

WIDE-SPAN LVL ROOF STRUCTURE FOR AN INDOOR SWIMMING POOL

Laurent Giampellegrini¹, Samuel Blumer², Hendrik Pfeffinger³

ABSTRACT: The wide-span roof structure for a new indoor swimming pool in Luxembourg was built as a prefabricated LVL ribbed slab system. The 23.75m span was achieved with π -elements consisting of slender (75mm) closely spaced and 1100mm deep webs. With the thickness-to-height ratio outside the standards and a structural behaviour close to the performance limits, the dimensional stability and torsional stiffness of the Kerto Q material was exploited to realise the desired filigree architectural appearance. Given the chloride-laden air of indoor swimming pools, metallic components were limited to a minimum to guarantee a durable and maintenance free structure. The bearing on the reinforced concrete substructure was developed in timber through widely notched supports in the girder webs, exploiting the tension capacity of the cross-layers in the LVL. The webs are connected to the roof plate via hot-dip galvanized dowels to maximise the corrosion resistance. The high and precise degree of prefabrication of the π -elements in transportable elements enabled a quick and efficient assembly on site.

KEYWORDS: Wide-span, LVL, ribbed slab, dimensional stability, corrosion

1 INTRODUCTION

As part of the redevelopment of a school in Luxembourg City, Cents, the campus was extended to include a sports centre as well as an indoor swimming pool. Embedded in the sloped topography, the school campus designed by Auer Weber Architects, Germany, Stuttgart, creates a new plaza for the local neighbourhood.



Figure 1: Exterior view of swimming hall within the school campus

2 STRUCTURAL SYSTEM

The timber roof structure covers the entire 36mx40m plan dimensions of the swimming hall. The indoor space is partitioned on axis 18', at roughly two thirds of its width, into the pool and the general facilities area. The structural

system of the roof follows this separation and consists of two simply supported spans: one over general facilities area and one over the indoor pool. Vertical supports for the roof are provided on an intermediary steel beam and concrete core wall on axis 18' and a concrete ring beam on the outer periphery. The concrete ring beam rests on regularly spaced slender concrete wall elements while the steel beam is supported on the concrete core walls and by additional intermediary steel columns. The lateral stability of the building is achieved through the concrete core and the peripheral concrete wall elements. The slabs of the timber roof are connected to form a diaphragm. On the short span, the roof diaphragm is interrupted to accommodate a skylight.

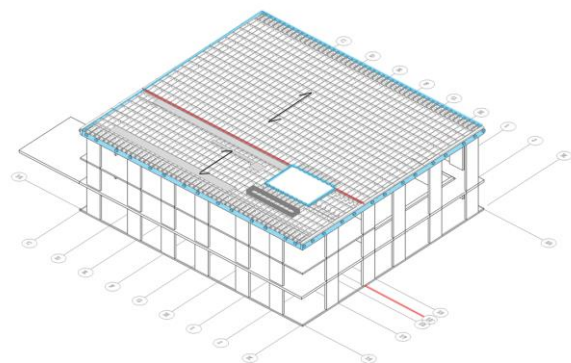


Figure 2: Axonometry of the indoor swimming hall (blue – concrete ring beam and core, red – steel support)

¹ Laurent Giampellegrini, PhD MSc DIC, Director ppa., knippershelbig, Germany, lg@knippershelbig.com

² Samuel Blumer, Dipl.-Ing. Dr.techn., sblumer, Austria, samuel.blumer@sblumer.com

³ Hendrik Pfeffinger, Dipl. Holzbau-Ing. (FH), Projektleitung, Holzbau Amann, Germany, h.pfeffinger@holzbau-amann.de

To achieve the architecturally desired uniform and seamless appearance of the entire roof, the structural elements spanning over the two partitions of the swimming hall roof consist of the same type of PI-Beam. The height, spacing and thickness of the ribs and plates is kept the same for both spans, although they differ significantly.

Spanning over a free length of 23.75m over the pool area, the prefabricated PI-Beams consist of a pair of slim ribs at 800mm centres with a height of 1100mm and a thickness of 75 millimetres. The ribs are structurally connected in shear to the top 69mm LVL slab by means of steel dowels. The choice for this type of connector was motivated by corrosion protection, a topic that is further elaborated in section 4 below. The production limits of the LVL Q-plates were exploited to a maximum and the webs and the top slab are both cut from one continuous plate element. The Q-panels were chosen for their high dimensional and torsional stability considering that the thickness-to-height ratio of the webs exceeds current standards. The webs are additionally restrained by 200m high transverse bulkheads spaced at 140cm centres along the length of the PI-Beam.

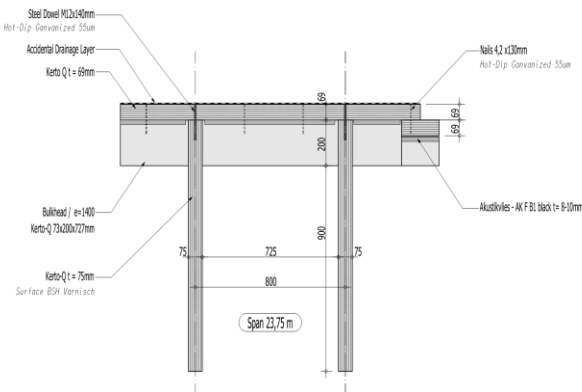


Figure 2: Section through LVL PI-Beams for the 23.75m span

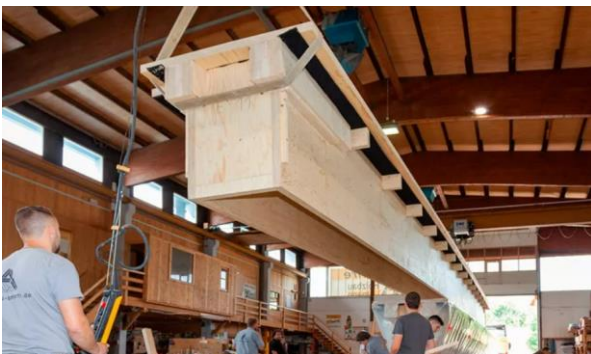


Figure 3 : Prefabricated PI-Beam in the workshop

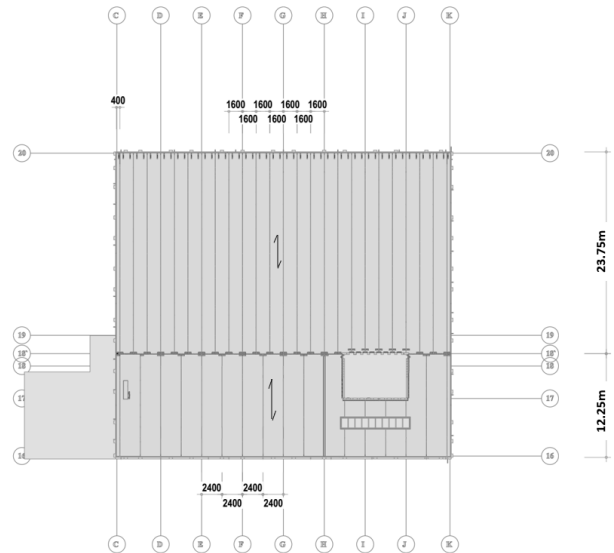


Figure 4: Plan view of roof

The LVL ribs are precambered which was achieved via CNC milling. The precamber was required on the one hand to avoid any visual sagging of the PI-Beams from the interior view and on the other, to secure the required slope of the roof for drainage. A different precamber was used at the top (180mm) and bottom (120mm) of the ribs.

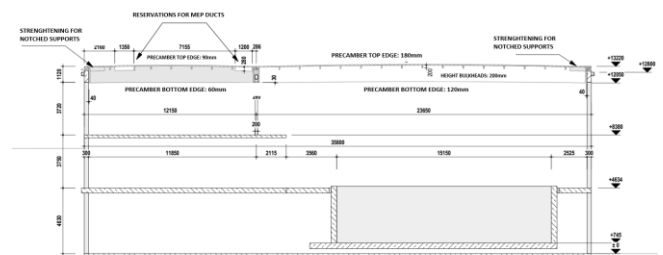


Figure 5: Section through swimming hall

The MEP ducts run in the direction of the span so that the number of reservations the roof structure could be kept to a minimum. The lateral distribution of the MEP fixtures was done in the smaller span where reservations were made at the top of the ribs. An acoustic ceiling with timber lamellas running in the transverse direction closes the space between the ribs. The PI-Beams were fully prefabricated in the shop including the accidental drainage layer to allow a fast and efficient assembly.

3 SPECIAL DETAILS

3.1 SUPPORTS

3.1.1 Introduction

To achieve the desired architectural appearance coupled with the ambition to minimise the use of metallic components, the support of the π -elements was realised with a deep notch that extends well beyond the usual half-depth limit the webs. Two main weak points are highlighted in the following figure:

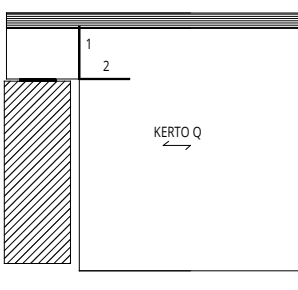


Figure 4: Support of the single span beam – Weak points

The notches reduces the shear capacity of the beam (1) and raises the risk of tensional failure (2). An alternative solution had been developed by the design engineers.

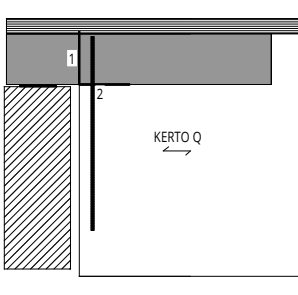


Figure 5: Thicker beam in upper part (1) and glued in rods (2).

For this solution, the supports were strengthened on either side of the webs (1) by glued-on LVL plates and strengthened with M14 glued-in rods (2) in the direct vicinity of the support. Additionally, the tensile strength of the cross-layers in the Kerto Q webs was exploited and at the top of the section, the diameter of the glued-in rods was increased via M22/M14 Rampa-sleeves to attain the necessary overall strength.

A verification method of the notch by a reduced shear capacity is ist given in Eurocode 5 [1].

$$\tau_d = \frac{1.5 \cdot V_d}{h_{notch} \cdot b_{notch}} \leq k_v \cdot f_{v,d} \quad (1)$$

Whereas k_v represents the reduction factor that takes into account the geometry of the notch (cf. Formula 6.62 in [1]) among others. The use of formula (1) has to fulfil geometrical parameters according to the Austrian national appendix of Eurocode 5 [3]. The height of the notch has to be bigger then half of the total height of the beam.

$$\frac{h_{notch}}{h_{beam}} \geq 0.5 \quad (2)$$

In our case, this geometrial requirement is not fulfilled. A finite element model of the entire beam and its support condition has been created.

3.1.2 Material and methods

One beam with a span of 23.5 [m] has been modelled with the commercial finite element software RFEM 5. The model consists of about 80'000 Triangular surface elements with a edge size of 2.5 [cm]. A detailed stress analyse has been performed on two different models. Model A (MA) consists of a thicker beam in the upper region without glued in rods. Model B (MB) has additionally been reinforced with glued in rods. The linear beam elements of the rods have been connected to the surface elements.

3.1.3 Results

The tension perpendicular to the fibre below the notch is represented in the following table.

Spec.	Reinforcement	σ_y [MPa]
MA	Thicker upper part	4.3 [MPa]
MB	Thicker upper part + rods	2.5 [MPa]

The stress distribution of Model B (MB) is represented in figure 6. The peak vertical stress is located directly below the thicker upper part of the beam. The thickening was pulled down a little on the front side.

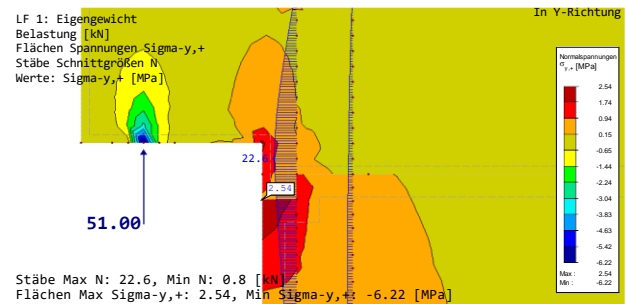


Figure 6: Traction perpendicular to the fibre $\sigma_y = 2.54$ [MPa]

Due to the higher resistance of Kerto Q, cracking can be prevented.

$$f_{t,90,edge,Rd} = \frac{k_{mod} \cdot f_{t,90,edge,Rk}}{\gamma_M} = 3 \text{ MPa} \quad (3)$$

Where $k_{mod} = 0.6$ is the reduction factor for permanent loading, $f_{t,90,edge,Rk} = 6$ MPa the tensile stress perpendicular to the grain according to the declaration of product of Kerto Q and $\gamma_M = 1.2$ the material safety factor for LVL timber defined [1] and [2]. The final solution presented in the following figure:

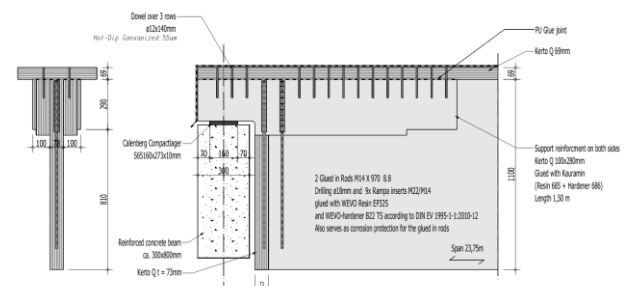


Figure 7: Final solution of the support

minimum specifications for material protection against corrosion can be taken according to DIN SPEC 1052-100 [4]. In DIN EN ISO 12944-2:1998-07 [7], swimming pools are classified under the category C4 which is a highly corrosive environment. Consequently, according to the DIN SPEC 1052-100 [4] a minimum average zinc coating of 55 μ m for screws, nails and steel plates is required. Although in the latter document, the corrosive environment is considered, no distinction is made between fasteners directly exposed to the atmosphere and those within and protected by the timber.

This distinction is made in [6], where the minimum requirements are given for corrosion protection for metallic fasteners in timber as a function of the equilibrium moisture content. The relevant table from [6] is reproduced below.

Table 2: Classes for corrosion resistant materials and zinc coatings for fasteners in the timber — Minimum requirements. Table 1 from [6]

Timber class	T1	T2	T3	T4	T5
Moisture content	$\omega < 10\%$ ^a	$10\% \leq \omega \leq 16\%$ ^a	$16 < \omega \leq 20\%$ ^a		Permanent $\omega > 20\%$
Treatment/acidity of timber	–	–	Untreated and pH > 4	Treated ^b or pH ≤ 4	–
Minimum zinc thickness on carbon steel	– ^c	10 μ m	20 μ m	55 μ m	n/a
Stainless steel grade	–	–	K2	K2 / K3 ^d	K3

^a Short periods with higher moisture content may be disregarded.
^b Treatment containing copper or salts (e.g. chlorides) and fire retardants that may influence corrosion rate.
^c The appearance may change without a protective coating.
^d Class of stainless steel depends on the type of treatment applied to the timber.

It can be seen that for a moisture content below 10%, no particular protection is required. This is very much in line with the conclusions of specialist approval [5] that was done for this project. In the latter study, it was concluded the low concentration of chloride aerosols that get into the atmosphere from the tap water operated swimming pool and deposit onto the timber surface would not pose any considerable corrosion risk for the fasteners embedded in the timber elements. This is due to the low humidity present in the timber (7-9%) on the one hand, and on the other, the phenolic resin used to glue the veneers in the LVL plate form an impenetrable barrier.

5 ASSEMBLY

To ensure a quick erection of the visible timber construction on site the contractor, Holzbau Amann, decided to preassemble the roof into elements in his workshop. To do so, the maximum width for transportation by truck and the maximum preassembly grade were to be considered.

The initial schedule arranged for preassembly of both type of elements, lengths 12,20m and 23,75m, to a width of 2,40m, each element consisting of 3 LVL beams. Due to production limitations with the supplier of the LVL boards from Finland it was not possible to manufacture the LVL boards thickness 69mm to 23,80m by 2,40m.

Hence the concerned roof elements were preassembled to 23,80m by 1,60m.

The fabrication of the roof elements in the contractor's workshop started by milling the LVL beams of 23,80m and 12,20m length on a CNC-machine. On the underside of each beam the precamber according to the results of the structural analysis was milled. Additionally, on top of each beam the roof pitch was milled by the CNC-machine, giving the roof its final shape.



Figure 8: Production of the π -elements in the factory

The threaded rods for the bracing of the supports were glued in the LVL beams in the workshop under controlled ambient conditions. Lateral stripes of LVL were glued to both sides of the beams to absorb the shear forces near the notches and slots.

Furthermore, a protective coating was applied to protect the wood from grime and effects of the weather during transportation and assembly.

Following the assembly of the beams to the LVL roof boards with dowels of hot-dip galvanized steel, 2 preassembled roof elements were loaded per truck. Each truck, moving from Southern Germany to the site in Luxembourg, was accompanied by an escort vehicle.



Figure 9: Two roof elements loaded on the truck

Arriving on site the preassembled roof elements, covered with sheet as a second protection, were lifted from the trucks and directly assembled to the concrete structure.



Figure 10: Delivery via a side street in Luxembourg



Figure 11: A prefabricated 23,80m roof element on the crane

To ensure the assembly of the timber roof without constraint forces, the contractor for the concrete structures had been preliminary advised of the required precision and the admissible tolerances of his works. The concrete works were verified by a surveyor, deflections were to be corrected by the concrete contractor. Thus, the timber roof was assembled quickly without any difficulties.



Figure 12: Assembly of the roof with individual LVL π -Panels

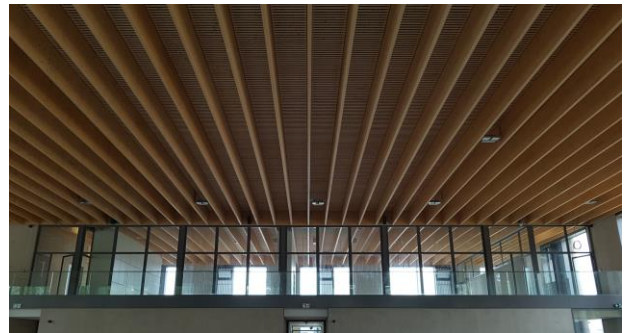
On one edge of the roof the LVL beams rest on the concrete ring wall, on the other edge on a flameproof coated steel profile. Above the steel profile, in between the LVL beams, LVL planks were installed vertically to realize the continuation of the fire cut below.

Once the timber roof installed, the connection in between the concrete columns on both edges and hence the bracing of the roof was ensured.



Figure 13: Support points

To protect the wood elements from the weather the waterproofing was installed in parallel to the assembly of the timber roof. Due to the milled pitch on the upper side of the LVL beams, the final roof pitch was in place right away.



The ensemble of air ducts and cable lines were projected in the design phase. Cutouts and slots to the LVL beams were realized in the workshop, making sure they were placed in structurally stress-free zones of the beams. Due to the detailed design the technical lots could project and perform their works safely.

The result is a sophisticated rib slabbed roof structure, milled and assembled in a quality close to joinery.



Figure 14: Roof underside with acoustic ceiling and LVL-Panels in visual quality

6 CONCLUSIONS

To meet architectural requirements and to provide a visually simple and durable structural design, various technical challenges had to be overcome and special solutions to be developed beyond the limits of the current regulations and standards. The solution developed exploits the material limits of the LVL panels and the details were designed with a minimum of metallic components given the stringent corrosion protection requirements. A high degree of prefabrication allowed for a fast and minimally disruptive assembly on site.

REFERENCES

- [1] Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings; German version EN 1995-1-1:2004 + AC:2006 + A1:2008.
- [2] National Annex Germany - Nationally determined parameters - Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings
- [3] National Annex Austria - Nationally determined parameters - Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings
- [4] DIN SPEC 1052-100:2013-08 Timber structures - Design of timber structures - Part 100: Minimum requirements for the materials or corrosion protection of fasteners
- [5] Specialist Approval: Corrosion of metallic timber screws for an indoor swimming pool in Luxembourg city, Prof. Dr.-Ing. Habil. Prof. H.C. Ulf Nürnberger, 10.10.2017, Stuttgart, Germany
- [6] Timber Structures – Dowel-Type Fasteners – requirements: German and English Version prEN 14592: 2017.
- [7] DIN EN ISO 12944-2:1998-07: Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 2: Classification of environments (ISO 12944-2:1998); German version EN ISO 12944-2:1998