popUP SUPERstructure
Introduction | Fascination

In nature...

Keukenhof, the Netherlands
Images: online source
In architecture...

Modern Pentathlon Park, Toronto
Images: by author
### Some causes that drive temporary architecture

<table>
<thead>
<tr>
<th>Cause:</th>
<th>Purpose:</th>
<th>Typology:</th>
<th>Large scale International Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Disaster</td>
<td>Shelter</td>
<td>Housing</td>
<td>Expo, Exhibit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Folly, Pavillion</td>
</tr>
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<td></td>
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<td></td>
<td>Arena</td>
</tr>
</tbody>
</table>
Types of temporary architecture

According to Robert Kronenburg, mobile and temporary building systems can be divided into three specific types:

1) Portable buildings

2) Relocatable buildings

3) Demountable buildings
Introduction | Temporary Architecture

Temporary architecture as addition to existing building/context

The stairs to Kriterion by MVRDV, Rotterdam
Images: online source
Introduction | Temporary Architecture

Temporary architecture as building

London 2012 Basketball Arena by Sinclair Knight Merz
Images: online source
“However, portable (moveable) buildings, though temporary in location, are not temporary in use. Their portability is precisely what makes them not disposable. The fact that they can be re-used means that they can represent an efficient use of materials and resources, and should therefore be designed with care. They are high-quality products tuned to a specific need if not a specific location.”


Design Goal: Folly/ Pavillon ——— FLEXIBILITY ——— Arena

Temporary architecture is not disposable, but rather it can mean flexible & re-usuable.
Overall Design Question

How can temporary architecture for large scale international events be designed to be easily assembled and disassembled in order to adapt to different programmatic needs and project scales, or re-used in a different setting when its temporary need has ceased to exist?
Main Thematic Research Question
Which technologies and techniques will allow for the creation of eco-friendly temporary and flexible architecture?

Sub-questions

- What materials will be most suitable for the creation of lightweight and demountable structures that have low environmental impact?

- What would be the optimal sizes for ease of handling and transportation?

- What assembly/disassembly methods and connections will be most suitable?
Research | Methodology

Material Parameters:
- High strength-to-weight ratio
- Thermo-mechanical prop.
- Embodied Energy
- Recyclable / Renewable
- Cost

LITERATURE / THEORY

Temporality in Architecture
- Historical Overview
- Current State-of-the-Art

Environmental Impact
- Materials commonly used today

QUALITATIVE ANALYSIS

Aesthetics

INPUT I
Materials
- Analysis (software)

SELECT 2 or 3 materials
- Case Studies w/ selected materials

OUTPUT I
Qualitative Analysis

INPUT II
Sizes
- Fabrication Methods

Analysis (Span & Height)

OUTPUT II
Quantitative Analysis

INPUT III
Connections
- Easy to assemble:
  - Demountable
  - Dry connections
  - Click connections
  - No glue or resin

Easy to assemble:
- Demountable
- Dry connections
- Click connections
- No glue or resin

Design

Site Context
- Technical Fascination

Technical Conditions
- Design Goal

Boundary Conditions

Research Evaluation
- Tool Box Design

Prototype I
- Final Design
- Final Prototype

Preliminary Design
- Experiment

Evaluate

Final

Quantitative Analysis

Analysis (ease of assembly)

Pre-selection

Analysis (Spam & Height)

Pre-selection

Analysis (length & height)

Pre-selection

Analysis (span & height)

Pre-selection

Analysis (length & height)

Pre-selection

Analysis (span & height)

Pre-selection

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Analysis (length & height)

Pre-
Research Design Manual
+ Interviews

Analyse Study

Tool Box

Experiment Prototypes

Validate Feasibility

Design Context
+ Program
Research | Problem statement

**MOST COMMON BUILDING MATERIALS**
- concrete: 90%
- aggregates: 8%
- brick: 2%
- other materials: 2%

**EMBODIED ENERGY IN BUILDING MATERIALS**
- steel: 51%
- aluminum: 32%
- other: 17%
- concrete: 30%
- all other industries: 70%
Embodied Energy of Materials as a Rising Issue

Why embodied energy will increase in importance

Embodied Energy Analysis.
Source: http://www.bdonline.co.uk/

The Pure Cycle as the Key for Material Re-use & Less Embodied Energy

... the inner circle
... circling longer
... cascaded use across industries
... pure/non-toxic/easier-to-separate inputs and designs

Design for Disassembly
Modular
Lightweight
Temporary

Four Principles for Circular Economy
Source: Ellen MacArthur Foundation
Material Universe before boundary conditions
Source: CES Edupack (author’s analysis)

Density x Flexural Strength boundary conditions
Source: CES Edupack (author’s analysis)

Density x Embodied energy boundary conditions
Source: CES Edupack (author’s analysis)
CATEGORY 1: METALS & ALLOYS

CATEGORY 2: COMPOSITES

CATEGORY 3: NATURAL MATERIALS

CATEGORY 4: ENGINEERED MATERIALS
### Materials Pre-Selection Choice

#### Most Used Materials
- **1) Metals & Alloys**
  - Steel (AISI 8630)
  - Aluminum (Al 6061)
- **2) Composites**
  - Fiber Reinforced Composite (EP-CF70)
  - Cardboard (CES Edupack standard)
- **3) Natural Materials**
  - Wood (Radiata Pine)
  - Bamboo (CES Edupack standard)
- **4) Engineered Materials**
  - Laminated Wood (acetylated Radiata Pine)
  - Laminated Bamboo (Moso)

#### Alternative Materials

#### Criteria I
- **Material Performance**
  - Density (kg/m³)
  - Flexural Strength - MoR (Mpa)
  - Strength-to-weight ratio (MoR/density)
  - Young’s Modulus – MoE (GPa)
  - Compressive Strength (Mpa)
  - Tensile Strength (Mpa)
  - Thermal Conductivity (W/m.oC)

#### Criteria II
- **Material Health**
  - Embodied Energy (MJ/kg)
  - CO2 footprint (kg/kg)
  - Water Usage (l/kg)
  - Recycle fraction current supply (%)
  - Combust for Energy Recovery (yes/no)
  - Biodegradable (yes/no)
  - Renewable Content (%)
Criteria I: Material Performance

Criteria II: Material Health

Criteria III: Cost
### Criteria I: Material Performance

<table>
<thead>
<tr>
<th>Material</th>
<th>Poor: 1 – 18 points</th>
<th>Good: 19 – 36 points</th>
<th>Excellent: 37 – 56 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALUMINUM</td>
<td>Poor</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>BAMBOO</td>
<td></td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>CARDBOARD</td>
<td></td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>FRP</td>
<td></td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>LAMINATED BAMBOO</td>
<td></td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>LAMINATED WOOD</td>
<td></td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>STEEL</td>
<td></td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>WOOD</td>
<td></td>
<td>Excellent</td>
<td></td>
</tr>
</tbody>
</table>

### Criteria II: Material Health

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<thead>
<tr>
<th>Material</th>
<th>Poor: 1 – 18 points</th>
<th>Good: 19 – 36 points</th>
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</tr>
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<td>Good</td>
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</tr>
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<td>STEEL</td>
<td></td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>WOOD</td>
<td></td>
<td>Excellent</td>
<td></td>
</tr>
</tbody>
</table>

### Criteria III: Cost

<table>
<thead>
<tr>
<th>Material</th>
<th>Expensive: 1 – 18 points</th>
<th>Reasonable: 19–36 points</th>
<th>Cheap: 37 – 56 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALUMINUM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<tr>
<td>STEEL</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>WOOD</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Final results per material & possible scenarios
**GROUND TRANSPORTATION**

**Road Class I**
- 7.82m
- Max. weight: 26.5ton

**Road Class II**
- 13.6m
- 7.82m
- Max. weight: 26ton

**Road Class III**
- 7.82m
- 13.6m
- Max. weight: 21.7ton

Max. length: 25.25m

**SEA TRANSPORTATION**

**Shipping Container**
- 20ft (6.1m) shipping container
  - Max. weight: 21.7ton
- 40ft (12.2m) shipping container
  - Max. weight: 26.5ton

Source: Information based on the EMS (European Modular System) by ACEA. Diagrams by author

Source: Mainfreight, Global Supply Chain Logistics. Diagrams by author

by author
### Handling on Site

**Category A**

- **Source:** Telehandlers by Genie

**Category B**

- **Source:** Material Lifts by Genie

**Category C**

- **Source:** Telehandlers by Genie

---

**Handelings by Genie Telehandler**

- GTH-5519
- GTH-636
- GTH-844
- GTH-1056
- GTH-1256
- GTH-1544

---

**Handelings by Genie Material Lift**

- SLA-5
- SLA-10
- SLA-15
- SLA-20
- SLA-25

---

**Legend**

- **max. weight**

---

*Research Sizes by author*
**Research** | Sizes - up to 6m span

<table>
<thead>
<tr>
<th>Profile</th>
<th>Deflection</th>
<th>Weight</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Steel</strong></td>
<td>51 x 122 x 5.6 mm</td>
<td>36 kg</td>
<td>€20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Aluminum</strong></td>
<td>50 x 132 x 5 mm</td>
<td>20 kg</td>
<td>€42</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FRP</strong></td>
<td>200 x 200 x 15 mm</td>
<td>42 kg</td>
<td>€2975</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cardboard</strong></td>
<td>66 x 148 mm</td>
<td>30 kg</td>
<td>€46</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Laminated Wood</strong></td>
<td>66 x 148 mm</td>
<td>30 kg</td>
<td>€92</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Laminated Bamboo</strong></td>
<td>66 x 148 mm</td>
<td>30 kg</td>
<td>€64</td>
</tr>
</tbody>
</table>

**CATEGORY 1: METALS & ALLOYS**

**PROPERTY**

Beam scale is 1/10 of sectional profile size

by author
Calculations Methodology

**GOAL:** Find lightest and safest choice for a 3KN/m load for a determined span

- For W = 3KN/m for Class C5 (areas where people may congregate). Source: Formichi, P. (2008). EUROCODE 1, Actions on Building Structures

**FORMULAS:**

1) Beam designed for maximum moment:
   
   \[ M_{\text{max}} = W \cdot L^2/8 \text{ (KN.m)} \]

2) Required Section Modulus
   
   \[ S_{\text{req}} = M_{\text{max}}/\text{MoR} \text{ (10}^3 \text{ m}^3) \]

3) MoR is the Modulus of Rupture or bending strength and it depends on the material

4) Compute Section Modulus to check if member passes or fails the required Section Modulus
   - Square/Rectangular beams: \[ S_{\text{r}} = b \cdot d^2/6 \text{ (10}^3 \text{ m}^3) \]
   - Other shapes: \[ S_{\text{r}} = I_{\text{xx}}/y \text{ (10}^3 \text{ m}^3) \]
     - \( I_{\text{xx}} \): Moment of Inertia (10\(^{-3}\) m\(^4\))
     - \( y \): distance to neutral axis (m)

5) Compare allowed deflections with the deflections of each member
   
   \[ \Delta_{\text{allowed}} = 5W \cdot L^4/384 \cdot E \cdot I_{\text{xx}} \]
   
   \[ E = \text{Young's Modulus (GPa)} \]
   
   \[ I_{\text{xx}} = b \cdot h^3/12 \text{ (10}^{-3}\text{ m}^4) \]

6) Find the weight in kg of each member
   
   \[ \text{Mass} = \text{area profile} \times \text{length} \times \text{density} \]

7) Find the final price in Euros
   
   \[ \text{Final price} = \text{price/kg} \times \text{mass} \]

Units Reference:

- GPA - 10\(^{11}\) N/m\(^2\)
- MPa - 10\(^6\) N/m\(^2\)
- KPa - 10\(^3\) N/m\(^2\)
- Pa - 1 N/m\(^2\)
CONNECTIONS USING THE SAME MATERIAL AS STRUCTURE

Clamped Connections
Connections that use a clamp or ring as a means to attach multiple elements.

Slotted Connections
Connections that allow elements to fit into each other through means of a slot or tenon.

Fitting Connections
Connections that allow elements to fit into each other through means laps that are similar in size and shape.

CONNECTIONS USING DIFFERENT MATERIAL FROM STRUCTURE

Fastened Connections
Connections that allow different elements to be fastened to each other by the use of fittings, ties or rope.

Inserted Connections
Connections that link different elements by inserting them into it.

Bolted Connections
Connections that have different elements such as steel plates that are bolted to the members.

NOTE: All figure references can be found on the appendix of the Design Manual (Research Paper).
Design Principles

01
- Flexible
- Modular
- Easy to transport
- Easy to handle on site

02
- Lightweight
- Durable
- Sustainable
- Affordable

03
- Easy to Assemble
- Easy to Disassemble
- Few parts
- Simplified design
Span sizes informed by transportation methods

**GROUND:**
- Road Class I: 7.82m
- 20ft (6.1m) shipping container

**SEA:**
- 40ft (12.2m) shipping container

**FLEXIBILITY**
- S (3m)
- M (6m)
- L (9m)
- XL (12m)
Span sizes influence in material choice

S (3m)  M (6m)  L (9m)  XL (12m)

FLEXIBILITY

<table>
<thead>
<tr>
<th>Size</th>
<th>Material</th>
<th>Weight</th>
<th>Cost</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>S (3m)</td>
<td>Steel</td>
<td>270 kg</td>
<td>837 €</td>
<td>3294 MJ</td>
</tr>
<tr>
<td>M (6m)</td>
<td>Steel</td>
<td>540 kg</td>
<td>1674 €</td>
<td>6588 MJ</td>
</tr>
<tr>
<td>L (9m)</td>
<td>Steel</td>
<td>2065 kg</td>
<td>6385 €</td>
<td>25200 MJ</td>
</tr>
<tr>
<td>XL (12m)</td>
<td>Steel</td>
<td>2754 kg</td>
<td>8514 €</td>
<td>33600 MJ</td>
</tr>
</tbody>
</table>
Shortlisted materials

- ALUMINUM: Poor Material Performance, Expensive Price
- BAMBOO: Good Material Performance, Reasonable Price
- CARDBOARD: Good Material Performance, Reasonable Price
- FRP: Good Material Performance, Reasonable Price
- LAMINATED BAMBOO: Excellent Material Performance, Reasonable Price
- LAMINATED WOOD: Excellent Material Performance, Cheap Price
- STEEL: Excellent Material Performance, Cheap Price
- WOOD: Excellent Material Performance, Cheap Price
Chosen scenario

- ALUMINUM: Poor Performance, Poor Health, Expensive Price
- BAMBOO: Good Performance, Good Health, Reasonable Price
- CARDBOARD: Excellent Performance, Excellent Health, Cheap Price
- FRP: Poor Performance, Poor Health, Expensive Price
- LAMINATED BAMBOO: Excellent Performance, Excellent Health, Reasonable Price
- LAMINATED WOOD: Excellent Performance, Excellent Health, Cheap Price
- STEEL: Excellent Performance, Excellent Health, Reasonable Price
- WOOD: Poor Performance, Poor Health, Expensive Price
Qualitative Analysis Chosen Material

Production of Acetylated Wood

Diagram showing products and by-products of the acetylation process.
Source: by author based on interview

Acetylation Process

Images by Accoya Wood
Qualitative Analysis Chosen Material

<table>
<thead>
<tr>
<th>Performance</th>
<th>untreated wood</th>
<th>acetylated wood</th>
<th>acetylated &amp; laminated wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durability</td>
<td>Class 4</td>
<td>Class 1</td>
<td>Class 1</td>
</tr>
<tr>
<td>Quality</td>
<td>variable</td>
<td>consistent</td>
<td>consistent</td>
</tr>
<tr>
<td>Density</td>
<td>100%</td>
<td>110%</td>
<td>110%</td>
</tr>
<tr>
<td>Flexural Strength (MoR)</td>
<td>100%</td>
<td>120%</td>
<td>120%</td>
</tr>
<tr>
<td>Strength-to-weight ratio</td>
<td>100%</td>
<td>108%</td>
<td>108%</td>
</tr>
<tr>
<td>Young’s Modulus (MoE)</td>
<td>100%</td>
<td>90%</td>
<td>105%</td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>100%</td>
<td>100%</td>
<td>114%</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>100%</td>
<td>100%</td>
<td>137%</td>
</tr>
</tbody>
</table>

* Classification presented in BS-EN 350-2
Class 1 - very durable
Class 2 - durable
Class 3 - moderately durable
Class 4 - slightly durable
Class 5 - not durable

** Some sources say that density increases during acetylation process due to vinegar, while others consider density increase irrelevant.

*** 20% increase between untreated wood and acetylated wood based on Accoya performance report. Source: Accoya, 2016c
Laminated Accoya wood is stronger in bending than solid Accoya wood but structural report shows same numbers. Source: Accoya, 2016b

**** 10% decrease between untreated wood and acetylated wood based on Accoya performance report. Source: Accoya, 2016c

***** Information based on Accoya structural report. Source: Accoya, 2016b
Research | Research X Design

Flexibility

Modular Sizes

Angular Connections

90 °  120 °  135 °  150 °

Bracing for Radial Variation
Analysis of a Pavilion Design
using Laminated Wood
Chosen connection category

CONNECTIONS USING THE SAME MATERIAL AS STRUCTURE
- Clamped Connections
- Slotted Connections
- Fitting Connections

CONNECTIONS USING DIFFERENT MATERIAL FROM STRUCTURE
- Fastened Connections
- Inserted Connections
- Bolted Connections

Research X Design

- Same material as structure
- 100% renewable materials
- Lightweight material
- Minimize number of parts
- Simplified design
- Easy to assemble
Angular Connections

Combination of different connection angles and modular sizes

Tenon and Mortise joint @ corners
Bracing for Radial Variation

Bracing of different sizes allow for radial variation.

Tusk Tenon and Mortise joint
Content

01 Introduction
- Fascination
- Temporary Architecture
- Design Goal
- Design Question
- Technical Question

02 Research
- Methodology
- Problem statement
- Materials
- Sizes
- Connections
- Research x Design

03 Design
- Context
- Project Phasing
- Program
- Possible Locations
- Vision

04 Next Steps
- Strategy
- Planning
- Questions
Why IBA Parkstad?

International Event/Expo to be held in 2020 in order to showcase future-proof, innovative and experimental projects that will draw attention to the region and help boost its economy and restore the pride of its citizens.
The Parkstad Region Challenge

-875 birth surplus in 2013
9% unemployment
2.05 average household size
1.180 population density inhabitant per km²

Shrinking Region

Data Source: Handboek IBA Zomer2015
The Parkstad Region Challenge

Population Density

-875
birth surplus in 2013

9%
unemployment

2.05
average household size

1.180
population density inhabitant per km²

Shrinking Region

Tourism for Tomorrow Award 2016

Top 100 Green Destinations
Dutch nature as seen by Tourists

as seen by the Americans, British and Chinese

as seen by Belgians and Germans

Data Source:
(source: https://www.mooistenatuurgebied.nl/over-de-natuur)
Images: online source
What makes the Parkstad Region unique?

The cultural and historic heritage of the Parkstad Region
popUP SUPERstructure

popUP responds to the needs of the present, while being able to gain new life in the future.

SUPERstructure: capacity of structure to be flexible and adapt to various scales and programs.

- series of interventions
- promote the region
- showcase innovation
- showcase sustainability
- increase tourism
- create jobs
- restore pride of citizens
Project Phasing

PHASE 1
Before IBA 2020

PHASE 2
IBA 2020

PHASE 3 (future vision)
After IBA 2020

popUP LANDescapes
popUP URBANescapes
popUP URBANescapes

Folly/ Pavilion → FLEXIBILITY → Arena
Design | Project Phasing

Before IBA 2020 - Promotion at Macro-regional scale
IBA 2020 - Meet IBA & Get Connected
IBA 2020 - Meet IBA & Get Connected

Meet IBA
Exhibition & Cultural Centre

Get connected

popUP URBANescapes
Follies to attract people to certain regions

popUP LANDescapes
Typological Comparison - Leisure & Cultural precedents

**SCALE**

**Folly/ Pavilion**
- Follies / Installation
  - Montreal Biosphere
  - Buckminster Fuller
- Pavillon / Exhibition
  - Parc de la Villette
  - Bernard Tschumi
- Museum / Exhibition
  - MuséeParc Alsace
  - by Bernard Tschumi
- Theatre / Presentations
  - Ummeges Hall
  - Bernard Tschumi
- Concert Hall / Performances
  - Zenith Amien Music Hall
  - by Bernard Tschumi

**PERMANENT**

**Arena**
- Arenas / Sports
  - London 2012 Velodrome
    - Capacity: 6000
  - London 2012 Aquatic Centre
    - Zaha Hadid
    - Permanent Capacity: 2500
    - Temporary Capacity: 17500

**TEMPORARY**

- Temporary Folly / Pavillion
  - Nomadic Museum
  - Shigery Ban
- Temporary Arena
  - TED Theatre
  - Rockwell Group
- Temporary Follies / Installation
  - Tomorrowland Festival
  - Capacity: +/- 5000

- Temporary Pavillon / Exhibition
  - Hannover Expo Japan
  - Shigery Ban
- Temporary Museum / Exhibition
  - Paper Bridge
  - Shigery Ban
- Temporary Theatre / Presentations
  - London 2012 Basketball Arena
  - Capacity: +/- 5000
03 Design | Program

FLEXIBLE INDOOR SPACES

Cultural
Mining & Industrial Heritage EXHIBITIONS

Social & Sustainable
Local Produce MARKET

FLEXIBLE OUTDOOR SPACES

Leisure
Recreational Gatherings FESTIVAL & CONCERT

Nature
Interaction with Landscape BARE NATURE

Historic
Interaction with Site History INSTALLATION
Heerlen is considered the Heart of the Parkstad Region. Rich Roman heritage at Via Belgica. City is situated strategically between main roads leading to Belgium and Germany.

Image: Google Earth
Clay pits excavated during Roman times for production of pottery.
Elevated pond location is a viewing point for surrounding landscape.

Image: Image: online
“From Black to Green”: project at the intersection between the Park and the waste left behind by the mining industry now aims to bring back to surface the Rode Beek stream and create a green corridor.

Image: by author
A former waste hill from the Wilhelmina state mine. Located close to some leisure attractions such as SnowWorld and Mondo Verde.

Image: online source
One of the top 100 UNESCO monuments of The Netherlands. Rich Cultural, religious and architectural heritage. Today has hotel, restaurant, vineyards.

Image: online source
Grunsvensplein - Exhibition & Cultural Centre
Schniveldse Bossen - Folly (Observatory)
Schutterspark - Folly (Bridge)
Next Steps | Strategy

- Research
  - Design Manual
  - Interviews

- Analyse
  - Study

- Tool Box

- Experiment
  - Prototypes

- Validate
  - Feasibility

- Design
  - Context
  - Program
### Next Steps

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### Module 2

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Thank you!