The Railway Station Stuttgart 21 – Computational Design and Digital Fabrication of Freeform Concrete Shells

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Abstract

As part of one of Germany biggest infrastructure projects in the 21^{st} century, a new railway underground station is currently under construction in the heart of Stuttgart. The station hall is 420m long, 80m wide and 15m high. The roof of the hall is a shell structure made of white concrete, which is supported by so-called chalices. The top of the chalices are open and are covered by filigree steel-glass constructions. The shape of the characteristic roof was designed by *Ingenhoven Architects* together with *Frei Otto* using soap skin and hanging models, which were converted afterwards into a compression load-bearing system. The freeform geometry combined with the high expected execution quality led to planning challenges that required the development of a number of highly sophisticated digital tools which are presented in the following paper.

The first part of this paper deals with the development of the interface between the geometrical model and the finite element model. The main challenge of the finite element modelling was to define the thickness of the shell since it varies across the whole length of the building. The same applied to the lower part of the chalices, which are modelled by beam elements with a varying cross-sectional geometry. In addition to the geometrical aspects, the definition of the reinforcement layer is complex. Therefore the entire preprocessing and parts of the postprocessing was not done in the environment of structural design software, but rather parametrically using the software Rhino3d. This had the advantage that all geometrical information was already available; with the aid of the plug-ins developed by the authors the finite element code could be generated in the Sofistik programming language.

The second part of the paper discusses the planning of the reinforcement. This included on the one hand the development of the digital workflow that was required for the structural design of such a construction; on the other hand it concerned the design principles that had to be considered for generating the rebars. These principles were derived from three essential aspects. The parametric generation of the individual rebar geometries took place in Rhino3d and formed the basis for later processing in Nemetschek. An associative modelling was used to provide an optimized process for generating all the reinforcement shop drawings. Besides the visual checks within the 3d model, clash detections and position checks for the rebars also took place with the help of specifically developed algorithms.

Using the parametric tools and the optimized digital workflow developed by the authors, more than 400 shop drawings and 11000 geometrically different rebars were generated for the construction of one chalice. In addition to the shop drawings, the digital information for the fabrication of the rebars was provided as code for the bending machine. This significantly reduced the work preparation of the contractor. The result of this planning process was a complete building information model (BIM) of the reinforcement with all the design information as well as all ducts and built-in components. The high precision of the reinforcement design being fully done in 3d ensured a smooth implementation from the placing of the reinforcement to the concreting process and the stripping of the formwork.