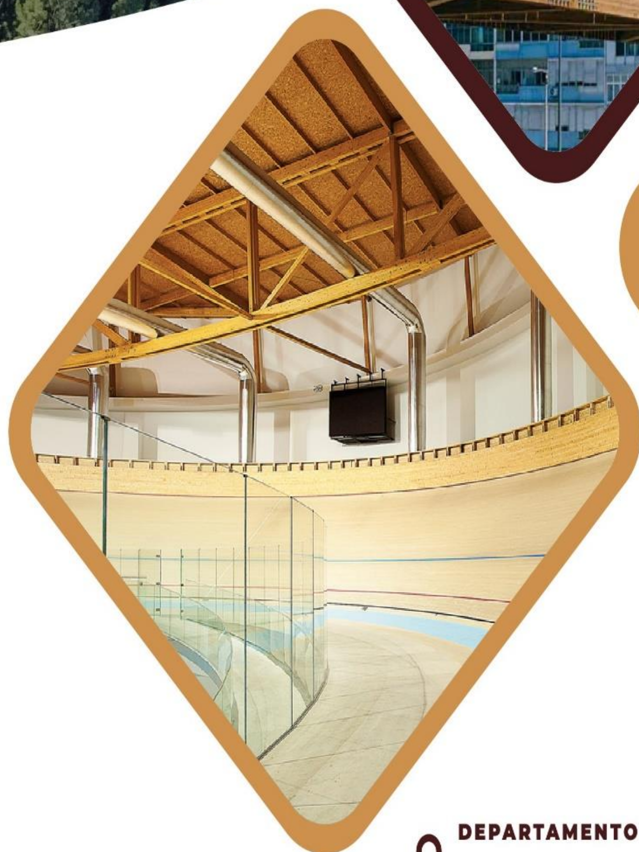
27 & 28
DE MARÇO
DE 2023

CONSTRUÇÃO EM MADEIRA

DESAFIOS E OPORTUNIDADES



Verification and Execution of the Metropol Parasol in Seville

Matthias Gerold

Interreg Sudoe
EGURALT
European Regional Development Fund
serQ centro de inovação e competências da floresta
UNIVERSIDADE D COIMBRA

DEPARTAMENTO DE ENGENHARIA CIVIL
UNIVERSIDADE DE COIMBRA

2nd Keynote

Harrer Ingenieure

Structural Design, Verification and Execution of the Metropol Parasol in Seville

Vita, Presentation of our office

Harrer Ingenieure

Dipl.-Ing. Matthias Gerold

Chief engineer for structural engineering, General Manager (CEO)
Admission as Checking Engineer for building techniques for concrete and timber
Sworn in as Publicly Appointed Expert for concrete, steel, timber and glass
Admission by the Federal Office for Railways as Inspector for verification of constructions, field of railway bridge construction and structural engineering

CEN/TC 250

- CEN/TC 250/HGB
- CEN/TC 250/SC 0 – SC 1
- CEN/TC 250/SC 2 – SC 4, SC 6 – SC 9 Evolution-of-Eurocodes
- CEN/TC 250/SC 5 (Head of German Delegation)
  - SC5/SG - AdHoc-Group_Durability
  - SC5/TG – Corrosion
  - WG 1_CLT
  - WG 2_TCC
  - WG 3_Cluster
  - WG 4_Fire
  - WG 5_Connections
  - WG 6_Timber-Bridges
  - WG 7_Reinforcement
  - WG 8_Seismic
  - WG 9_Execution
- CEN/TC 250/SC 8
- CEN/TC 346 Conversation-of-Cultural-Heritage

DIN NA Bau – German Mirror Committee timber structure

- NA 005-04-01-01 AK DIN-EN-1995
  - 01-01AK_Leitungsteam
  - 01-10-AK_Basis-of-design-and-materials
  - 01-11AK_CLT_Cross-laminated-timber
  - 01-12AK_TCC_Holz-Beton-Verbund
  - 01-13AK_Cluster_Stability_Diaphragm
  - 01-14AK_Structural-Fire-Design
  - 01-15AK_Connections-and-fasteners
  - 01-16AK_Timber-bridges
  - 01-17AK_Reinforcement
  - 01-18AK_Seismic
  - 01-19AK_Execution
- NA 005-04-01-03 AK_Holzwerkstoffe_Schnittholz
- NA 005-04-01-04 AK_Geklebte-Produkte
- NA 005-04-01-05 AK_vorgefertigte-Bauteile
- NA 005-04-01-06 AK_Holzschutz
- NA 005-04-01-07 AK_Verbindungsmittel
- NA 005-04-01-08 AK_Seismic
- NA 005-04-01-09 AK_Auslegung von Normen
- NA 005-04-01AA_DIN-EN-1995
- NA 005-04-01AA_Adhoc-Gruppe Konvergenz
- NA 005-04 FBR_Holzbau_LenkungsgremiumFachbereich 4
- NA 005-51-06 AA_DIN-EN-1998
- NA 005-57-05 AA_Seismic Bridges
- NA 005_57 FBR-Brücken_KOA-07
- NA 042-03-06 AA_Holzschutz
- TA-BSH

Vita, Presentation of our office

Harrer Ingenieure

Hoch- und Ingenieurbau

- Tragwerksplanung
- Bautechnische Prüfungen
- Bauüberwachung
- Bauherrenberatung
- Gerichts- und Privatgutachten
- Beweissicherungen
- Bauphysik

Brücken-, Tunnel- und Grundbau

- Objekt- und Tragwerksplanung
- Bautechnische Prüfungen
- Baumanagement Ingenieurbau
- Bauüberwacher Bahn, Technisch Berechtigter, Erhaltungsmanagement

im Straßen- und Eisenbahnbereich sowie bei Wasserstraßen

Risk Management & Sonderkonstruktionen

- Baudynamik
- Nichtlineare Berechnungen
- Destruktives Engineering (Rückbau, Sprengungen)
- Naturkatastrophen
- Risikoanalysen
- Lebensdaueranalyse
- Monitoring

Industrie- und Gewerbebau

- Objekt- und Tragwerksplanung
- Gesamtplanungen
- Bauherrenberatung

im Industrie-, Gewerbe-, Anlagen und Kraftwerksbau sowie in der Energieversorgungswirtschaft

Projekt-management

- Projektsteuerung
- Bauherrenberatung
- Objektüberwachung
- Projektleitung
- Bauherrenaufgaben
- E-Vergabe

www.harrer-ing.net

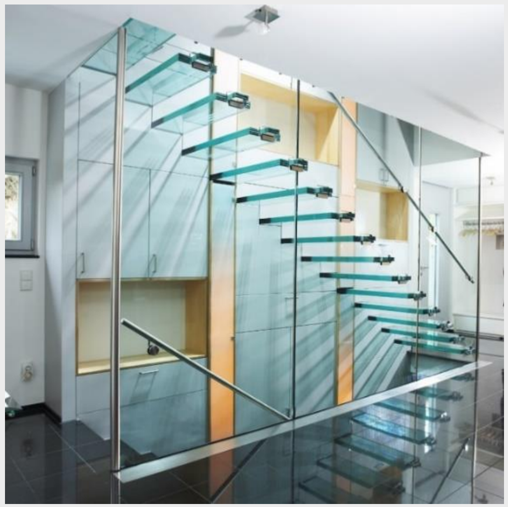
Sonderbereiche

Brandschutz • VgV-Verfahren • Planungswettbewerbe • Sicherheits- und Gesundheitskoordinator • BIM

Vita, Presentation of our office

Harrer Ingenieure

working with all building materials – in practice, research and development, standardisation and teaching



glass stair
hanging on
a glass wall

load
bearing
plastic
structures

staff Harrer Ingenieure

staff devision civil engineering – timber construction

Vita, Presentation of our office

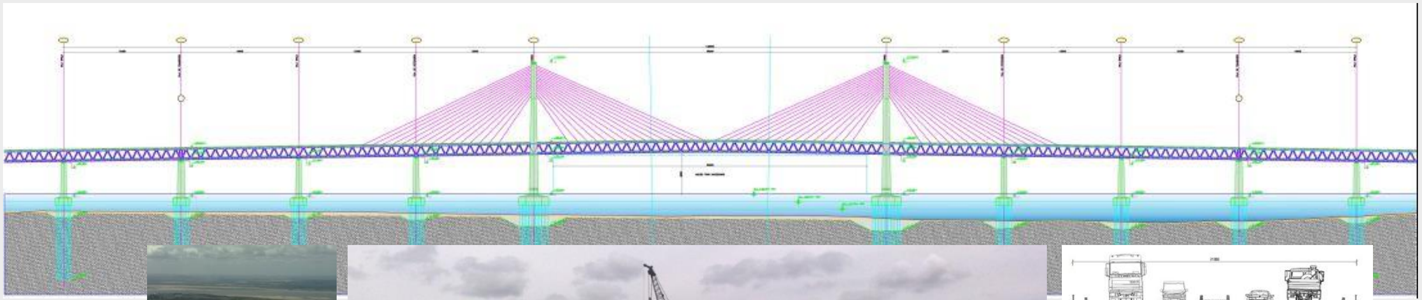
Harrer Ingenieure

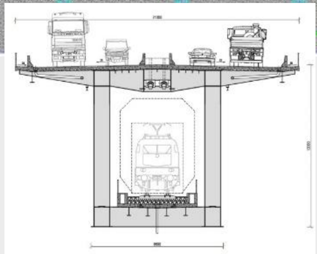
Civil engineering

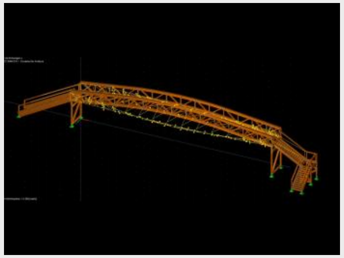
Vita, Presentation of our office

Harrer Ingenieure

Bridge construction, tunnelling, civil underground engineering





Structural Design, Verification and Execution of the Metropol Parasol in Seville Plaza de la Encarnación

Harrer Ingenieure

Architect Jürgen Mayer H., Berlin
won the design contest together with Arup, Berlin

Metropol Parasol in the Plaza de la Encarnación, Seville -

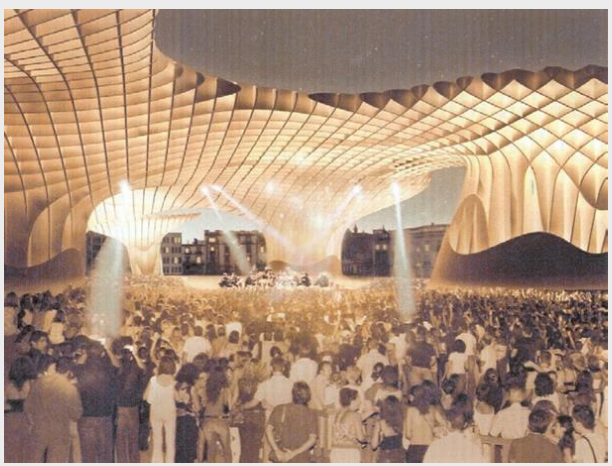
Introduction

6 interlocking trees = mushrooms = parasoles → Metropol Parasol

120 m long
width 45 m
26 m high

2007 – 2011
consulting Finnforest Merk Aichach
Design on the basis of EN 1995-1-1

cost
timber construction
ca. 15,0 Mio. €



Framework construction or lattice – consisting of LVL panels in an orthogonal grid measuring 1,50 m x 1,50 m

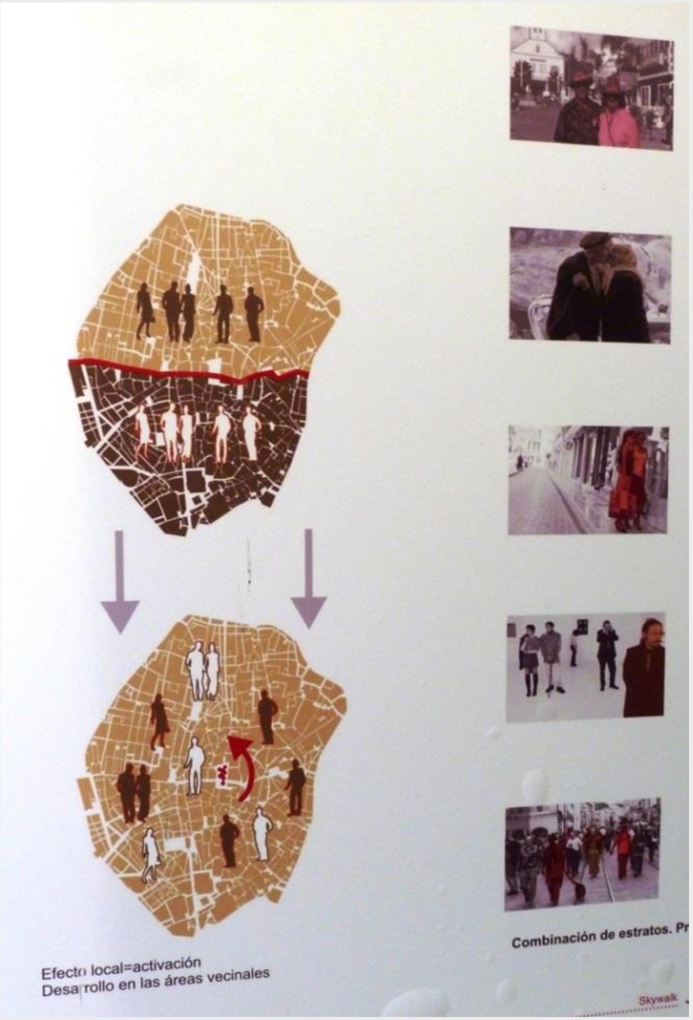
Metropol Parasol in the Plaza de la Encarnación, Seville - Introduction

Harrer Ingenieure

main street

Aerial photograph of the Metropol Parasol on the Plaza de la Encarnación, Seville

Metropol Parasol in the Plaza de la Encarnación, Seville - Introduction



City plan

Metropol Parasol in the Plaza de la Encarnación, Seville - Introduction

Excavations of Roman mosaics (underground)

Metropol Parasol in the Plaza de la Encarnación, Seville - Introduction

Harrer Ingenieure

Stair to the new square
(concrete slap);

shops and markets on street level

Metropol Parasol in the Plaza de la Encarnación, Seville - Introduction

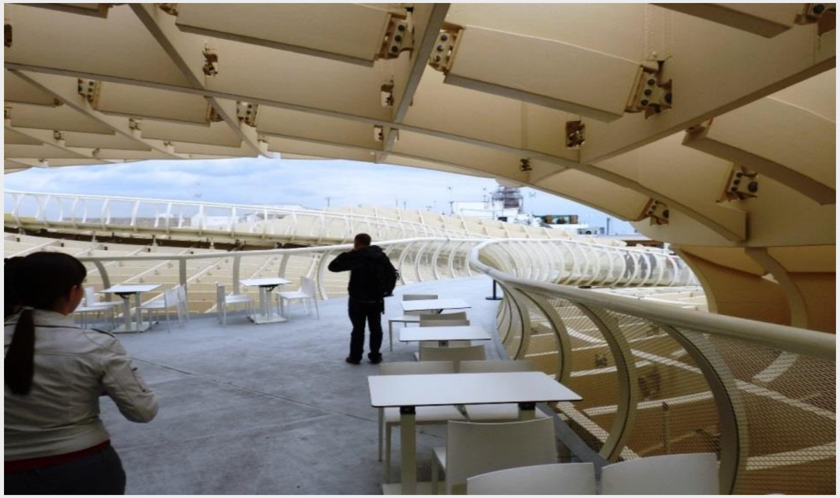
Harrer Ingenieure

Steel load-bearing platform
of the restaurant and cafe area

Steel structure
crossing the main street under traffic

Metropol Parasol in the Plaza de la Encarnación, Seville - Introduction

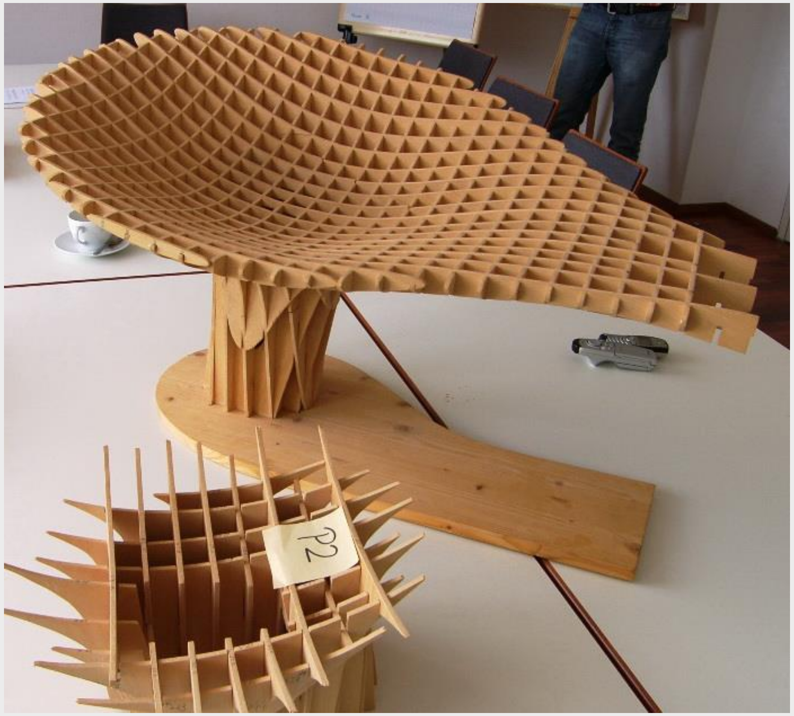
Harrer Ingenieure



Seashell design for restaurant and cafe; sidewalk

The timber-frame mushroom structure - Geometry

Harrer Ingenieure

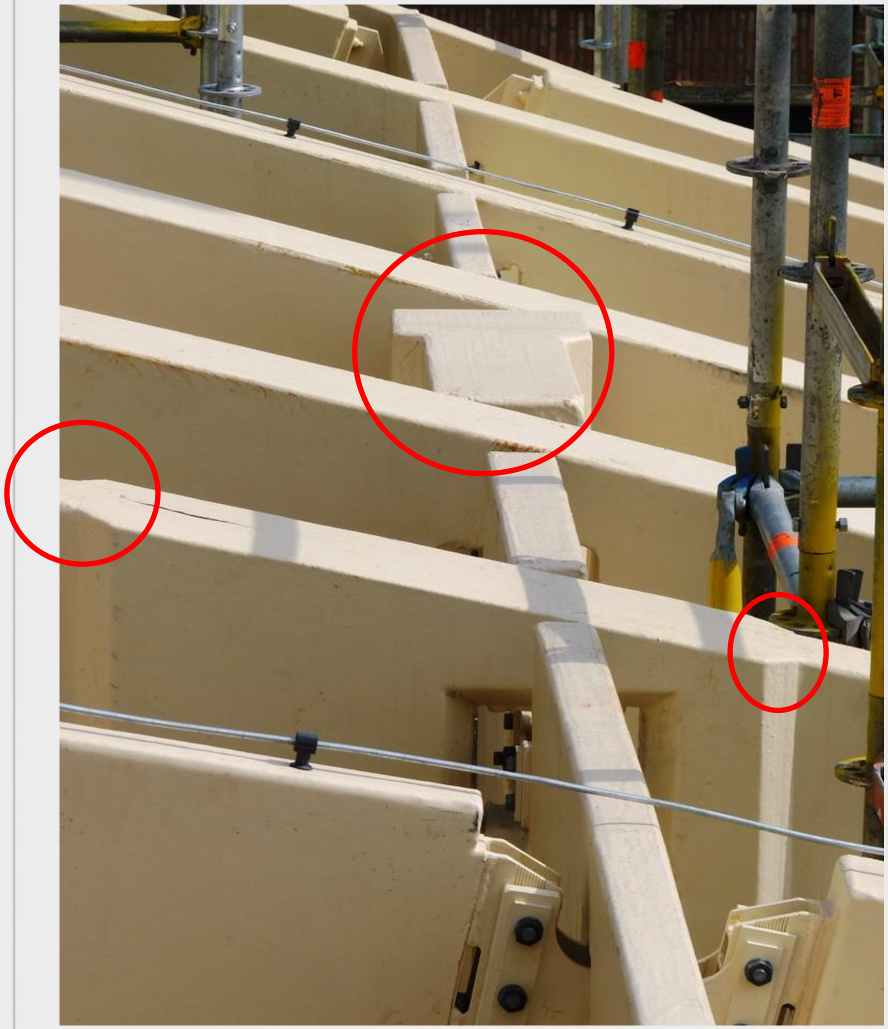


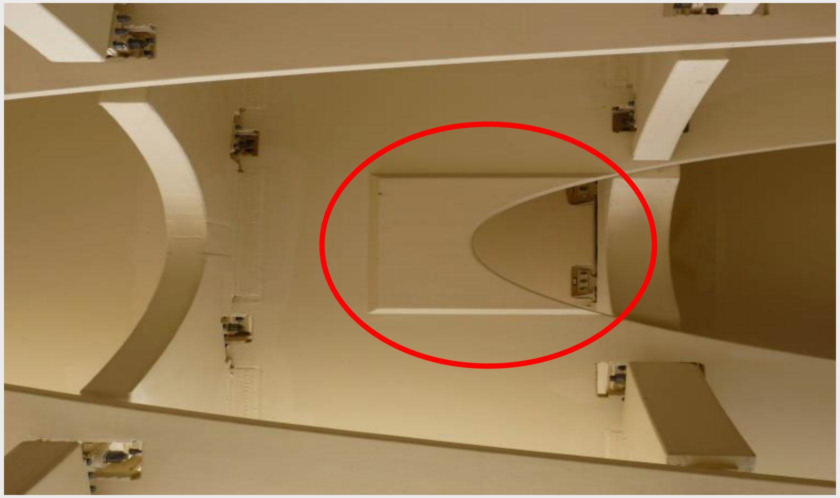
Parasoles / mushroom / Pilze

caps
elements between 1,50 m and 16,5 m long
widths between 68 mm and 311 mm
maximum depth of about 3 m
→ protection from sun

trunk
maximum diameter of 15 m
made from glued LVL (Kerto-Q)-panels with a minimum thickness of 140 mm
hollow on the inside allowing integration of the steel emergency steel staircase and reinforced concrete elevator shafts

Harrer Ingenieure





Different element widths / Widening of the web of the beam

Metropol Parasol in the Plaza de la Encarnación, Seville - The timber-frame mushroom structure - Geometry

Harrer Ingenieure

Component system of parasol caps

Metropol Parasol in the Plaza de la Encarnación, Seville - The timber-frame mushroom structure - Geometry

Harrer Ingenieure

3.400 elements

with a gross total volume of 3.500 m^3

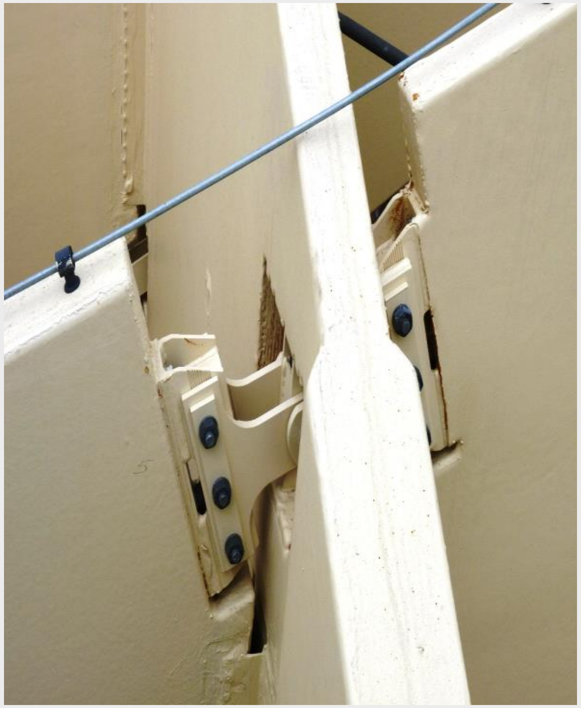
produced by Finnforest Merk in Aichach

> 3.000 connection nodes alone in the cap

The first natural frequencies
of the walkable roof shell
lie within the range of 1 to 2 Hz.

Metropol Parasol in the Plaza de la Encarnación, Seville – The frame structure - **Connections meet high standards**

Harrer Ingenieure



Completion of the timber elements

vacuum pressed elements, designed with reduced strength properties

Metropol Parasol in the Plaza de la Encarnación, Seville – The frame structure - Connections meet high standards

Connection 1:
Moment resisting connection
(11.000 pieces)

distributed over the top and bottom of the diaphragm elements
special, standardized connection with inhibited torsional rotation

can be closed quickly via a bolt during construction

The tabs are connected to the flange using a tooth-type interlocking with 3,5 mm separation and pre-tightened bolts type 10.9

Metropol Parasol in the Plaza de la Encarnación, Seville – The frame structure - Connections meet high standards

Harrer Ingenieure

In total 700 tons of steel

connection capacity:
N_{Rd}= - 1363 kN (compression)
N_{Rd}=   1251 kN (tension).

Detail: epoxy glued-in rods under normal workshop conditions

80°C – MPA Stuttgart (D)

The frame structure - Connections meet high standards

Harrer Ingenieure

Metropol Parasol in the Plaza de la Encarnación, Seville – The frame structure - Connections meet high standards

Harrer Ingenieure

Nailed steel angle
to transfer shear forces

Connection 3: Angled connector plate
with connection for diagonal bracing

Special features of design and verification

Harrer Ingenieure

Iterative calculation of internal forces

After all boundary conditions for the precalculation of the structure were determined, Finnforest was able to furnish a huge matrix that defined a connection type and the corresponding weight of the connection details for all angles of timber strut, any possible timber thickness, every grain angle and force-grain angles.
All other loads, such as the weight of the visitors, wind-loads, but also shrinkage and swelling of structural parts due to changes in temperature and moisture were determined by Arup essentially on the basis of EN 1991 and entered into the computer. Their three dimensional structural models provided the internal forces.
The load bearing capacity of timber beams was then prooved by Harrer Ingenieure for these calculated loads and their dimensions were increased as necessary. Connections with load bearing capacity that were too small were replaced with larger connections.

Component and detailed verifications

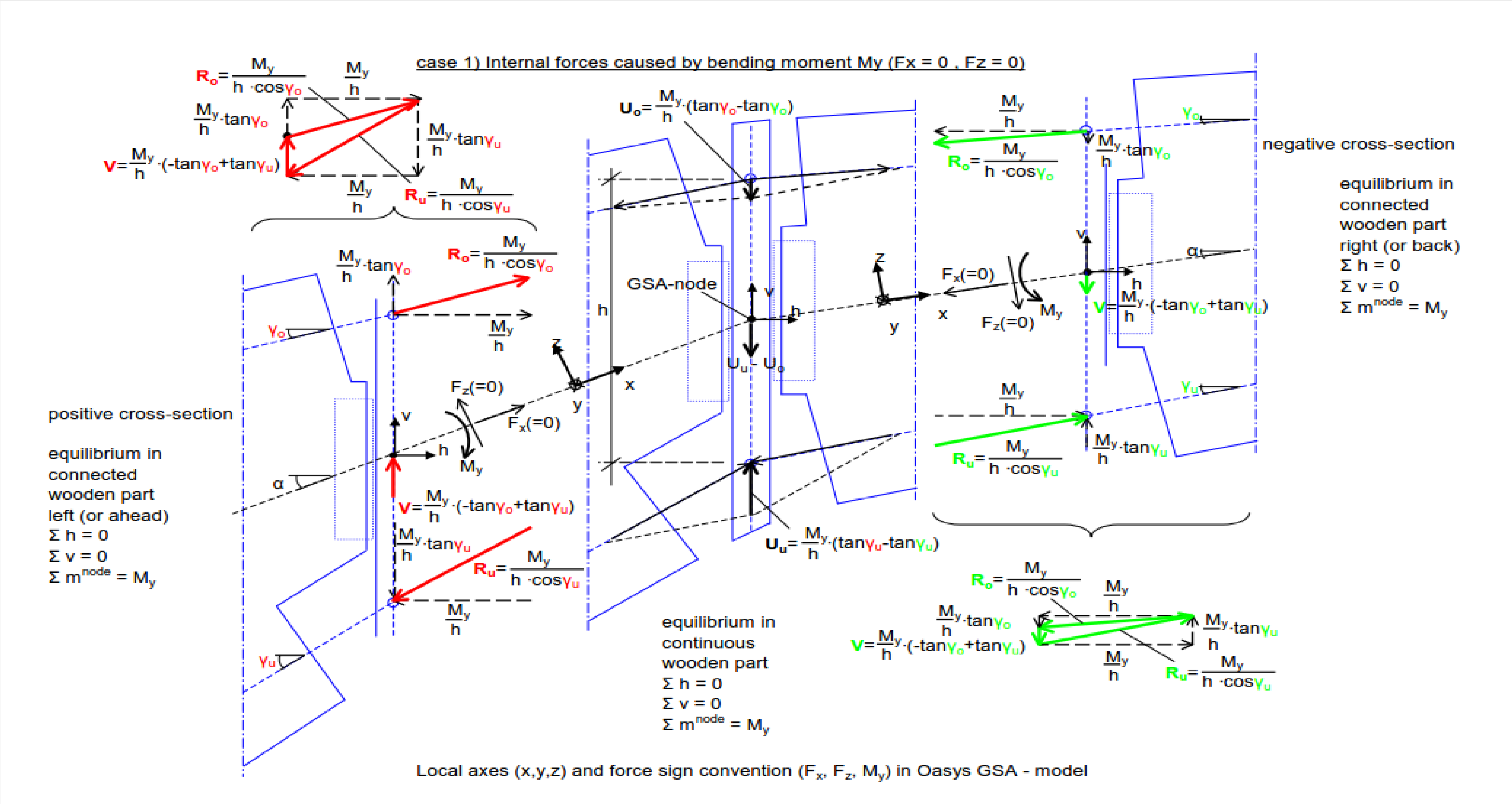
verification of the cross-sections and connections was performed largely by Harrer Ingenieure.
Due to the large number of elements and compounds, self-programmed evaluation routines were used for this purpose.

Basis of verification of engineered timber panels

design rules in accordance with the proposal of a study from TU Munich
KREUZINGER, H.; SCHOLZ, A. 1999 Nachweis in Grenzzuständen der Tragfähigkeit bei Platten und Scheiben aus Holz und Holzwerkstoffen unter Spannungskombinationen

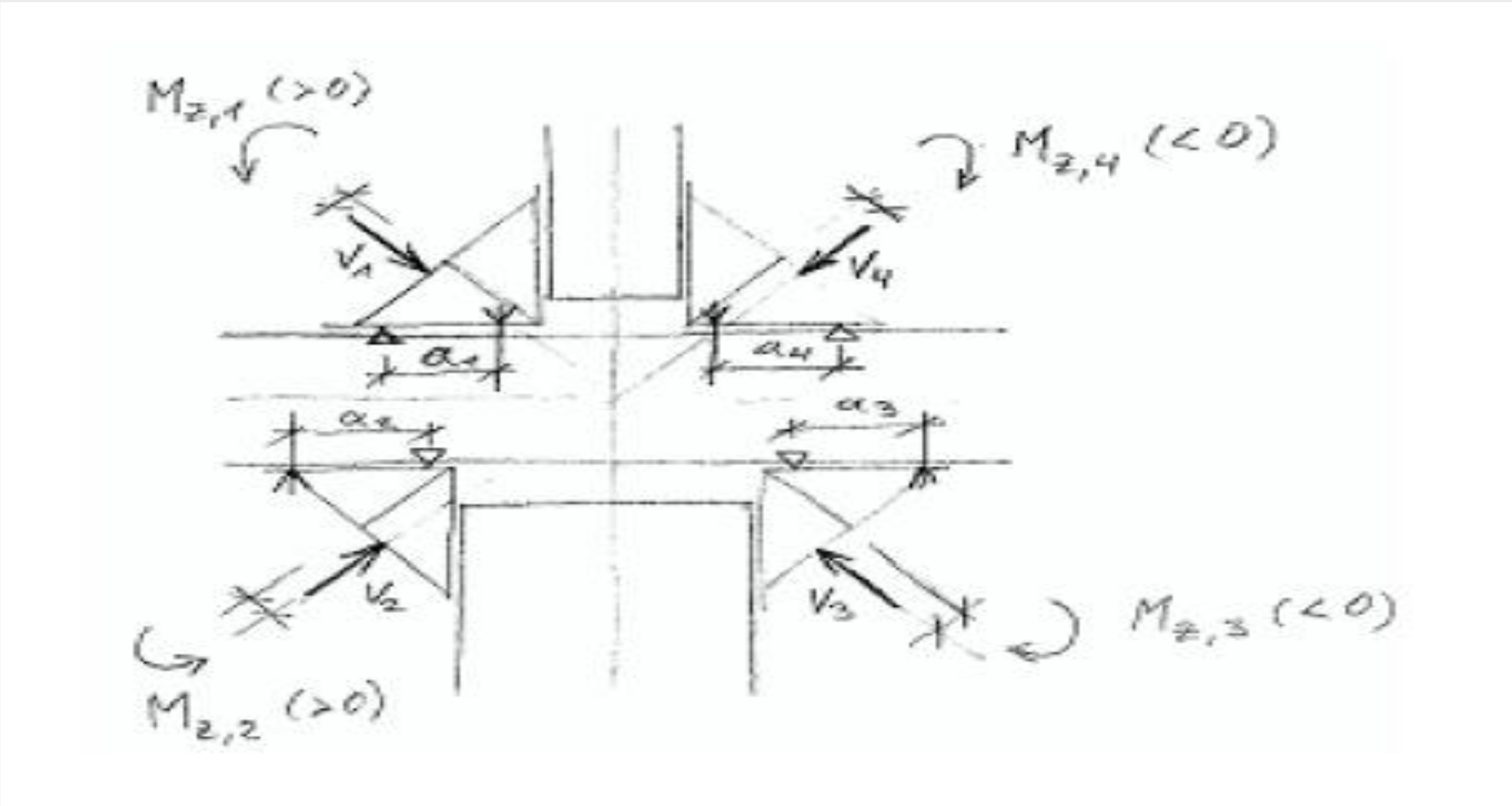
Design and verification of the caps

Harrer Ingenieure



View of a beam joint: resolution of forces for different connection types in the node (here: just moment for a strut and tie model)

Metropol Parasol in the Plaza de la Encarnación, Seville – Design and verification of the caps



Top view of girder: additional fittings of unsymmetrical diagonal connections

Harrer Ingenieure

Design and verification **of the trunks**

Interaction given by KREUZINGER, H.; SCHOLZ, A. 1999

$$\frac{\sigma_y}{f_y} \leq 1 \quad \text{and} \quad \frac{\sigma_x}{f_x} + \frac{\tau_{xy}}{f_{v,xy}} \leq 1 \qquad (1)$$

with

σ_y , σ_x Longitudinal stresses parallel and perpendicular to the grain from normal forces n_y, n_x in the panels and bending moments m_y, m_x

t_{xy} Shear stress from shear force n_{xy} and torsional moment m_{xy}

This verification is provided in detail for the calculation according to EN 1995-1-1 as follows

$$\frac{\frac{\gamma_F \cdot n_y}{d}}{f_{c,0,d}\ (f_{t,0,d})} + \frac{\frac{\gamma_F \cdot m_y}{d^2/6}}{f_{m,0,flat,d}} \leq 1 \qquad (1a)$$

and

$$\frac{\frac{\gamma_F \cdot n_x}{d}}{f_{c,90,edge,d}\ (f_{t,90,edge,d})} + \frac{\frac{\gamma_F \cdot m_x}{d^2/6}}{f_{m,90,flat,d}} + \frac{\frac{\gamma_F \cdot n_{xy}}{d} + \frac{\gamma_F \cdot m_{xy}}{0,3 \cdot d^2}}{f_{v,0,edge,d}} \leq 1 \qquad (1b)$$

The total design has to be made mainly in Spanish.

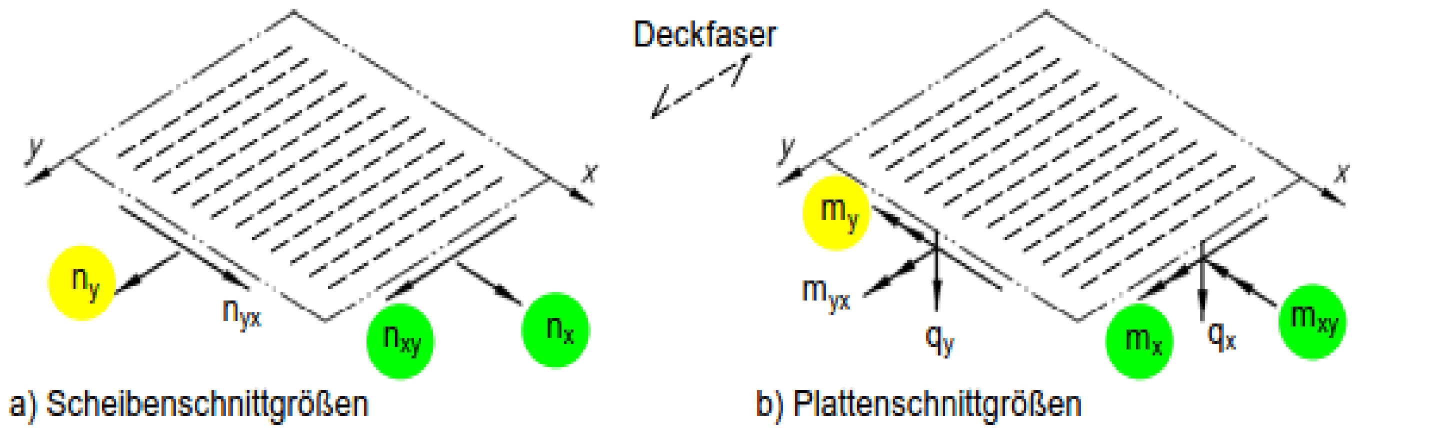
$$\frac{\frac{\gamma_F \cdot n_y}{d}}{f_{c,0,d}\;(f_{t,0,d})} + \frac{\frac{\gamma_F \cdot m_y}{d^2/6}}{f_{m,0,flat,d}} \le 1$$

(1a)

and

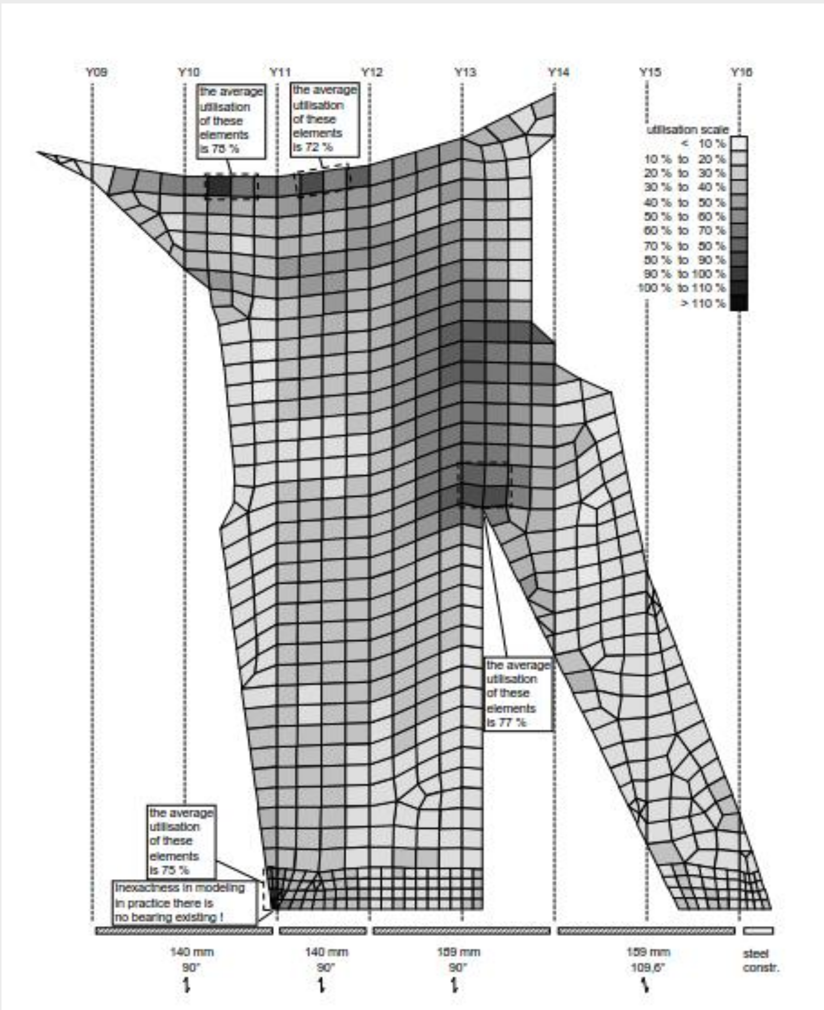
$$\frac{\frac{\gamma_F \cdot n_x}{d}}{f_{c,90,edge,d}\;(f_{t,90,edge,d})} + \frac{\frac{\gamma_F \cdot m_x}{d^2/6}}{f_{m,90,flat,d}} + \frac{\frac{\gamma_F \cdot n_{xy}}{d} + \frac{\gamma_F \cdot m_{xy}}{0,3 \cdot d^2}}{f_{v,0,edge,d}} \le 1$$

(1b)



Definition of internal forces of timber-based panels depending on the grain direction

Harrer Ingenieure



Strut and tie model (2 trunks)

Structure of the FEM
of a trunk panel (example)

trunk P5: 10.000 finite elements
with various maximum and minimum internal forces
in the middle of an element.

Both equations (1a) and (1b) needed to be performed and the results evaluated for all these
→ Harrer Ingenieure developed a computer program

Hints: Finite Element Modelling

Guidelines for a Finite Element Based Design of Timber Structures

Proposal: Technical Specification

These guidelines provide regulations for the application of numerical methods for the design of timber structures in ULS and SLS in daily engineering practice and expert engineering applications. Furthermore, guidelines for the use of numerical methods in product development and certification are given.

The guidelines are compiled in the light of the revision of the Eurocodes and the upcoming discussions about Finite Element based design in general and especially in timber construction. Their development is largely based on prEN 1993-1-14.

Contributions by:

Lea Buchholz
Alex Sixie Cao
Laszló Dunai
Matthias Gerold
Philippe Grönquist
Georg Hochreiner
Ulrike Kuhlmann
Bastian Kuhn
Julian Lukas
Sabrina Machanek
Pedro Palma
Michael Schweigler
Cristobal Tapia
Janusch Töpler
Eleni Toumpanaki
Luka Vojnovic

Harrer Ingenieure

Design and verification of the trunks and caps

2 to 3 mm thick sprayed-on Polyurethane-2K-coating with beige top coating (UV-protection)

→ Service class 2, Load duration „medium"

Verification by Boromir Radovic MPA Stuttgart (D)

Logistics and installation

about 50 trucks
from Aichach to Seville
with standard dimensions
+
50 special transports due
to oversize or high height

coating with polyurethane
in a temporary storage
facility in Seville

Installing the trunks

Metropol Parasol in the Plaza de la Encarnación, Seville - Logistics and installation

Harrer Ingenieure

Construction of the scaffolding for the cap assembly

Metropol Parasol in the Plaza de la Encarnación, Seville - Logistics and installation

Harrer Ingenieure

Connecting the timber beams

built between June 2008 and March 2011

on March 4, 2011
the last support was raised
in the presence of project partners and politicians

Metropol Parasol in the Plaza de la Encarnación, Seville - Logistics and installation

On March 4, 2011, the last support was raised in the presence of project partners and politicians

Summary: personal notes

commonly used in steel constructions
in timber constructions,
larger grid dimensions should be used
to reduce the number of steel connections

Lattice system

Hints: Durabilty, Maintenance, Inspection

Harrer Ingenieure

EN 1990:2022 valid for all materials

3.1.2.26
maintenance
set of activities performed during the service life of the structure so that it fulfils the requirements for reliability
Note 1 to entry: Activities to restore the structure after an accidental or seismic event are normally outside the scope of maintenance.

A.2.4 Durability
(1) All structural parts that rely on a design assumption of inspection or maintenance in order to satisfy their durability requirements over the design service life, shall be designed to permit inspection and maintenance.
NOTE 1 See 4.6 regarding durability requirements.
NOTE 2 Inspection and maintenance is needed of structural members designed using the damage tolerant method for fatigue. Material related guidance on damage tolerant method is given in relevant material Eurocodes.
NOTE 3 Maintenance activities can include: renewal of protective coatings; renewal of replaceable structural parts or elements other than structural; cleaning; treatment of detected fatigue cracks.
(2) Where inspection or maintenance of a structural part is not possible, the structural part shall be designed to achieve adequate durability over the design service life without inspection or maintenance.
NOTE See the other Eurocodes for measures to achieve adequate durability over the design service life without inspection or maintenance, which can include: provision of sacrificial material; protection of the part; use of materials with enhanced durability; control of the environment surrounding the part.

4.8 Quality management
(1) Appropriate quality management measures should be implemented to provide a structure that corresponds to the design requirements and assumptions.
(2) The following quality management measures should be implemented:
- organizational procedures in design, execution, use, and maintenance;
- controls at the stages of design, detailing, execution, use, and maintenance.

NOTE See Annex B and the other Eurocodes for guidance on appropriate quality management measures.

Metropol Parasol in the Plaza de la Encarnación, Seville – Hints: Durabilty, Maintenance, Inspection

Harrer Ingenieure

→ prEN 1995-2 give detailed information how to protect and maintain timber bridges, Annex D (informative) gives examples full page

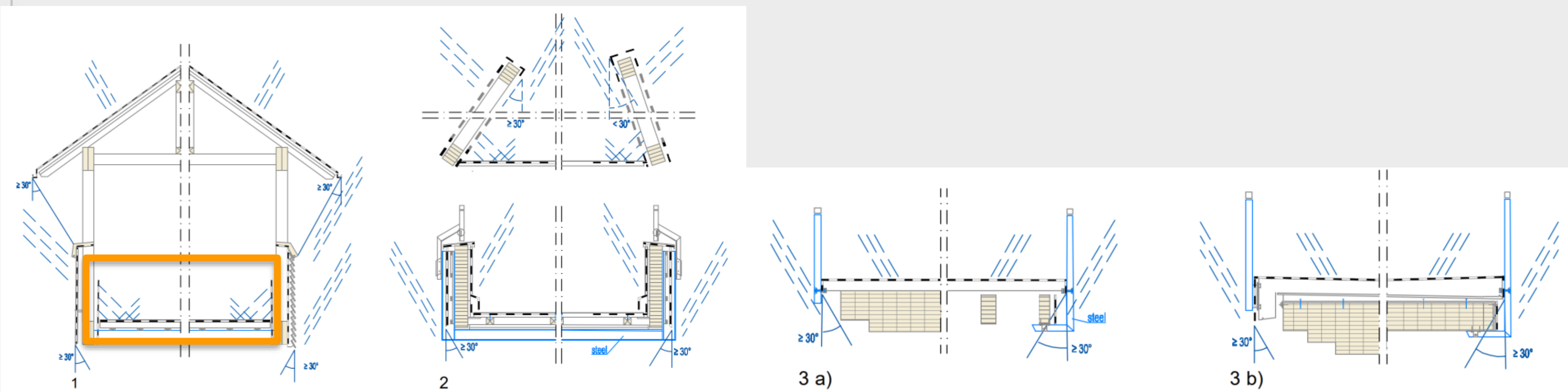
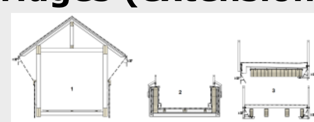


Figure D.1 - Examples of Protected timber bridges (extension of Figure 3.2):



1 Covered road bridge (with traffic inside)
2 Arch bridge (up) and Trough bridge (down)
with deck located at the base of the main bridge structure
3 Bridge with deck located above the main bridge structure; e.g.
a) sealing system
b) timber-concrete-composite

→ Detailing Annex D Possibilities
T- Pos 1
T- Pos 2

T- Pos 3, 4, 5

Annex B (informative) Inspection and Maintenance of Timber Bridges

Metropol Parasol in the Plaza de la Encarnación, Seville -

Summary: architectural and engineering highlight

Harrer
Ingenieure

Summary: thanks

Mr. Kunz of Finnforest Merk

Metropol Parasol in the Plaza de la Encarnación, Seville - Summary: thanks

Employees of Harrer Ingenieure

Metropol Parasol in the Plaza de la Encarnación, Seville - Summary: thanks

Harrer Ingenieure

Preliminary discussion, interpreting skills

Metropol Parasol in the Plaza de la Encarnación, Seville -

Summary: architectural highlight

Seville is definitively worth to visit Europe’s second largest cathedral

Summary: some more technical highlights

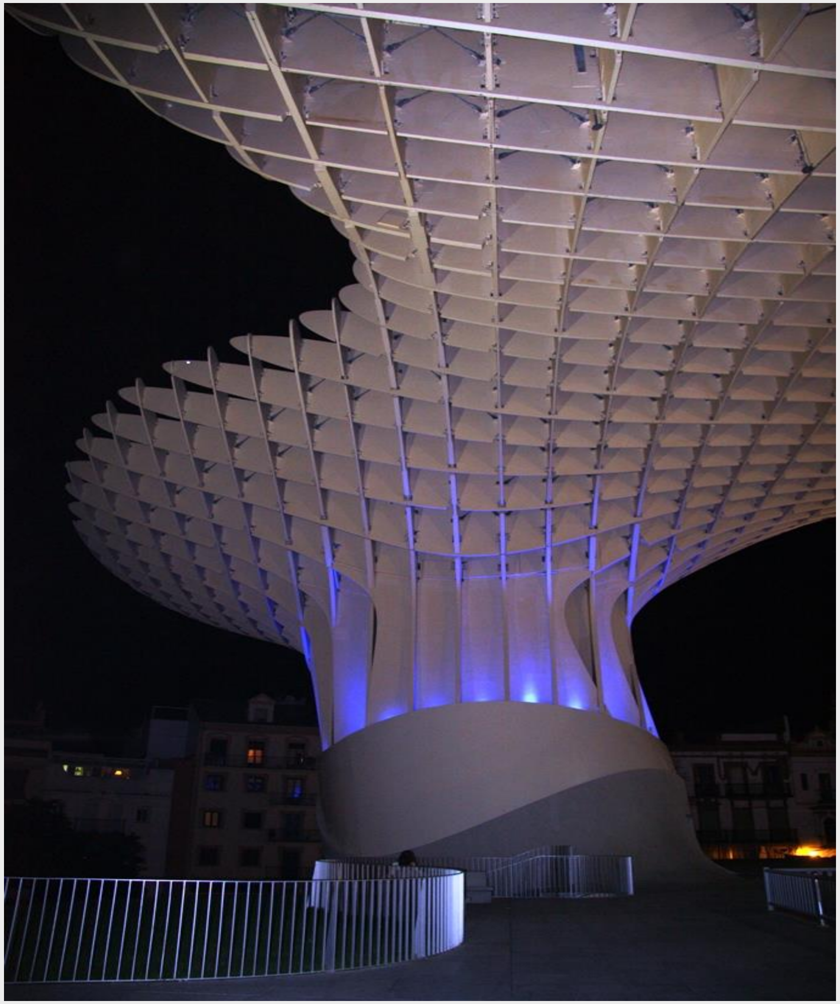
Calatrava's bridges

Harrer Ingenieure

Summary: personal highlight

Easter week, Seville

Summary: technical highlight



Thanks for beeing

one of the keynote speakers