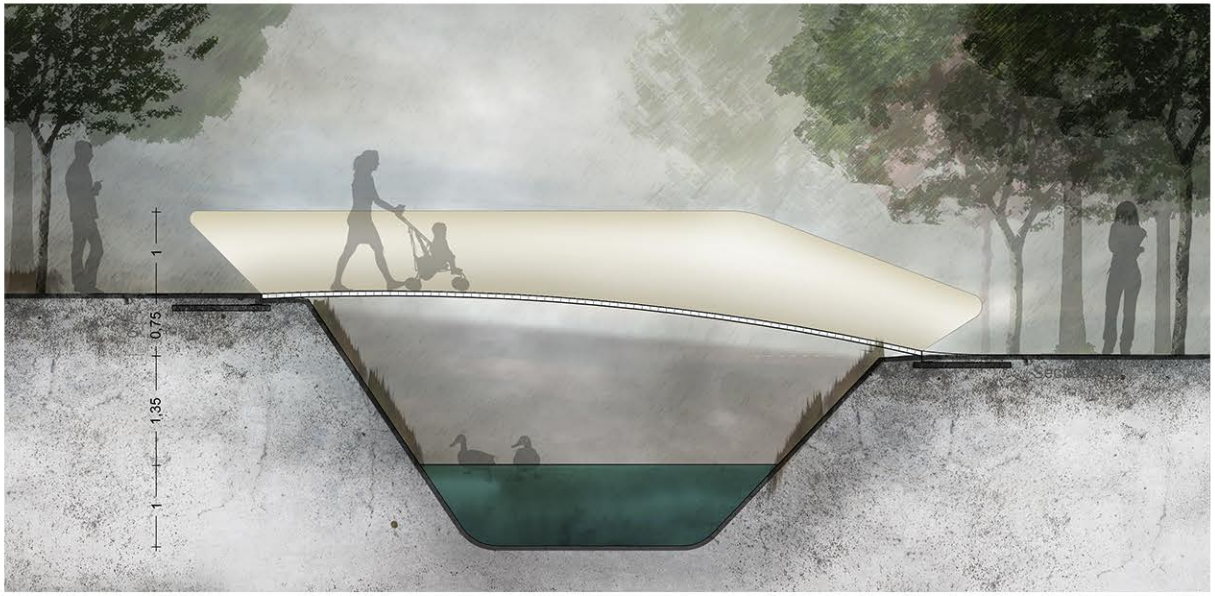
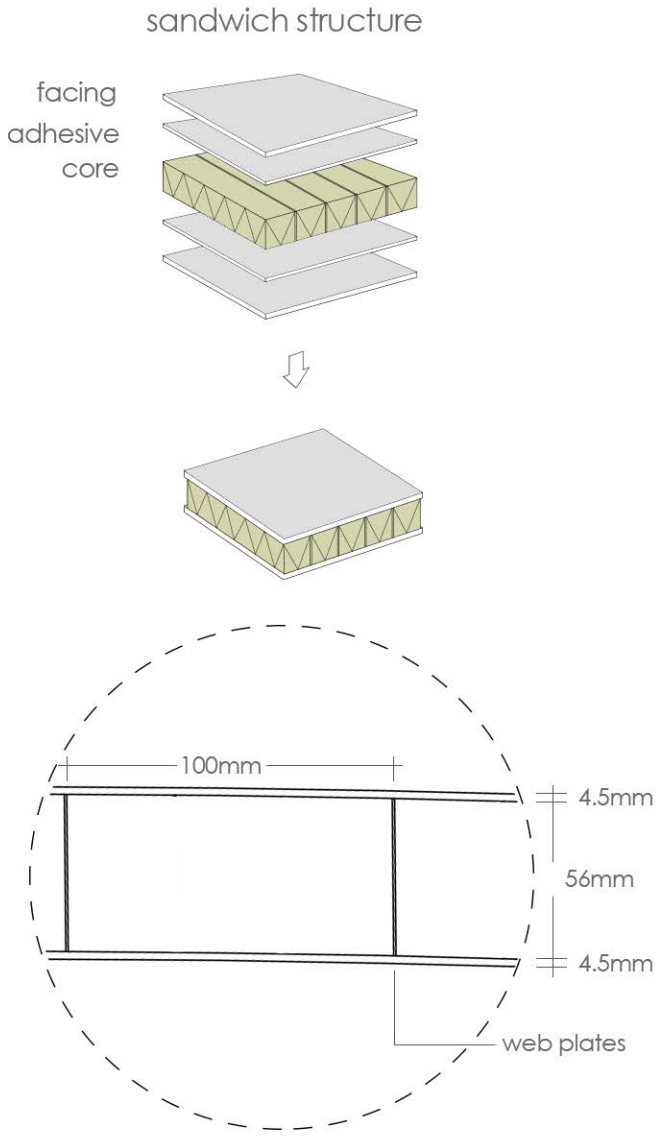


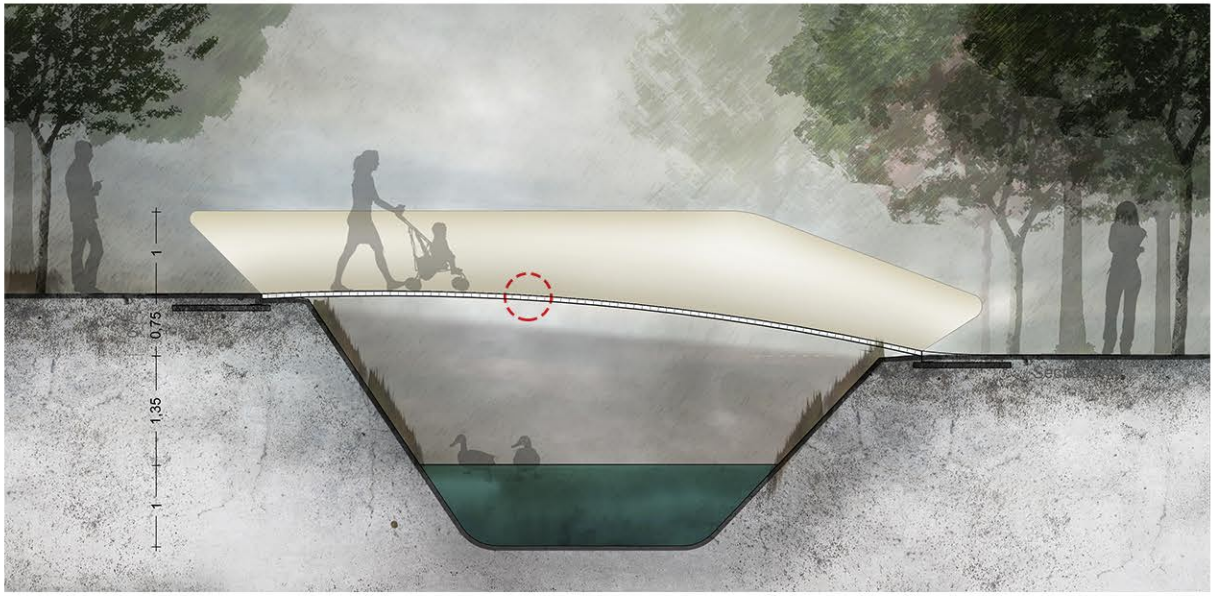


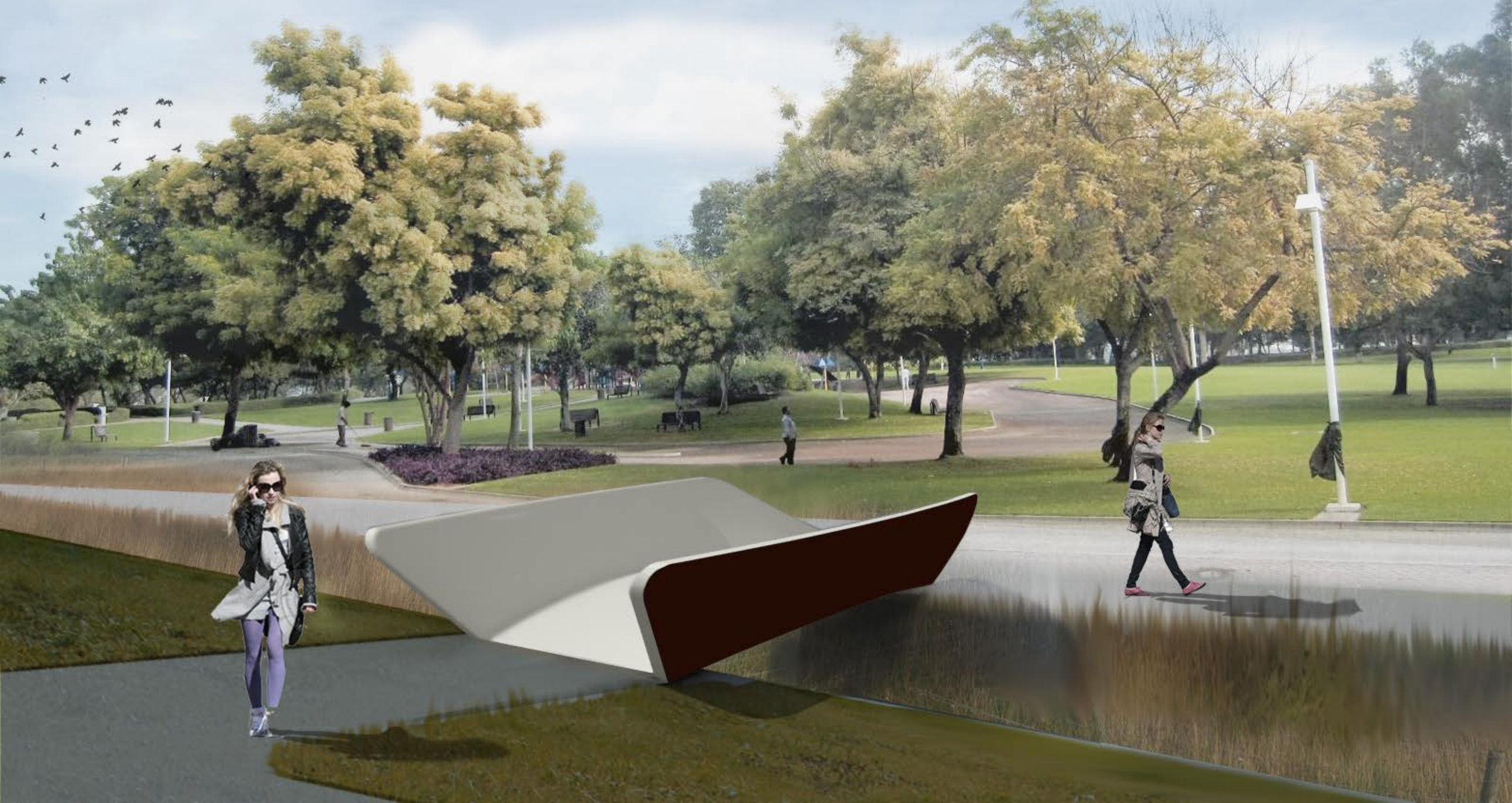


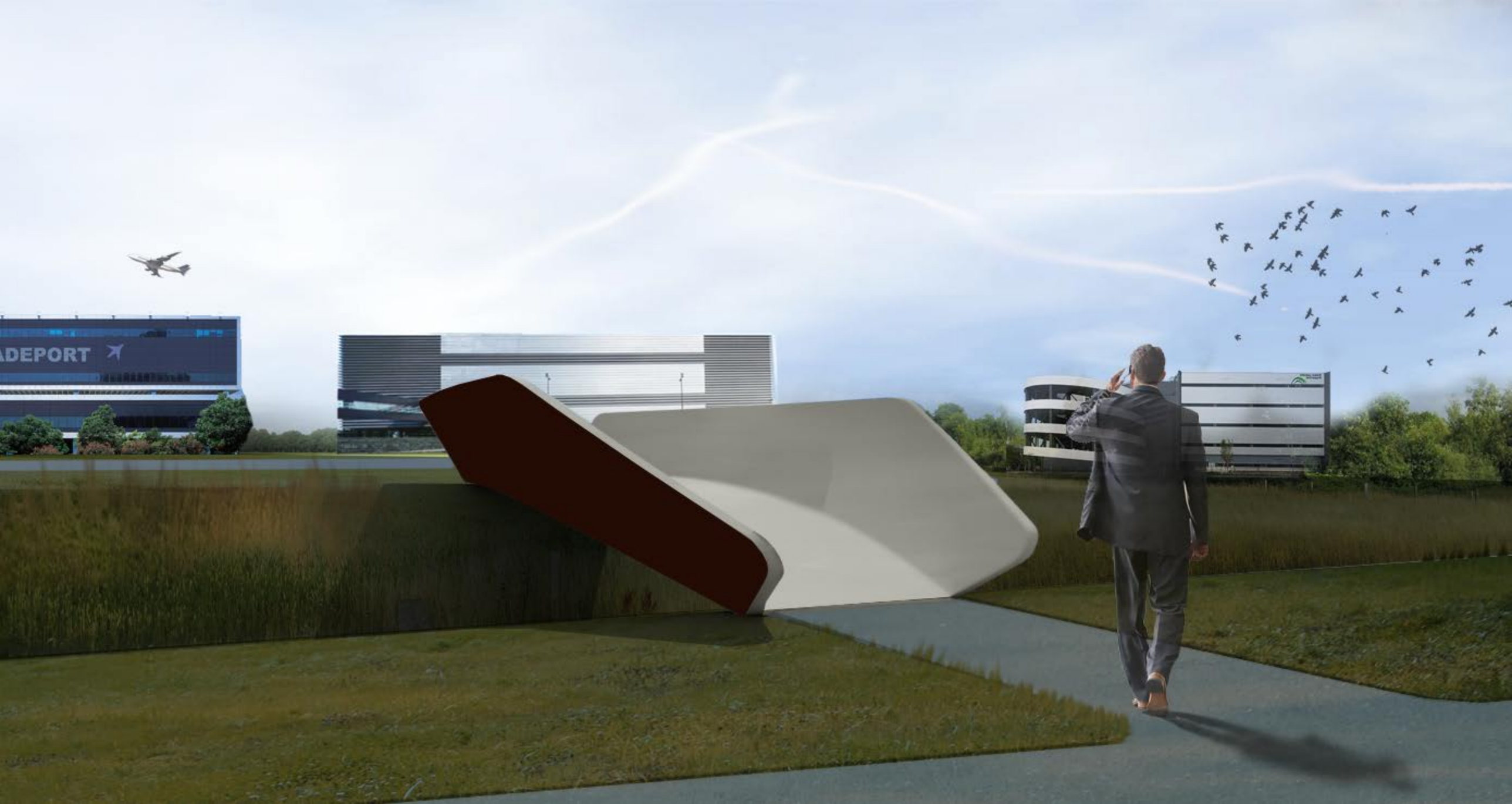
Design



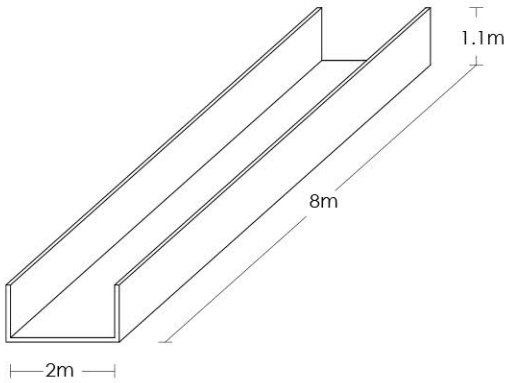
Detail of the deck






ADEPORT

SIMPLIFIED APPROACH



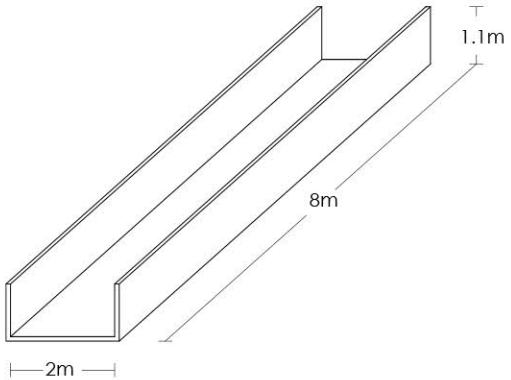
straight U-beam

no curved corners

vertical parapets

1m continuous parapet height

SIMPLIFIED APPROACH



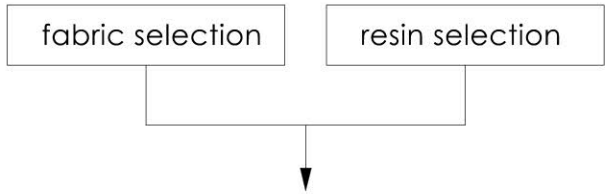
straight U-beam

no curved corners

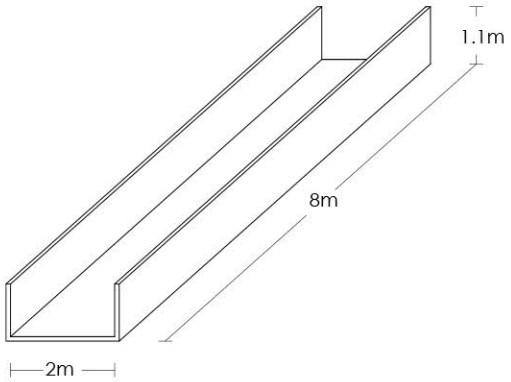
vertical parapets

1m continuous parapet height

CALCULATION PROCESS



SIMPLIFIED APPROACH



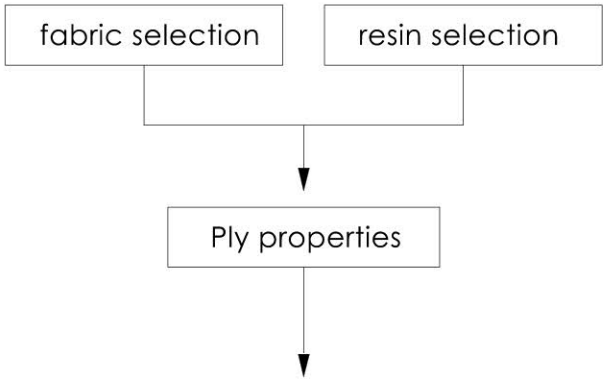
straight U-beam

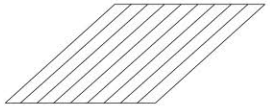
no curved corners

vertical parapets

1m continuous parapet height

CALCULATION PROCESS





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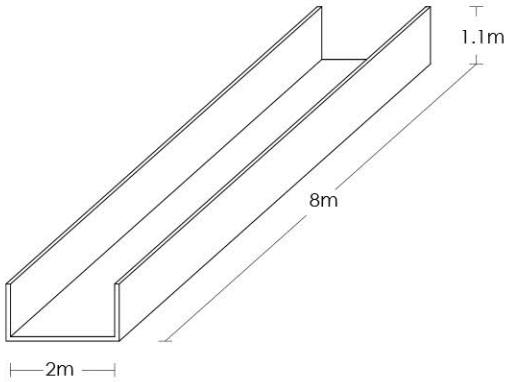


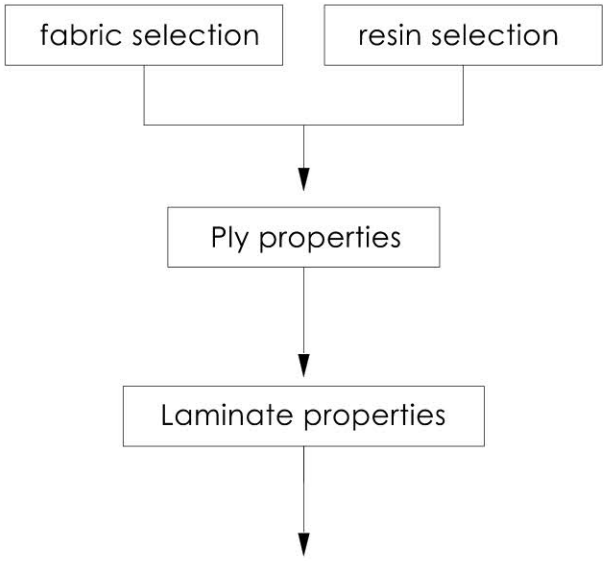
straight U-beam

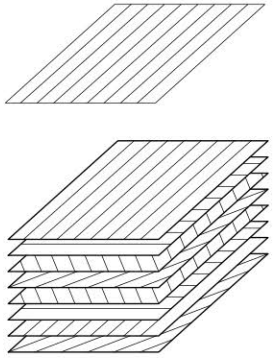
no curved corners

vertical parapets

1m continuous parapet height

CALCULATION PROCESS





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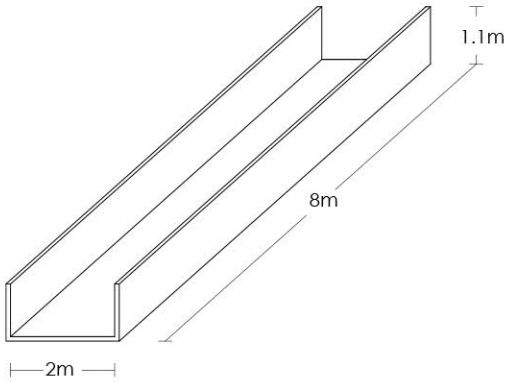


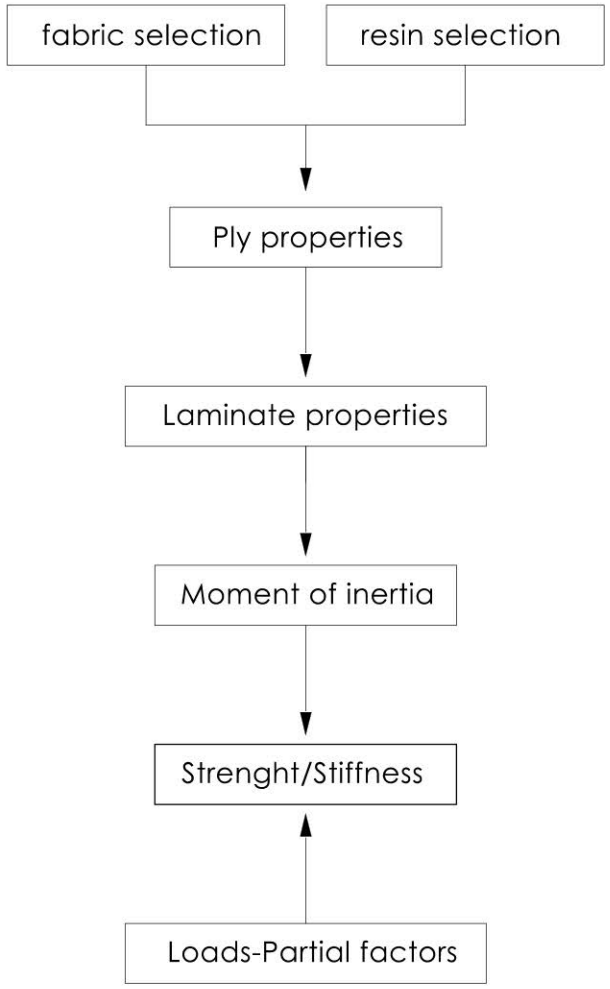
straight U-beam

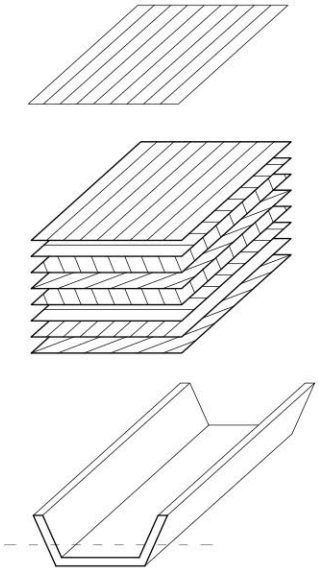
no curved corners

vertical parapets

1m continuous parapet height

CALCULATION PROCESS





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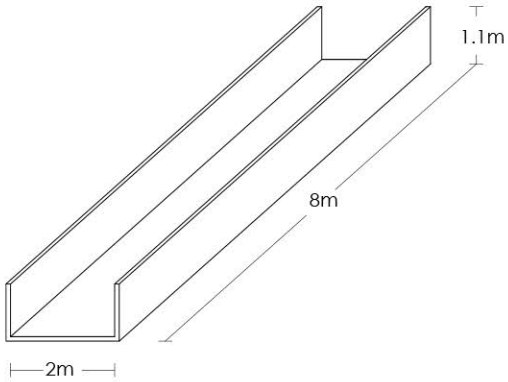


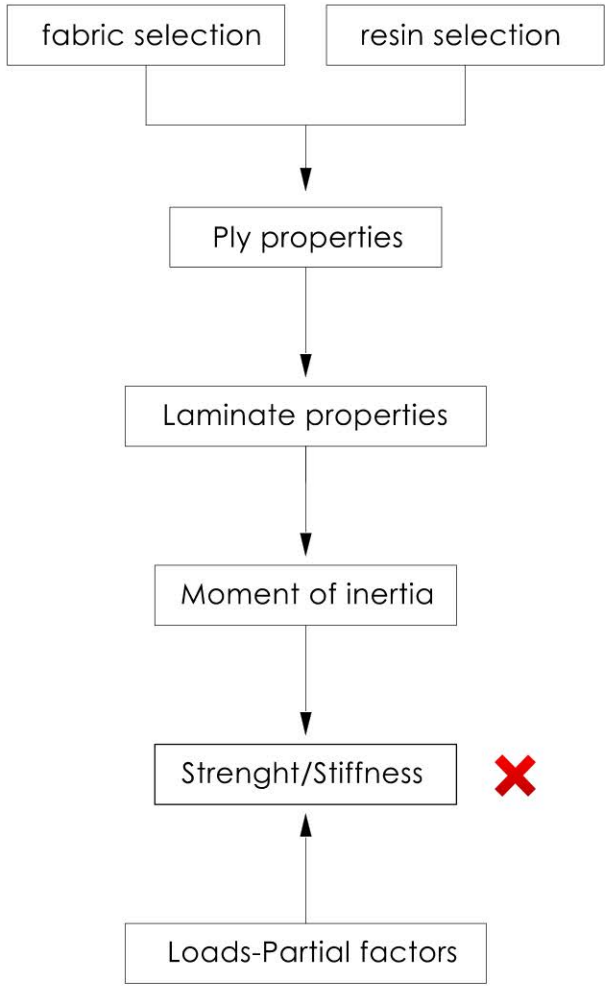
straight U-beam

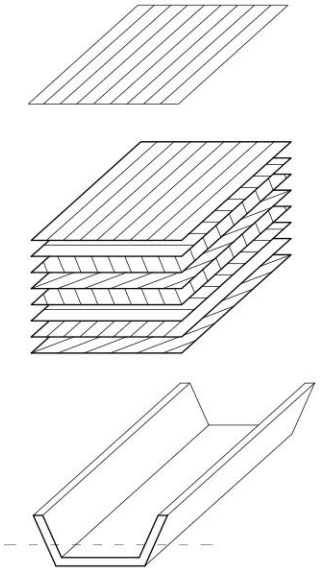
no curved corners

vertical parapets

1m continuous parapet height

CALCULATION PROCESS





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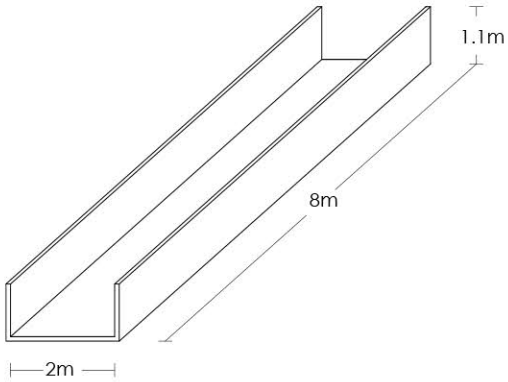


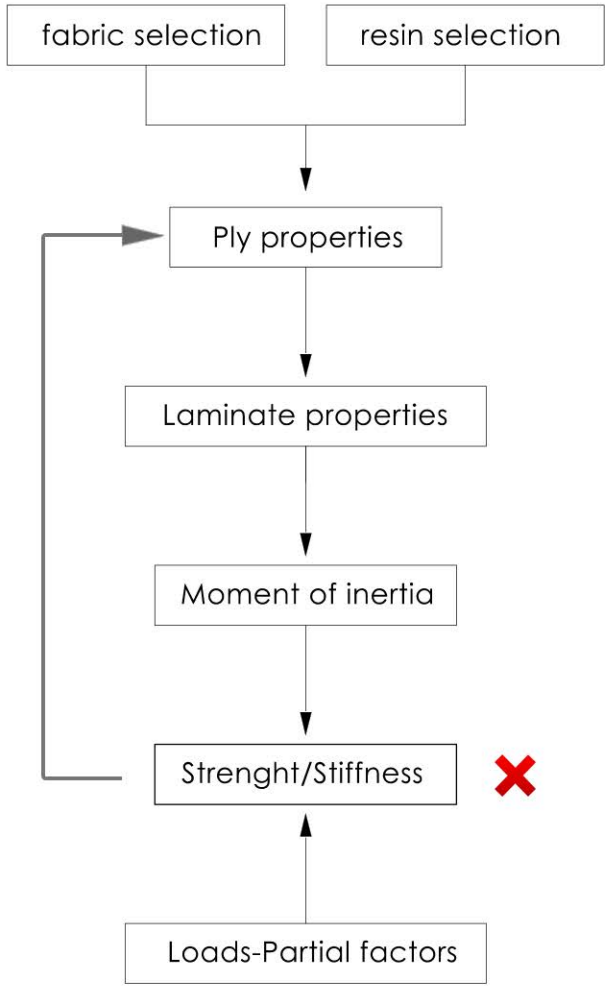
straight U-beam

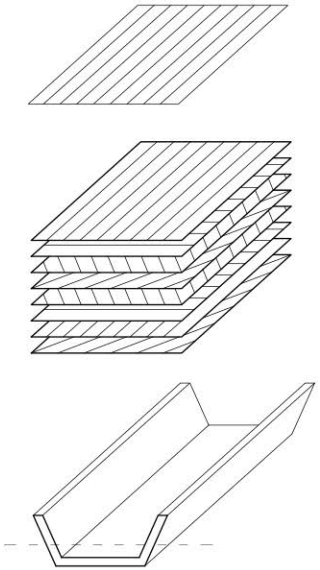
no curved corners

vertical parapets

1m continuous parapet height

CALCULATION PROCESS





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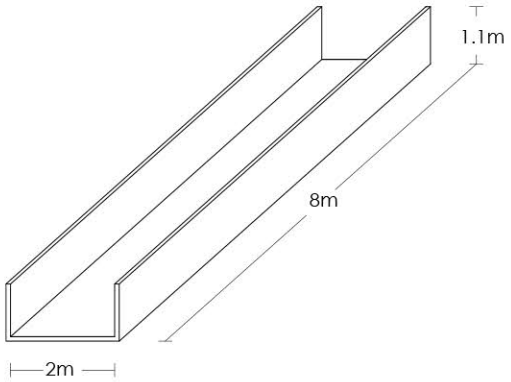


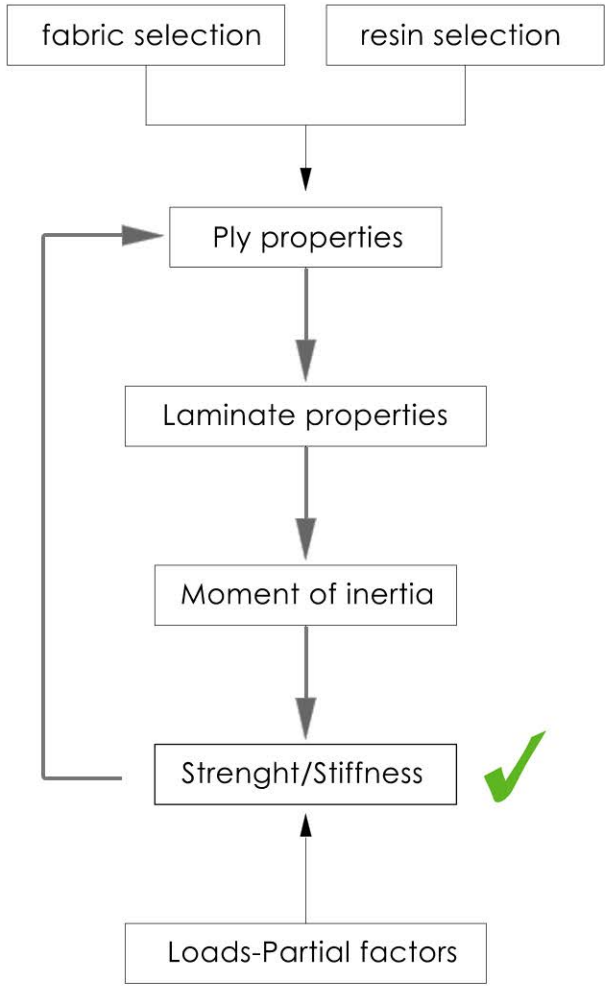
straight U-beam

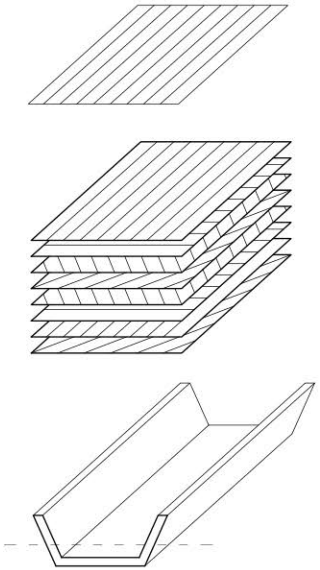
no curved corners

vertical parapets

1m continuous parapet height

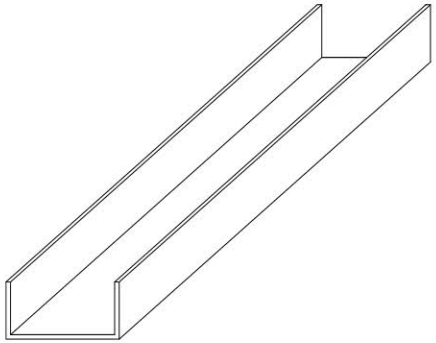
CALCULATION PROCESS





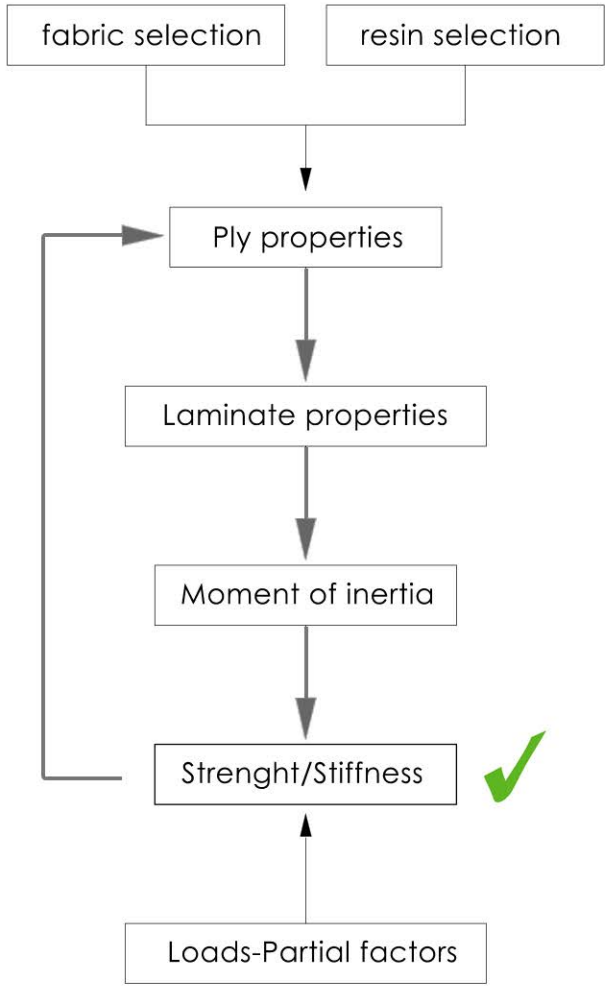
Structural calculation

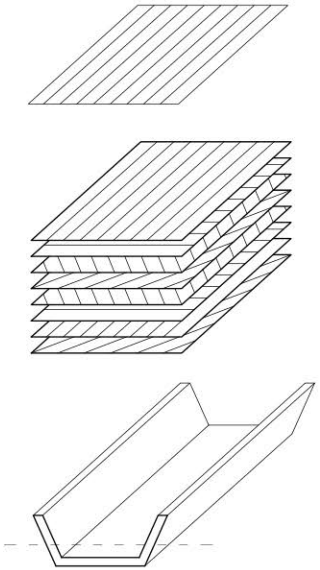
SIMPLIFIED APPROACH



STRONG GEOMETRY → MINIMUM MATERIAL USE

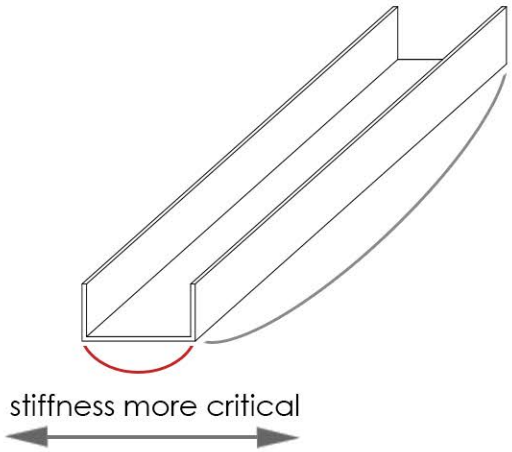
CALCULATION PROCESS





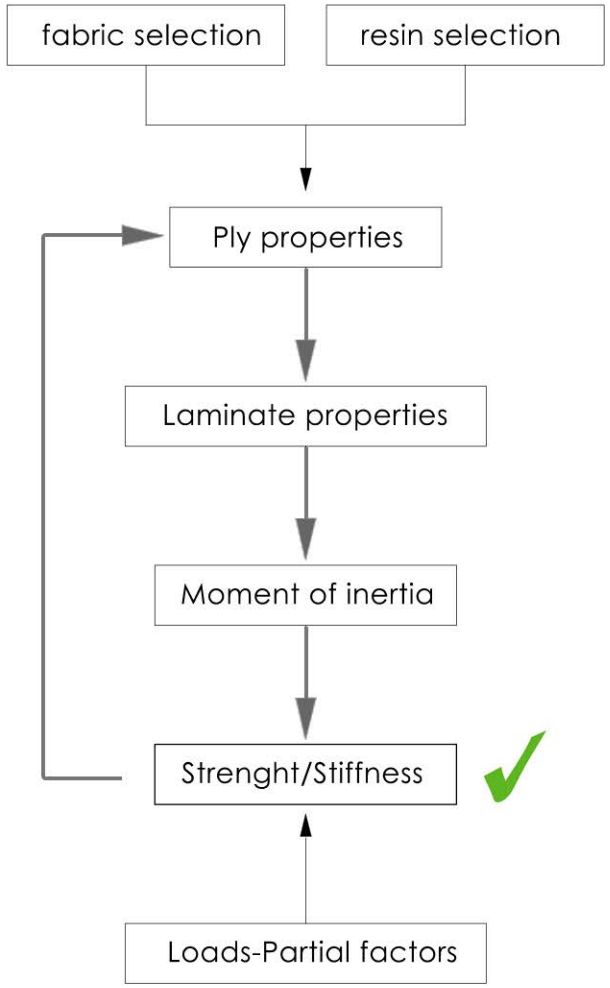
Structural calculation

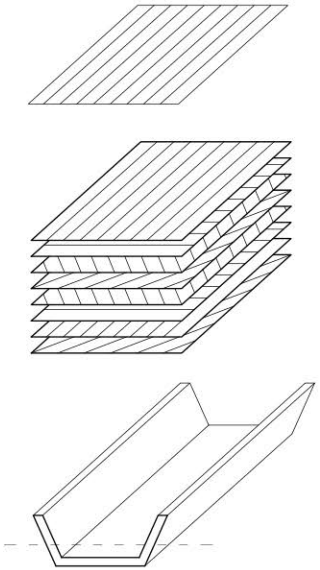
SIMPLIFIED APPROACH



STRONG GEOMETRY → **MINIMUM MATERIAL USE**

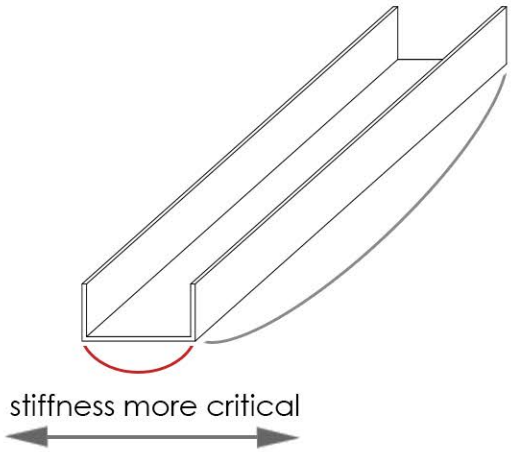
CALCULATION PROCESS





Structural calculation

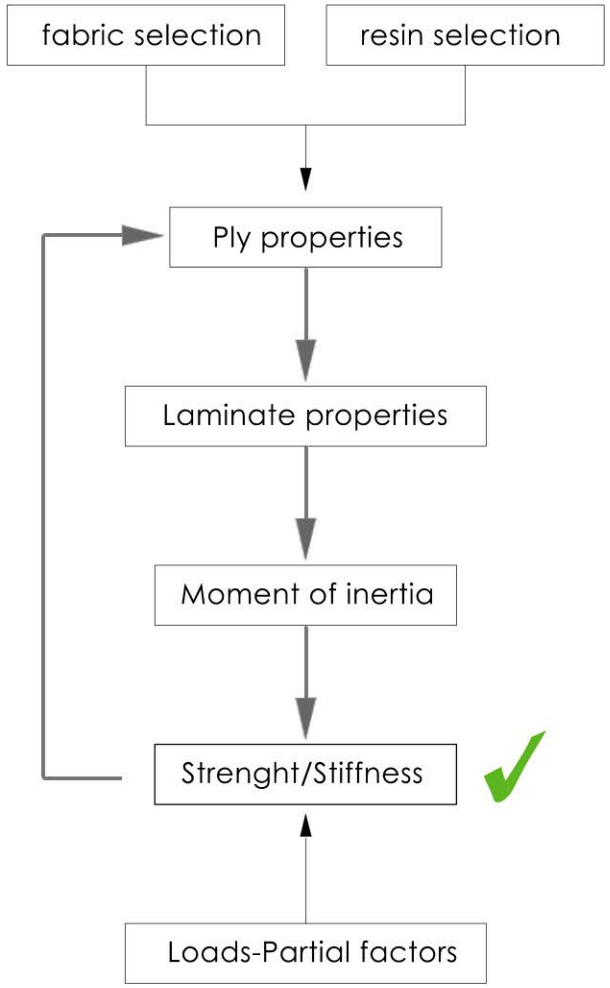
SIMPLIFIED APPROACH

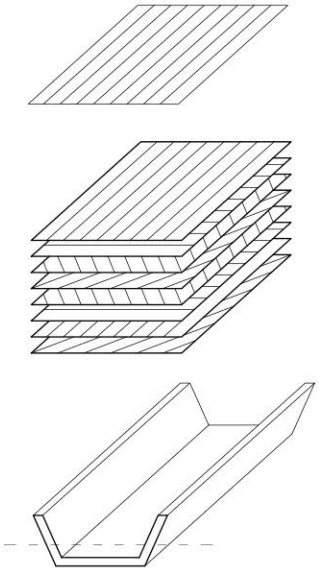


STRONG GEOMETRY → MINIMUM MATERIAL USE

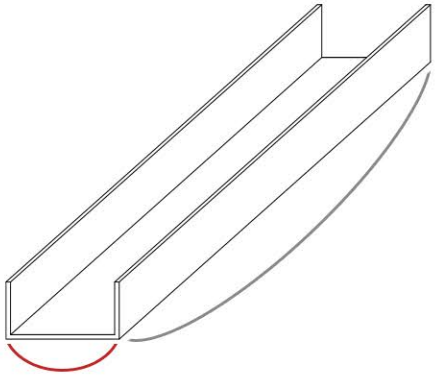
↑ FIBRE ORIENTATION

CALCULATION PROCESS

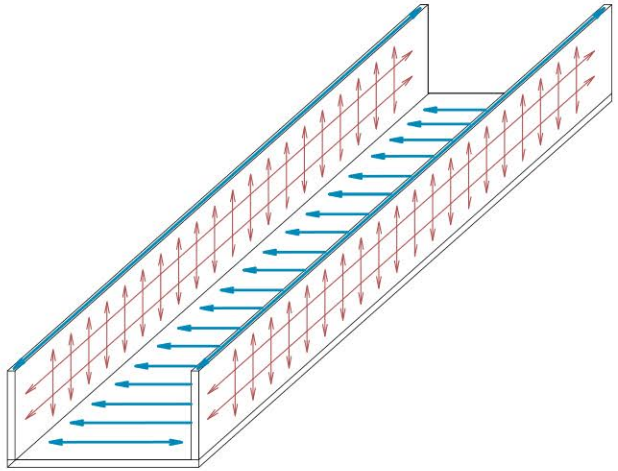




SIMPLIFIED APPROACH

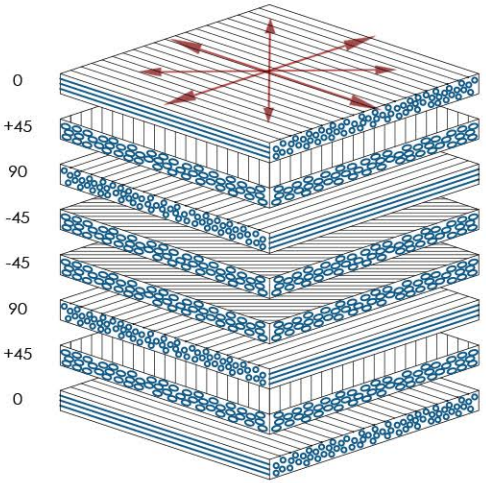


stiffness more critical

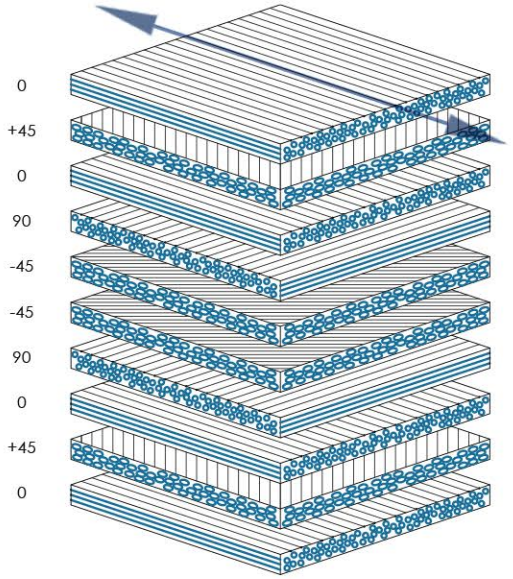


STRONG GEOMETRY → MINIMUM MATERIAL USE

↑ FIBRE ORIENTATION



QUASI-ISOTROPIC

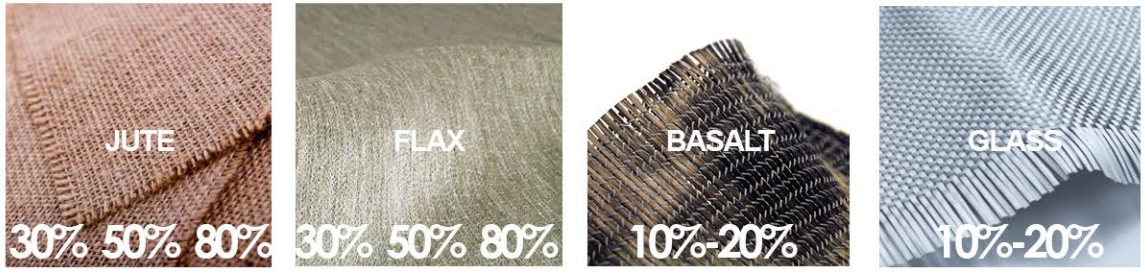


ORTHOTROPIC

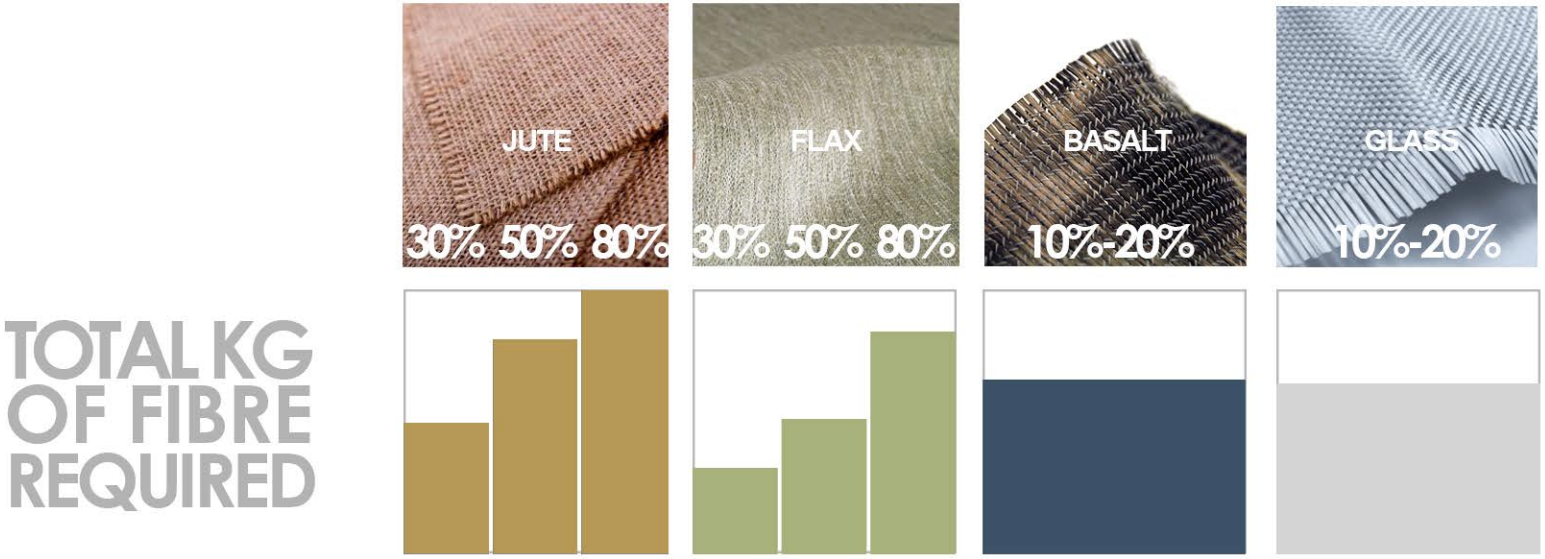
DURABILITY

MOISTURE
FIRE RESISTANCE
UV RESISTANCE

Structural calculation results

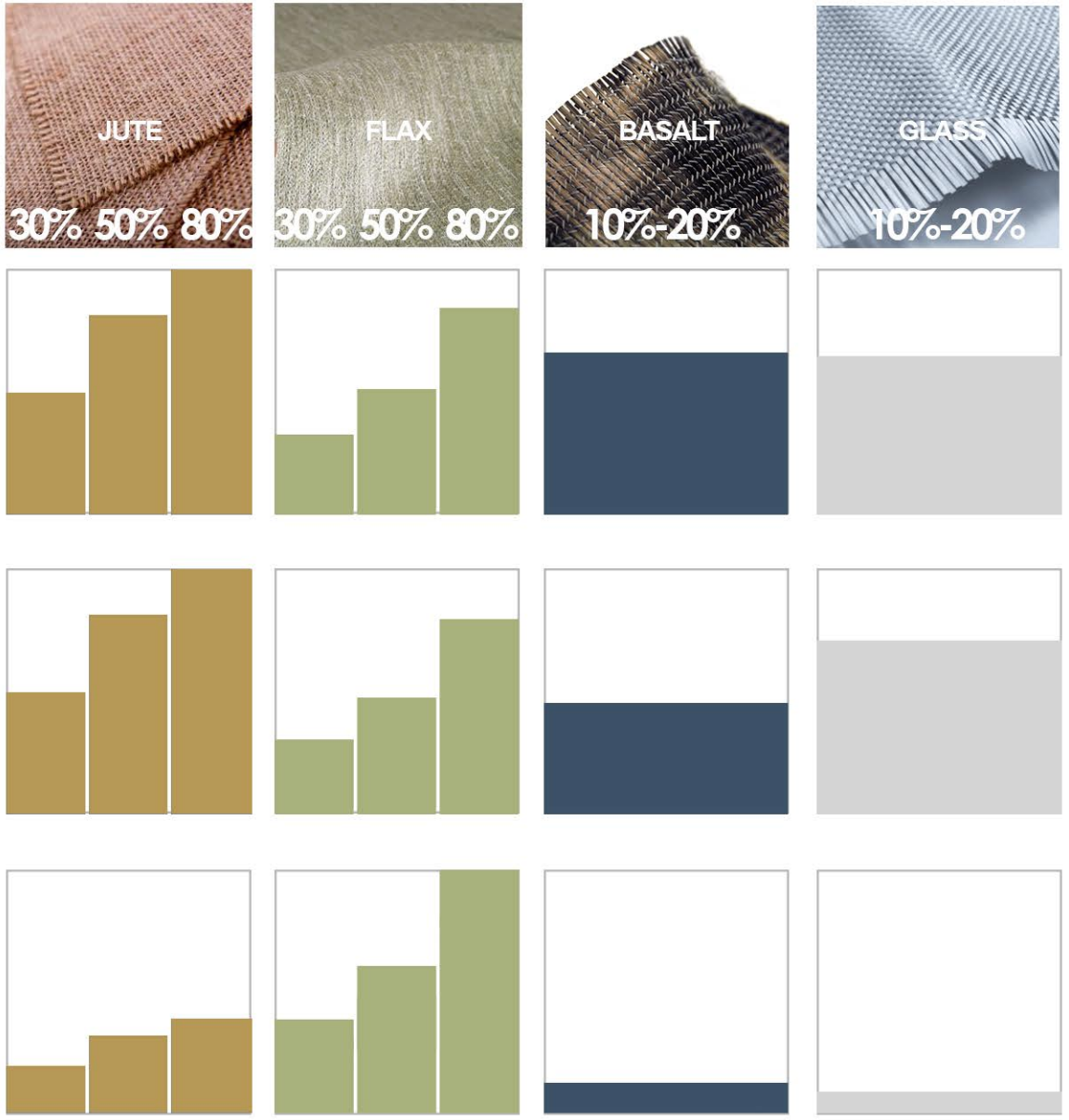


Structural calculation results

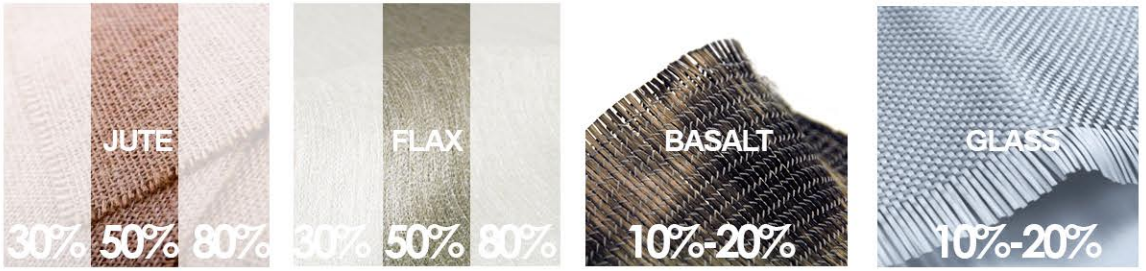


Structural calculation results

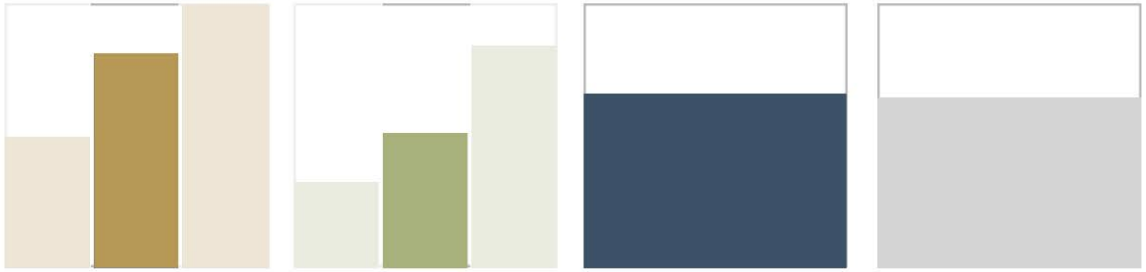
Structural calculation results



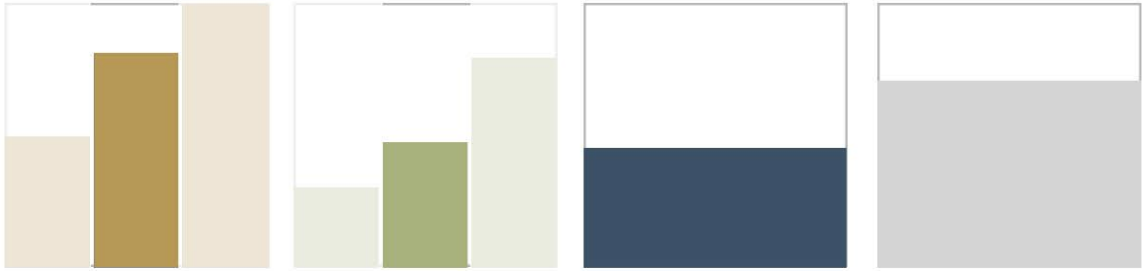
Structural calculation results



TOTAL KG OF FIBRE REQUIRED



TOTAL ENERGY CONSUMPTION OF REQUIRED FIBRE



TOTAL COST OF FIBRE REQUIRED

Conclusion

DURABILITY
COST EFFICIENCY
LESS MATERIAL USE

Sustainability can be approached through different ways

We should not consider only sustainable materials but
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The bridge is still bio-based at a significant percentage due to
furan resin and core from balsa wood

Although basalt is not based on a renewable resource
it is the most sustainable solution