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
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.
Problem Definition

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- Plastic industry ranks third in the world amongst all other industry.
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Source of heavy environmental pollution.
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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- Increased application in automotive industry, telecommunications, industrial design, packaging, medical science

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)

- Construction
- Pharmaceutical & medical
- Others
- Consumer products
- Horticulture & agriculture
- Catering
- Technical applications (incl. automotive)
- Bottles
- Other packaging (incl. carrier bags)

Biodegradable
Biobased/non-biodegradable

PLA & PLA-blends
Starch blends
Bio-PET 30
Bio-PET
Bio-PE
Other (biodegradable)
Other (biobased/non-biodegradable)

Source: European Bioplastics | Institute for Bioplastics and Bioocomposites (December 2013)
Goal of the study

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

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

Composites

[Diagram showing classification of materials: Resins, Thermoplastics, Thermosets]
Goal of the study

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

Composites
Goal of the study

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

Composites
Research on plant fibres

**Naturally occurring fibres**
- Plant: Flax, Hemp, Jute, Sisal, Ramie, Cotton
- Animal: Silk, Wool, Futhers

**Man-made fibres**
- Inorganic/mineral: Glass, Carbon, Basalt, Ceramic
- Organic: Polyethylene (PE), Polyamide (PA), Polyimide (PI), Polyaclonitrite (PAN), Polytetrafluoroethylene (PTFE)
- Metal: Steel, Aluminum, Copper
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)
Polyimide (PI)
Polyacrylonitrile (PAN)
Polytetrafluoroethylene (PTFE)

metal

Steel
Aluminum
Copper
Research on plant fibres

- temperate climate zone

![Jute](image1)

![Flax](image2)

![Glass fibre](image3)

![Basalt fibre](image4)
Research on plant fibres

- temperate climate zone
- bast fibre category (long fibres)
Research on plant fibres

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

- 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

JUTE  FLAX  BASALT  GLASS
Research on artificial fibres

- type of volcanic rock
- most common rock on earth's crust

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Research on artificial fibres

- type of volcanic rock
- most common rock on earth's 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

JUTE | FLAX | BASALT | GLASS

MECHANICAL PROPERTIES

DENSITY

STRENGTH

STIFFNESS
<table>
<thead>
<tr>
<th>Mechanical properties</th>
<th>Durability</th>
<th>Cost</th>
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<tbody>
<tr>
<td><strong>Density</strong></td>
<td><strong>Strength</strong></td>
<td><strong>Stiffness</strong></td>
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<tr>
<td>JUTE</td>
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<table>
<thead>
<tr>
<th>Durability</th>
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<tbody>
<tr>
<td>Water resistance</td>
</tr>
<tr>
<td>Fire resistance</td>
</tr>
<tr>
<td>UV resistance</td>
</tr>
<tr>
<td>Mechanical Properties</td>
</tr>
<tr>
<td>-----------------------</td>
</tr>
<tr>
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**Density**

- JUTE: Low
- FLAX: Medium
- BASALT: High
- GLASS: Very High

**Strength**

- JUTE: Low
- FLAX: Medium
- BASALT: High
- GLASS: Very High

**Stiffness**

- JUTE: Low
- FLAX: Medium
- BASALT: High
- GLASS: Very High

**Durability**

- Water Resistance: JUTE: Low, FLAX: Medium, BASALT: High, GLASS: Very High
- Fire Resistance: JUTE: Low, FLAX: Medium, BASALT: High, GLASS: Very High
- UV Resistance: JUTE: Low, FLAX: Medium, BASALT: High, GLASS: Very High
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<td>Water Resistance</td>
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<tr>
<td>Efficiency</td>
<td>Textile Price (€/m²)</td>
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TU Delft
Life Cycle Assessment

Environmental assessment method

JUTE  FLAX  BASALT  GLASS
Life Cycle Assessment

Environmental assessment method

JUTE

FLAX

BASALT

GLASS

ENVIRONMENTAL IMPACT → FIBRE PRODUCTION ← ENERGY CONSUMPTION
Life Cycle Assessment

Environmental assessment method

JUTE  FLAX  BASALT  GLASS

ENVIRONMENTAL IMPACT → FIBRE PRODUCTION ← ENERGY CONSUMPTION

8
ENVIRONMENTAL IMPACT CLASSIFICATION FACTORS

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Life Cycle Assessment

Environmental assessment method

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ENVIRONMENTAL IMPACT ➔ FIBRE PRODUCTION ➔ ENERGY CONSUMPTION

ACIDIFICATION
Environmental assessment method

- JUTE
- FLAX
- BASALT
- GLASS

Environmental Impact ➔ Fibre Production ➔ Energy Consumption

Acidification

Aquatic Toxicity

Ecotoxicity
Life Cycle Assessment

Environmental assessment method

JUTE  FLAX  BASALT  GLASS

ENVIRONMENTAL IMPACT  FIBRE PRODUCTION  ENERGY CONSUMPTION

ACIDIFICATION  AQUATIC TOXICITY  ECOTOXICITY  HUMAN TOXICITY

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Life Cycle Assessment

Environmental assessment method

JUTE | FLAX | BASALT | GLASS

ENVIRONMENTAL IMPACT → FIBRE PRODUCTION ← ENERGY CONSUMPTION

ACIDIFICATION | AQUATIC TOXICITY ECOTOXICITY | HUMAN TOXICITY | EUTROPHICATION

algae
Life Cycle Assessment

Environmental assessment method

JUTE  FLAX  BASALT  GLASS

ENVIRONMENTAL IMPACT  FIBRE PRODUCTION  ENERGY CONSUMPTION

ACIDIFICATION  AQUATIC TOXICITY ECOTOXICITY  HUMAN TOXICITY  EUTROPHICATION

GLOBAL WARMING

algae
Life Cycle Assessment

Environmental assessment method

JUTE  FLAX  BASALT  GLASS

ENVIRONMENTAL IMPACT → FIBRE PRODUCTION ← ENERGY CONSUMPTION

ACIDIFICATION  AQUATIC TOXICITY ECOTOXICITY  HUMAN TOXICITY  EUTROPHICATION

GLOBAL WARMING  DEPLETION OF RESOURCES

algae
Life Cycle Assessment

Environmental assessment method

JUTE  FLAX  BASALT  GLASS

ENVIRONMENTAL IMPACT  FIBRE PRODUCTION  ENERGY CONSUMPTION

ACIDIFICATION  AQUATIC TOXICITY ECOTOXICITY  HUMAN TOXICITY  EUTROPHICATION

GLOBAL WARMING  DEPLETION OF RESOURCES  OZONE DEPLETION

algae
Life Cycle Assessment

Environmental assessment method

![Images of Jute, Flax, Basalt, and Glass fibers]

**Environmental Impact** → **Fibre Production** ← **Energy Consumption**

- **Acidification**
- **Aquatic Toxicity**
- **Ecotoxicity**
- **Human Toxicity**
- **Eutrophication**

- **Global Warming**
- **Depletion of Resources**
- **Ozone Depletion**
- **Photochemical Oxidants Creation**

*Images show various environmental impact categories and their associated icons.*
Life Cycle Assessment

Environmental assessment method

Sources:
Existing research and LCAs
Databases

Environmental Impact ➔ Fibre Production ➔ Energy Consumption

Acidification
Aquatic Toxicity
Ecotoxicity
Human Toxicity
Eutrophication

Global Warming
Depletion of Resources
Ozone Depletion

Photochemical Oxidants
Creation

algae
Life Cycle Assessment

- Jute
- Flax
- Basalt
- Glass

- Acidification
- Aquatic Toxicity
- Ecotoxicity
- Human Toxicity
- Eutrophication
- Global Warming
- Depletion of Resources
- Ozone Depletion
- Photochemical Oxidants
- Creation
- Energy Consumption
Life Cycle Assessment

Carding

JUTE

FLAX

BASALT

GLASS

Agricultural

Fibre processing

Fabric processing

Spinning

Acidification

Aquatic toxicity

Ecotoxicity

Human toxicity

Eutrophication

Energy consumption

Weaving

Global warming

Depletion of resources

Ozone depletion

Photochemical oxidants creation

VOC

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Life Cycle Assessment

agricultural

fibre processing

fabric processing

ACIDIFICATION

AQUATIC TOXICITY

ECOTOXICITY

HUMAN TOXICITY

EUTROPHICATION

ENERGY

CONSUMPTION

GLOBAL WARMING

DEPLETION

OF RESOURCES

OZONE DEPLETION

PHOTOCHEMICAL

OXIDANTS

CREATION

carding

JUTE

FLAX

BASALT

GLASS

spinning

weaving

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Life Cycle Assessment

melting

extraction

fibre processing

1500-1700°C

extrusion

ACIDIFICATION

AQUATIC TOXICITY

ECOTOXICITY

HUMAN TOXICITY

EUTROPHICATION

ENERGY

CONSUMPTION

GLOBAL WARMING

DEPLETION

OF RESOURCES

OZONE DEPLETION

PHOTOCHEMICAL

OXIDANTS

CREATION

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Life Cycle Assessment

- Extrusion
- Extraction
- Fibre processing
- Fabric processing

Acidification
Aquatic toxicity
Ecotoxicity
Human toxicity
Eutrophication
Energy consumption

Global warming
Depletion of resources
Ozone depletion
Photochemical oxidants creation

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TU Delft
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 development

<table>
<thead>
<tr>
<th>Properties</th>
<th>Tensile strength (MPa)</th>
<th>E-modulus (GPa)</th>
<th>Elongation at failure (%)</th>
<th>Moisture absorption (%) per 24h</th>
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<tbody>
<tr>
<td>PLA</td>
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<td>3.45-3.85</td>
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<td>1,2-50</td>
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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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Heat deflection temperature VST B 50[°C]

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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

Bio-polymers are generally classified into:

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**DURABLE**

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- maximizing the content of renewable raw materials
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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

- Polymer
- Honeycomb
- Aluminum
- Balsa
<table>
<thead>
<tr>
<th>Material</th>
<th>Energy Consumption</th>
<th>Environmental Impact</th>
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<tbody>
<tr>
<td>POLYMER</td>
<td></td>
<td></td>
</tr>
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**Core materials**

### ENERGY CONSUMPTION

- PVC
- PET
- PUR

### 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

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

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<td>Vacuum assisted RTM</td>
<td>Continuous laminating</td>
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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

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Research on manufacturing processes

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 batch 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
Schiphol Logistics Park
Schiphol Logistics Park
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

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)

3. Design aesthetics
   - reflection of the plasticity of molded plastic
Design concept

- 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
Design research
Design research
Design research
Design research
Design research

Structural testing (stiffness)

Boundary Conditions
- Supports
- Loads
- Cross section
- Material mechanical prop.
Design research

Structural testing (stiffness)
Design
Design

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TU Delft
Design

sandwich structure

Detail of the deck

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Structural calculation

SIMPLIFIED APPROACH

straight U-beam
no curved corners
vertical parapets
1m continuous parapet height
Structural calculation

SIMPLIFIED APPROACH

8m

2m

1.1m

CALCULATION PROCESS

fabric selection

resin selection

straight U-beam

no curved corners

vertical parapets

1m continuous parapet height
Structural calculation

SIMPLIFIED APPROACH

8m
2m
1.1m

straight U-beam
no curved corners
vertical parapets
1m continuous parapet height

CALCULATION PROCESS

fabric selection

resin selection

Ply properties
Structural calculation

SIMPLIFIED APPROACH

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Ply properties

Laminate properties
Structural calculation

SIMPLIFIED APPROACH

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CALCULATION PROCESS

1. fabric selection
2. resin selection
3. Ply properties
4. Laminate properties
5. Moment of inertia
6. Strength/Stiffness
7. Loads-Partial factors
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Structural calculation

Simplified Approach

Strong Geometry → Minimum Material Use

Calculation Process

- Fabric selection
- Resin selection

→ Ply properties

→ Laminate properties

→ Moment of inertia

→ Strength/Stiffness

→ Loads-Partial factors
Structural calculation

SIMPLIFIED APPROACH

stiffness more critical

STRONG GEOMETRY → MINIMUM MATERIAL USE

CALCULATION PROCESS

fabric selection → resin selection

Ply properties

Laminate properties

Moment of inertia

Strength/Stiffness

Loads-Partial factors
Structural calculation

SIMPLIFIED APPROACH

stiffness more critical

CALCULATION PROCESS

fabric selection  resin selection

Ply properties

Laminate properties

Moment of inertia

Strength/Stiffness

Loads-Partial factors

STRONG GEOMETRY

MINIMUM MATERIAL USE

FIBRE ORIENTATION

TUDelft
Structural calculation

SIMPLIFIED APPROACH

stiffness more critical

STRONG GEOMETRY

MINIMUM MATERIAL USE

FIBRE ORIENTATION

QUASI-ISOTROPIC

ORTHOTROPIC
Structural calculation

MOISTURE
DURABILITY
FIRE RESISTANCE
UV RESISTANCE

JUTE
FLAX
BASALT
GLASS
Structural calculation results

JUTE 30% 50% 80%
FLAX 30% 50% 80%
BASALT 10%-20%
GLASS 10%-20%
Structural calculation results

 TOTAL KG OF FIBRE REQUIRED

 JUTE 30% 50% 80%  
 FLAX 30% 50% 80%  
 BASALT 10%-20%  
 GLASS 10%-20%  

 TOTAL ENERGY CONSUMPTION OF REQUIRED FIBRE

 JUTE  
 FLAX  
 BASALT  
 GLASS  

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Structural calculation results

<table>
<thead>
<tr>
<th>Material</th>
<th>TOTAL KG OF FIBRE REQUIRED</th>
<th>TOTAL ENERGY CONSUMPTION OF REQUIRED FIBRE</th>
<th>TOTAL COST OF FIBRE REQUIRED</th>
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<tbody>
<tr>
<td>JUTE</td>
<td>30% 50% 80%</td>
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<tr>
<td>FLAX</td>
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<tr>
<td>BASALT</td>
<td>10% 20%</td>
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</tr>
<tr>
<td>GLASS</td>
<td>10% 20%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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TU Delft
Sustainability can be approached through different ways. We should not consider only sustainable materials but *sustainable use* of materials.
Sustainability can be approached through different ways.

We should not consider only sustainable materials but sustainable use of materials.

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.