MUMUTH – FREELY FORMED SPATIAL STRUCTURE

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Summary

The international competition for a new building for music and music education, initiated 1999 by the county of Styria/Austria, was won by the Dutch architectural office UNStudio (Ben van Berkel and Caroline Bros). The building is 72 m long, 23 m wide and 17 m high. It contains a concert- and theater hall, practice rooms, offices, technical rooms and the foyer. The central element of the foyer is the so-called "Twist", a freely formed spatial structure. The structural design during the competition phase was accompanied by British office of Ove Arup & Partners Ltd. The authors of this paper carried out the detail design during construction phase. The demanding architecture required the use of special methods and computer programs.

Keywords: Complex spatial structure, non-uniform-rational B-splines (NURBS), composite construction, formworks made by CNC mills, self compacting concrete (SCC)

1 Introduction

In 1999, the Dutch architectural office UN Studio (Ben van Berkel and Caroline Bros) together with the British structural design office Ove Arup won the competition for a new building for music and music education, initiated 1999 by the county of Styria/Austria (Fig. 1). For the construction stage, the structural design offices convex/Graber-Szyszkowitz ZT GmbH und Zenkner-Handel Consulting Engineers, both from Graz, were awarded with the detail design.

The 72 m long, 23 m wide and 17 m high building consists of three parts: the concert- and stage part, so-called „Theaterbox“; the office part and the foyer part with the rehearsal rooms (Fig. 2).

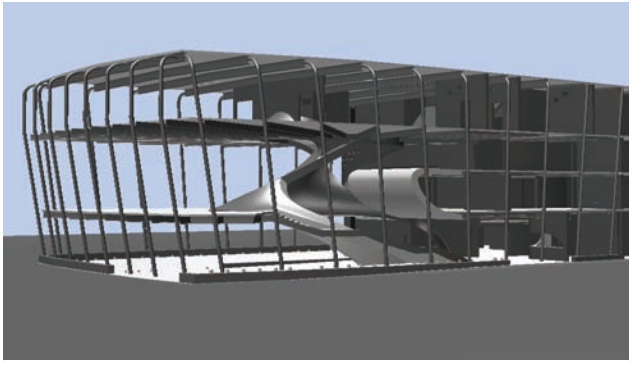

Fig. 1 The load bearing structure (Rendering: convex ZT GmbH)

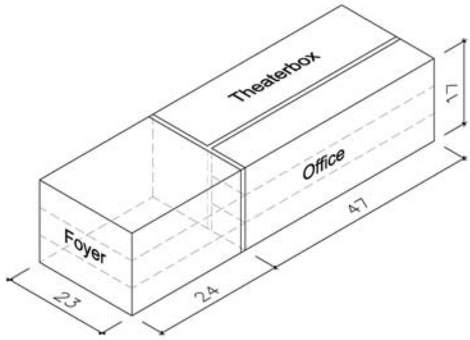

Fig. 2 Main dimensions and functions

2 Load bearing structure

The vertical load bearing structure of the Theatherbox and of the office part consists of reinforced concrete walls. The facade is supported by slender steel columns. The horizontal load bearing structures are the reinforced concrete slabs above the ground floor and the composite slabs with 17 m span above the Theaterbox and the upper storeys of the office part. The most difficult part of the load bearing structure is the foyer and rehearsal part with the freely formed spatial structure of the Twist.

The heterogeneous soil characteristics, the different foundation levels and the varying foundation loads required a piled foundation. 82 bored piles with a diameter of 90 cm and lengths between 7 m to 22 m were used. The piles are connected with tie beams (Fig. 3).

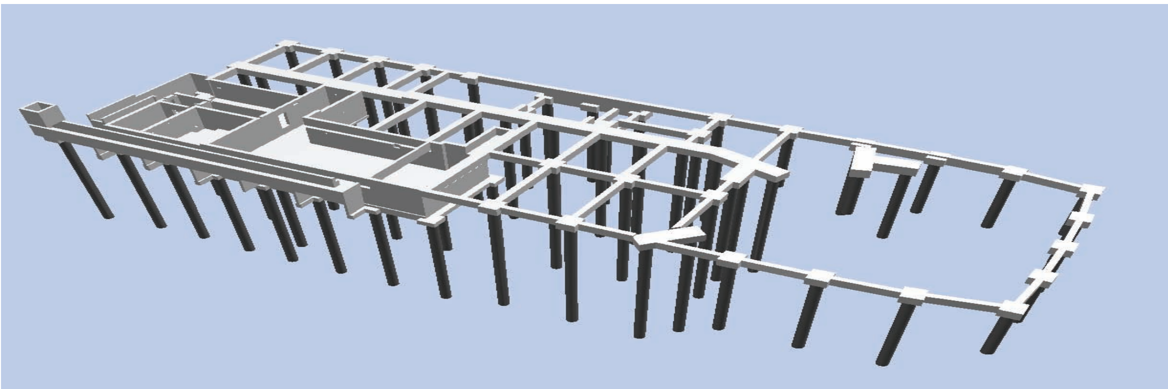

Fig. 3 Piled foundation and parts below ground (Rendering: convex ZT GmbH)

3 Twist

3.1 Basic concept

The basic concept behind the development of the structure of the Twist is described in detail in [1]. In the following, the realisation of this basic idea and the structural design model is explained.

3.2 Structural concept

The Twist connects the slab above the ground floor with the slab above the first and second upper storey. The slabs in the foyer area are composite slabs with radial running steel beams that are supported by the steel columns at the outer perimeter and the inner Twist. These loads and the self weight of the Twist are supported by the Stringer and the Theatertwist.

The primary load bearing structure of the Twist is a spatially curved steel truss made of steel pipes. The outer lying main pipes and the inner lying secondary steel pipes are connected with struts and diagonals like a truss (Fig. 5, 6). The upper opening of the Twist is embraced by a welded hollow square profile. To this flange, the radial running I-beams are connected by means of bolted connections. This complex steel structure is the inner core for the final composite construction of the Twist. The structural analyses for the entire construction were done by using spatial finite element programs.

It is to be noted that the original intention was to construct the Twist as a steel structure with spray concrete and later surface finishing. However, in order to achieve the architectural requirement of a fully smooth surface, the concept was later revised to the above described composite construction. In order to keep the original quantities of concrete, volume elements made of styrofoam were placed between the steel pipes (Fig. 8).

3.3 Tender for construction works

The entire Twist was tendered as a lump sum, being described in detail and visualised (Fig. 4).

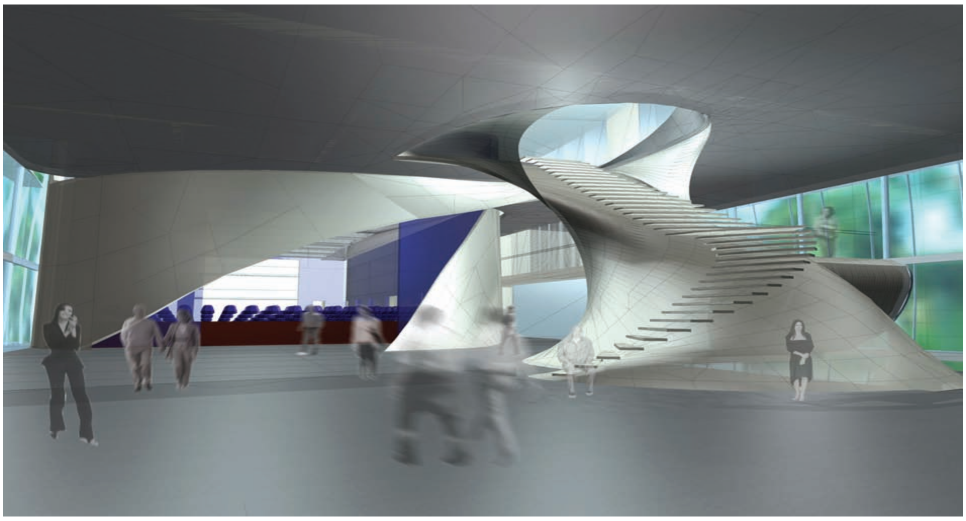

Fig. 4 Foyer and Twist (Rendering: UNStudio)

3.4 Detail design

The first step in detail design was the preparation of the guide design for the structural steelwork inside the Twist. The main challenge was the generation of the geometry of the steel pipes that would fit into the freely formed spatial structure of the Twist. The determination of geometry & dimensions was done in close cooperation with the architect (Fig. 5) and was later the basis for the workshop drawings of the steel structure (Fig. 6).

The determination of the concrete geometry was done jointly by the architect, the contractor providing the formwork and the detail designer, responsible for the additionally required reinforcement. One of the main difficulties was that either party was using a different software: the architect applying the software „Rhinoceros“, the contractor using company-specific software and the detail designer using the software „Allplan“. It became necessary to identify a common interface between the applied software.

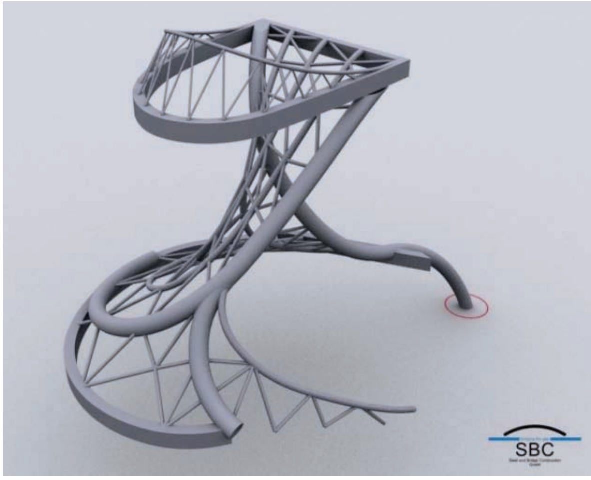

Fig. 5 The steel structure of the Twist (Rendering: SBC GmbH)

Fig. 6 Partially finished steel structure

In order to create the common interface, intermediate steps were required such that the geometry was correctly described, and the reinforcement drawings could be prepared. So, the Twist was sectioned in different parts (Fig. 7).

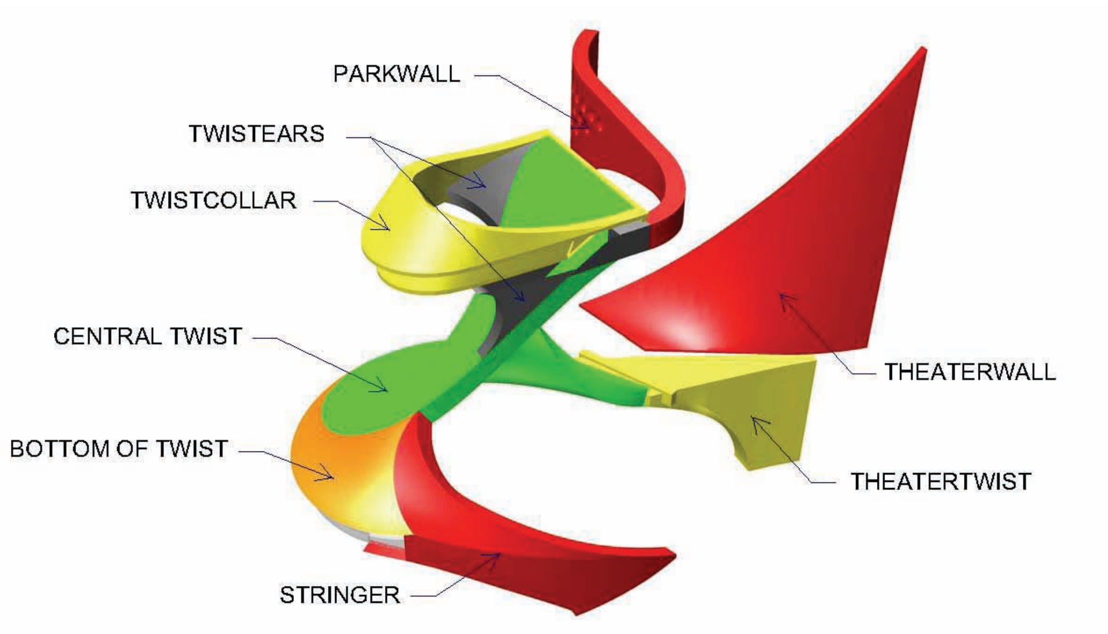

Fig. 7 Coding of the Twist sections (Rendering: convex ZT GmbH)

The exposition of the formwork and reinforcement for the Theatertwist and the Stringer was still possible in plan view and sections, however for the central twist, special ways of information transfer became necessary. Two layers of reinforcement bars with Ø 10 mm on each face were used. The warping of the reinforcement was effected like the in plan view projected warping of the already built steel structure. The third dimension was achieved by lifting the reinforcement in the correct position. The second layer of reinforcement consisted of straight bars that winded upwards along an imaginary axis (Fig. 8).

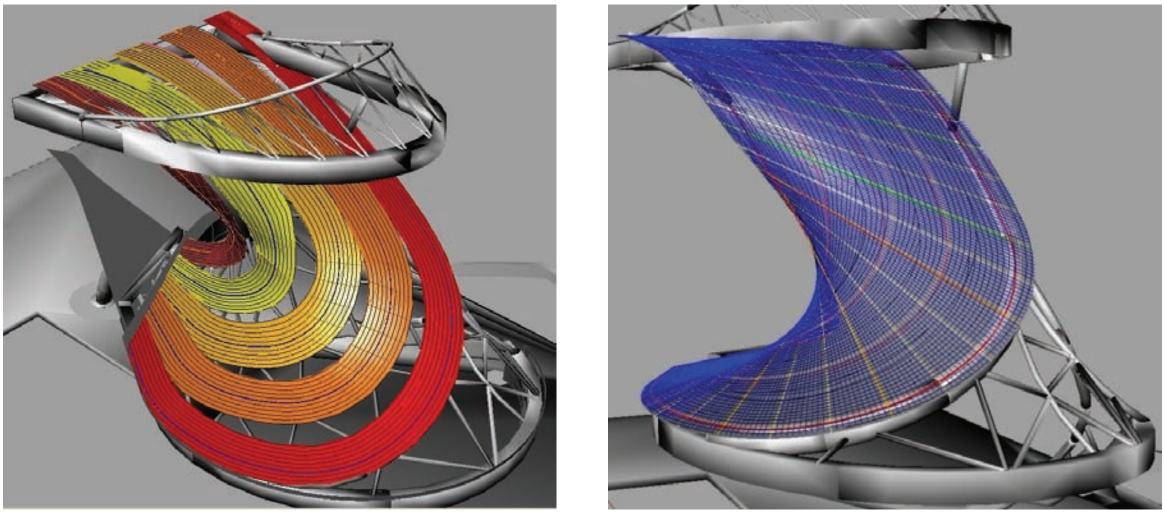

Fig. 8 Longitudinal and cross reinforcement (Rendering: convex ZT GmbH)

As an additional instruction for the placement of reinforcement, a non-dimensional sketch was prepared, indicating the diameter of the used reinforcement and its principal elevation with respect to the steel structure (Fig. 9). In order to reduce weight, styrofoam elements were placed between the reinforcement layers on top and bottom face.

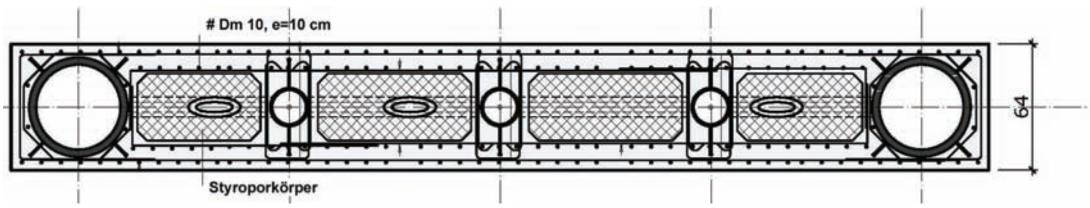

Fig. 9 Principal cross-section

3.5 Construction

The original idea of a timber formwork with trapezoidal fins with an easily deformable coating was soon discarded. Instead of, the formwork was made of digitally milled styrofoam elements (EPS W30) that were coated with seven layers of epoxy resin. In total, fifty such elements were produced.

For the placement of these formwork elements, a square supporting scaffolding was built around the Twist (Fig. 10). After placement of the top and bottom reinforcement (Fig. 11), the formwork elements were placed and propped against the supporting scaffold. The formwork elements were additionally fixed against horizontal and vertical loads during concreting by means of fifty pre-stressed GEWI-anchors with diameter 50 mm that were placed through the supporting structure.

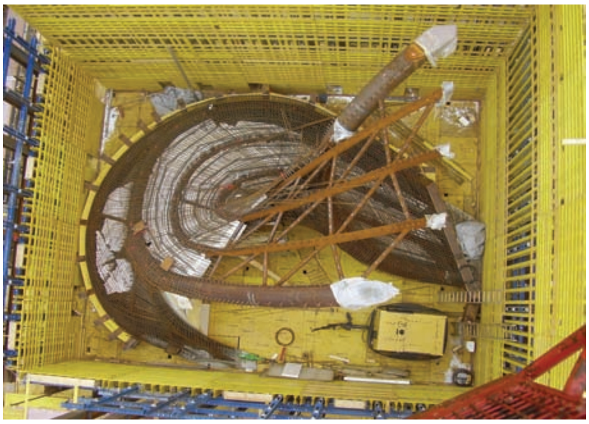

Fig. 10 Supporting scaffold, view from top

Fig. 11 Supporting scaffold, placing of reinforcement

A permanent digital calibration of the used 3-D models for steelwork, formwork and reinforcement were required during the design phase. During construction, daily surveys were made in order to achieve the necessary precision. Even the formwork elements were CNC-milled, corrections on site were required.

After concreting of the Theatertwist and the Stringers, the central Twist was concreted in three stages. The concreting was done by using self-compacting concrete, which was pressed in from diameter 125 mm openings just above bottom level of the Twist. The concrete used was a C35/45(56)/SCC/BS2/RS/GK16 with a water content of 190 l/m³. On site a super plasticiser with 12 kg/m³ was added. The concreting speed was about 3,5 m³/h. The cube strength after fifty-six days resulted in 70 N/mm². In total, 60 m³ concrete (equalling a total mass of 150 to) was used for the Twist (Fig. 12).

Fig. 12 The Twist after striking

4 Result

After closure of the sidewalls (the so called Parkwall and Theaterwall) in the second and third upper storey, the load bearing structure of the Twist was completed. The measured deformations of the Twist immediately after striking were around 30 mm. After six months, they marginally increased to 50 mm. The measured eigenfrequencies are within the allowable range.

The achieved bottom surface of the fairfaced concrete was satisfactory. Nearly no pores are visible. However, on the top surface, bigger pores are visible due to non-escaped air. Here, a remediation is required.

5 Conclusion

Such a demanding architecture resulted in higher design and construction costs. Highest skills in design and ultimate perfection in construction were the prerequisites for the achievement of such a structure. A total duration of twenty-nine months shall not surprise, considering the encountered difficulties. It was a rewarding experience for the structural designer with respect to the employment of innovative design and construction methods.

References

[1] Schmid, V., (2004): „Der Entwurf frei geformter Raumtragwerke am Beispiel des MUMUTH-Twist“, Bauingenieur, Band 79.

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