UHPFRC in Architecture

The future of concrete composites in a sports complex
CONTENTS

- Fascination and design with UHPFRC
- Context; The Brettenzone and Westerpark
- Public Sports Complex Amsterdam
- Architecture & Structural Design
- Climate design
- Conclusions and Questions
Technical Fascination;
Introduction to the world of high performance concretes
Ancient concrete

Pont du Gard 38 v. Chr.

Pantheon, 27 v. Chr.
Present day Concrete

Steinkirche Cazis – Atelier Werner Schmidt

Gare de Saint-Exupéry – Santiago Calatrava

Casar de Cáceres – Justo Garcia Rubio

Wyss Garden Center – Heinz Isler
Concrete compounds

<table>
<thead>
<tr>
<th></th>
<th>Vol. (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (Portland)</td>
<td>325</td>
</tr>
<tr>
<td>Sand (aggregate)</td>
<td>660</td>
</tr>
<tr>
<td>Gravel (aggregate)</td>
<td>1300</td>
</tr>
<tr>
<td>Water</td>
<td>160</td>
</tr>
<tr>
<td>Total (density)</td>
<td>2445</td>
</tr>
</tbody>
</table>

Compounds of an every day concrete

*Playing with the compound ratio’s or diversifying with ingredients result in better performing concretes*
Increasing mechanical performance

Result: Increased compressive strength
Fiber Reinforcement

UHPFRC under a 4-point bending test
Concrete Strength

Compressive vs. Tensile strength (MPa)

High Performance Concrete (HPC)

Ultra High Performance Concrete (UHPC)

Ultra High Performance Fiber Reinforced Concrete (UHPFRC)
Comparing materials

<table>
<thead>
<tr>
<th>Mechanical properties</th>
<th>OC (C35/45)</th>
<th>UHPC (C170/200)</th>
<th>UHPFRC (steel fibers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m$^3$)</td>
<td>2400</td>
<td>2450</td>
<td>2600</td>
</tr>
<tr>
<td>Compressive strength (MPa)</td>
<td>45</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>3,2</td>
<td>6,0</td>
<td>10,0</td>
</tr>
<tr>
<td>Flexural strength (MPa)</td>
<td>4,8</td>
<td>10,0</td>
<td>40,0</td>
</tr>
<tr>
<td>Young’s modulus (GPa)</td>
<td>34</td>
<td>55</td>
<td>60</td>
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</tbody>
</table>
Comparing materials

<table>
<thead>
<tr>
<th>Mechanical properties</th>
<th>UHPFRC</th>
<th>Glulam (GL28)</th>
<th>Steel (S235JR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>2600</td>
<td>410</td>
<td>7850</td>
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<tr>
<td>Compressive strength (MPa)</td>
<td>200</td>
<td>26,5</td>
<td>360</td>
</tr>
<tr>
<td>Axial Tensile strength (MPa)</td>
<td>10</td>
<td>19,5</td>
<td>360</td>
</tr>
<tr>
<td>Flexural strength (MPa)</td>
<td>40</td>
<td>28</td>
<td>235</td>
</tr>
<tr>
<td>Young’s modulus (GPa)</td>
<td>60</td>
<td>12,6</td>
<td>205</td>
</tr>
</tbody>
</table>
Advantages in short

- Increased mechanical performance
- Less raw material needed
- Simplified reinforcement, reduced construction time and enhanced job safety
- Dense matrix causes impermeability, increased lifespan
Design with UHPFRC

What has been done? What is (im)possible?
Applications – Civil Engineering

Gartnerplatz Brucke – Kassel University

Pont du diable – Rudy Ricciotti

Seoul footbridge – Rudy Ricciotti
Architectural Applications

RATP – Graphic Architecture
Huize het Oosten – Ten Bras Westinga
Saxon Sion – Chamion Mensens

Stade Jean de Bouin – Rudy Ricciotti
Stanze – La Ville Rayee
Architectural Applications

- LandboMidtØst - Hinnerup
- HiCon Staircase - Denmark
- L’arch – Michel de Broin
- Parkbrug Voorstonden – Balustrade Fragment
- LandboMidtØst - Hinnerup
Ambitions / Challenges

- Use UHPFRC in the main supporting structure of a building
- Show the structure on the outside
- Experience slenderness and elegance
- Structural design vs architecture
Prefab application is necessary
Outside application
Design for compression to get best results
Expensive (due to fibers and expertise needed)
Context: Brettenzone and Westerpark

Problem statement and Design principles
Background – Brettenzone

Source: Google Earth
Brettenzone – Inaccessibility

Source: Radiaal West, PvE Brettenscheg
Brettenzone - Pathway
Context westerpark

Source: Google Maps
Westerpark – Current Situation
Westerpark – New Functions
Sports Complex at Intersection
Public Sports Complex Westerpark
Program, Concept and Design
Program

- Multifunctional Sports Hall 44x24 m
- Swimming pool; 12x25 m (6 lanes)
- Central public space in park at intersection
Concept and Design

- Elevated Pathway; experience park on different levels
- Sportive and Undulating; route itself becomes part of the sports park
- Pathway determines the shape of the complex
Formfinding
Functional Set-up

Sports + Public Center + Swimming
Functional Set-up

Sports + Public Center + Swimming

Fun route

Brettenpad
Zoom to building scale
Function/Routing

- Top Floor
  Viewing Platform
- 3th
  Restaurant
- 2nd
  Fun route entrance
- 1st
  Brettenpad crossing
  Tribunes sports functions
- GF
  Sports halls, Dressing rooms
  Public main hall

Internal staircase from foyer
Elevators
Function/Routing

- Atrium staircase from GF to top floor
- Elevators

Top Floor
Viewing Platform

3rd
Restaurant

2nd
Fun route entrance

1st
Brettenpad crossing
Tribunes sports functions

GF
Sports halls, Dressing rooms
Public main hall
Brettenpad
Brettenpad
Longitudinal Section
Entrance Sports Foyer
First Floorplan
Structural Design vs Architecture

UHPFRC in design, structural systems, structural elements, experience
Exploded view
Structural Design; Prefab UHPFRC
Structural Design; Second Floorplan
Center Structure Analysis
GSA Analysis – LC1 Dead Load

Deflections

Combined stresses (C1)
GSA Analysis – LC2 Wind Load

Deflections

Combined stresses (C1)
GSA Analysis – LC3 Point loads

Deflections

Combined stresses (C1)
Results

External (yellow)
- Top: ø150mm
- 4th: ø180mm
- 3th: ø200mm
- 2nd: ø220mm
- 1st: ø240mm
- Bottom: ø260mm

Internal (blue)
- Top: ø100mm
- 4th: ø140mm
- 3th: ø190mm
- 2nd: ø190mm
- 1st: ø190mm
- Bottom: ø190mm
Center column floor detail

- Stainless steel connection to be poured in with concrete and bolted together
- UHPFRC internal column segments
- Welded connection to THQ beam
- THQ beam 320x190 mm
- Concrete slab floor 300mm
- Steel 16 mm

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- Internal diagonal columns
- External straight columns
- Radial THQ 320x190 beams
- Lightweight concrete slab floor
Center internal glazing

Reference balustrade (Source: Metaglas)
Center Detail Fragment
Elevation
Isometric

WALKWAYS + FACADE
UHPFRC COLUMNS
UHPFRC ARCHES
STEEL BAR SPACEFRAME
STEEL VOLUME FRAME
GRAND STAND

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GSA Analysis

Single frame

GSA Oasys model
GSA Analysis – LC1 Dead Load

Deflections

Combined stresses (C1)
GSA Analysis – LC2 Wind Load

Deflections

Combined stresses (C1)
GSA Analysis – LC3 Point Load

Deflections

Combined stresses (C1)
Results

- **End;** $h = 190\text{mm}$
- **Start;** $h = 280\text{mm}$
- **UHPFRC Arch;** $h = 400\text{mm}$
- **Steel frame;** $h = 160\text{mm}$
- **Space frame bars;** $\varphi 40\text{mm}$
- **Top;** $h = 400\text{mm}$
- **Mid;** $h = 300\text{mm}$
- **Bottom;** $h = 400\text{mm}$
Sports Hall Fragment
Arch Facade Connection

- UHPFRC Arch 400mm
- Stainless steel stabilizers 50mm
- Hinged spaceframe connection
- Curved glazing for natural roof light strips

- Aluminium sandwich panel 35mm
- Sheep wool insulation 160mm
- Secondary aluminium framework to mount ceiling panels
- Curved and perforated 5 mm aluminium panels for acoustic insulation

Variation 100, 600, 800
Section Sports Hall
Section Sports Hall
Connection of volumes
Structural connection
Structural connection
Materialization

Center; bronzed metal gauze

Reference; de Baljurk, The Hague

Sports halls; single curved aluminium panels

Reference; Floriade Paviljon Haarlemmermeer
Climate design
Heating, ventilation and acoustics
Swimming pool Acoustics

- Aluminium perforated panels on ceiling
- Spraypan acoustic insulation on walls
- Water tanks for grey water recycling
Swimming pool Heating/ventilation

- Air outlet in roof
- Technique room in grand stand
- Air inlet in facade
- Exhaust moist air through ceiling ducts
- Treated and heated dry air
- Additional floor heating in changing rooms
- Evaporation

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Ventilation and Lighting

- Principle duct system
  - Corner profiles
  - Volume steel frame 160mm (curved)
  - Straight duct sections 1200x800x200mm
  - Lighting in line with vents
  - Vent exhaust 300mm
  - Aluminium cap (curved)
Ventilation and Lighting

Volume steel frame 160mm (curved)

Straight duct sections 1200x800x200mm

Aluminium cap (curved)

Aluminium perforated panels for acoustic insulation

Vent exhaust 300mm

Reference: Haagse Hofbad, Venhoeven CS
Swimming pool perspective
Conclusive
Achievements and next steps
Achievements

- Design on all scales
- Adding a valuable function to the Westerpark, giving new meaning to the park in relation to its surroundings
- Working with a new construction material and turning it into architecture
- Elegant and slender design with the help of static structural analysis
- Creating experience
Experience

SHORT FILM
Questions