Boathouse

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GRUPPE B

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Subject and Task

In Summer 2018 the TUM Craft Race at the Starnberger lake takes place for the first time. The Lake with panoramic views of the Alps is a very popular destination and recreation area for the metropolitan region of Munich. The center for watersports of the ZHS(Zentraler Hochschulsport München) lies perfectly situated close to Starnberg at the north-west end of the lake. Besides activities like Sailing, Windsurfing, Stand-Up-Paddling and Slacklining there is a private lawn for sunbathing with access to the lake for swimming.

For the TUM Craft Race interdisciplinary teams from Product design and Sports should design and build their own boats and compete in a race. For this reason the ZHS wants to construct a new boathouse with workshop area to provide space for the students to design and test their prototypes.

Design Requirements

- Design a new boathouse and workshop
- about 6 parking spaces for boats of the type 470 „Jolle“ (refer to scheme below)
- maximum 200sqm workshop area, clearance height 10m
- the building(s) do not need to be next to the water. A carriage can be used to transport the boats
- the parking spaces should be sheltered however the driveway does not need a roof
- think about good integration within the existing context. Removing old buildings depending on your concept is possible
Subject and Task

Located 25 kilometres southwest of Munich, lake Starnberg is Germany’s fifth largest freshwater lake. It is a popular recreation area for the city. Because of its associations with the Wittelsbach royal family, the lake is also known as Fürstensee (Prince’s Lake). The climate of the rural district of Starnberg lies between the humid continental climate and the oceanic climate.

The site of the project, which belongs to the Property of ZHS(Zentraler Hochschulsport München), lies to the West of the lake, next to the Munich Yacht Club. To the West of the construction site is a small road called Untererseeweg and a railway for regional train and S7 of Munich, which is also the main transportation for the students from the city of Munich.
Concept Development

View of Starnbergsee

Workshop with large clear height and good nature light; Boatshed that can be outside; Office with 3m clear height

View from the main space of the building

Close combination of the different functions with different requirement
Concept Development

First Phase

Second Phase

Third Phase
Concept Development

First Phase

All functions were combined in a whole block. Concrete arcs were used to form the huge open space. In this stage, we expected a pure space without beams and columns.
Concept Development

Second Phase

Because of the large span of the workshop space, it is difficult to support the whole space without beams, which weakens the initial vision image. So we decided to accentuate the beam structure rather than getting rid of it. As a result, a lighter timber structure was used instead of concrete.
Concept Development

Third Phase

In this stage, we optimized the office and service functions to minimize the inner space, which reduced the volume of the building and shortened the inner circulation.
Site plan
Floor Plan

OG1, OG2 1:300
Section

Schnitt 2-2 1:300
Elevation
Elevation
Structure Concept

After the architectural model is set up the structural model can be developed. The structural system consists of primary beams, secondary beams, shear walls and columns. The primary beams are made of timber, while the secondary beams, shear walls and columns are made of reinforced concrete. The concrete grade varies between C25/30 – C35/45 for the different structural elements. For the glulam beams the grade GL 24 C is used.
Structure Concept

Vertical Loads

The vertical load transfer starts with the primary beams, which transfer the loads of the roof to their supports. These supports are shear walls and secondary reinforced concrete beams. While the shear walls are continuous to the foundation, the secondary beams are supported by columns and shear walls, as well. From these walls the applied loads are transferred to the foundation.

Basically, the structural system of the boathouse can be divided into two parts, into the workshop area and into the garage. These two parts have different structural systems. However, both systems interact with each other in order to transfer lateral forces to the ground.

The primary timber beams (12 cm x 50 cm) of the workshop area are supported by an outer wall (t=30 cm), inner wall (t=25 cm), secondary reinforced concrete beam (25 cm x 60 cm) and have a cantilever at the end. Between the support of the inner wall and the first secondary beam is a large span of 10 m. In order to minimize the deflection at the middle of the span a big cross section is needed. The two spans in the garage are 7 m. The cross-section of the timber beams in this part is also (12 cm x 50 cm). The size of the columns for supporting the secondary beams (d=30 cm) is everywhere the same, because of the large clear height a bigger diameter is chosen in order to avoid buckling. Since the secondary beam in the garage is supported by three columns, the cross section of the beam can be reduced to 25 cm x 50 cm.
Structure Concept

Horizontal loads

The horizontal loads are transferred to the foundations by the shear walls, which have fixed support conditions at the bottom. For the horizontal loads both building parts interact with each other. This means the lateral loads are not only transferred to the foundation by the wall, where the wind loads are applied but also by other shear walls e.g. inner walls. Wind forces are also transferred by beams to shear walls.
Structure Concept

Design loads

The loads, which are applied, are dead, wind, snow and live loads. The dead load of the roof is estimated to 2 kN/m^2. The site is located at 584 m above sea level and the maximum height of the building is 13 m. According to DIN EN 1991-1-4/NA the site is in the wind zone 2 and in the snow zone 2. After the calculations of the wind loads, a wind pressure on the building of 0.64 kN/m^2 was applied. For the uplift, which is caused by the wind a mean value of 1.1 kN/m^2 was applied. The value for the snow load on the roof is calculated to 1.58 kN/m^2. For the live load on the floors category C is chosen from DIN EN 1991-1-1/NA, Tab. 6.1 DE. Therefore 3 kN/m^2 as live load are applied on the floor slabs.
Applying the loads

In order to apply the dead load from the roof the automatic load distribution is used, so the loads can be applied on the plane of the primary beams. The snow load is applied as line load on the primary beams because Sofistik does not accept two area loads from the automatic load distribution which overlap. If the two automatic distributed loads overlap then Sofistik applies the forces with more than 100%, which leads to wrong results.

The live loads of the floor slabs are applied via dependent area loads. The wind loads are also applied as area loads on the walls. However, line loads are used for applying the wind loads of the glass façade to the shear walls which are connected directly to the glass façade. For the self-weight the glass façade is self-supporting by the vertical cross bars, which transfer these loads to the foundations.
Analytic Model

First Problems with the models

At the beginning a few problems with the modelling occurred because the analytic model did not fit to the architectural model. The problem was that the support conditions of the middle support of the primary beams were neither recognized by Revit nor Sofistik. The problem was first solved by changing the architectural model. Which had the results, that the architectural model did not match the reality anymore. After a consultation with staff members from Sofistik this problem could be solved by using projections to move the analytic lines of the different structural elements to the right position.

Another problem which occurred was that for the roof a slab was modelled in order to apply distributed loads on the roof. The result of this was that the structural system did not follow anymore the system which was chosen earlier. The slab did not transfer the loads to the primary beams anymore but transferred it directly to the secondary beams and the shear walls. This lead to high moments in the slab and in the secondary beams. It also made the primary beams useless. That it is why the roof slab was taken out again of the analytic model.
The decisive load case is the combination $1.35 \ G_k + 1.5 \ S_k + 1.5 \ Q_k + 1.5 \times 0.6 \ W$. The uplift of the wind is neglected in this case because it acts advantageous for the structure in this combination.
Structure Analysis

For checking the deflection of the structure the following load cases are used: \( w\_{\text{inst}} = 1.00 \, G_k + 1.0 \, S_k + 0.7 \, Q_k + 0.6 \, W \) and \( w\_{\text{qs}} = 1.00 \, G_k + 0 \, S_k + 0.6 \, Q_k + 0 \, W \). The maximum deflection is calculated with \( w\_{\text{fin}} = w\_{\text{inst}} + w\_{(\text{creep})} \)
\( w\_{\text{creep}} = k\_{\text{def}} \, w\_{\text{qs}} \). The value for \( k\_{\text{def}} \) is 0.6 for laminated timber. This leads to a maximum deflection of 32.0 mm at the lever arm of the primary beams in the workshop area. The allowed deflection is \( w\_{\text{fin}} = l/100 \). (Schneider Bautabellen: Holzbau 9.15). Therefore the allowed deflection is 40 mm, which means the design criteria is met.
Validation of results

For checking the calculations from Sofistik, some elements were also calculated with other programs in order to validate the results. The bending diagram of the timber beams were checked with Stab2d a software for calculating reaction forces on beams. The bending diagrams from Stab2d are very similar to the results from Sofistik. As simplification in Stab2d the different stiffness conditions of the supports is neglected, which leads to small differences in the values. Nevertheless, it can be assumed that the calculations are correct and the structural model works like it was expected.

Furthermore, a design check for the timber beams was carried out with RSTAB, because Sofistik does not do design checks for timber elements. The result of this design check was a stress ratio of 0.33, which means that the timber beams have the same stress ratio as the concrete parts.
The collaboration and tasks of each role was predefined in a process management map. It was created to show the next steps in the BIM process and to show the progress in the project. It was also used to show the data transfers between the different design disciplines. The collaboration process was separated into three stages. Each phase had to be terminated before moving to the next phase. Due to unforeseen errors and problems, as well as changes in the original design of the building which occurred during the design process, the time schedule had to be adjusted. To enforce the schedule and see the progress in the group, weekly meetings were arranged at the beginning of the project.

Phase 1: Design concept
In the first phase of the building process an analyzation of the building requirements and the building site was done. According to the result of this evaluation a building design was created and discussed. The structural requirements and possibilities for structural elements and materials were discussed in the group. To guarantee a smooth collaboration process and a structured schedule a process map was created to ensure an organised workflow.

Phase 2: Design development
After the first rough design a 3D-model was created to view the geometry. With the help of this visualisation it was possible to determine possible weaknesses in the original design for aspects of construction and structural requirements. During this phase a continuous changing and optimization of the project was done. The structural engineer could create a first structural model by transferring the data of the 3D-model to SOFISTIK. The architectural model was checked by Solibri for geometry clashes as well as modelling errors. A first quantity takeoff was created using RIB-iTWO.

Phase 3: Final design
In the final design phase, the main objective was to optimize the started developments. The structural analysis was completed and the results and additional structural requirements were implemented in the architectural model. The final checks and quantity takeoff were created and the results checked for plausibility.

Actual occurred schedule
Due to various errors and inexperience in the programs used a lot of time had to be invested searching for errors and possibilities to create and modify the architectural and structural models.
Collaboration with Building Information Modelling

Predefined process management map
Solibri Model checking clashes

Check 1

To avoid errors and too many design changes in a later stage of the project, a model check was done shortly after the first architectural model in Revit. This was also done before the export to Sofistik to ensure that no errors or wrong geometries were transferred and work has to be done twice. The clashes in the model after the first collision check were minor and most could be ignored because they were intentionally created e.g. calculation geometry for the quantity take off. One real collision that was detected was the overlapping of floors and walls and also the walls ran through more than one storey. These errors were easily fixed by the architect.

Check 2

After the structural calculations many of the wall thicknesses and loadbearing elements changed, which is why another Solibri check was done, to ensure no new clashes were added. As no new errors were detected, the model could be transferred to RIB-iTwo and no revision of the geometry had to be done.
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Problems

Collaboration problems

One General collaboration and data exchange problem was working on one Revit file, as the architectural and the structural model were designed in one shared Revit file. For data exchange a cloud system was used to upload project files so that the team could view these. Unfortunately, there were difficulties with the file names, so that confusion occurred which files were the latest. Also occasionally older versions of the file were overwritten and the previous file deleted. This was a problem as it sometimes happened that small changes in the model by the architect caused various errors for the structural model which had to be solved. As the copying of elements from the previous working model was not possible anymore a large amount of work had to be done to repair the structural calculation model.

Quantity take-off

To make a summary of the amounts of building materials the software RIB-iTwo was chosen. The data exchange worked using CPI-files exported by Revit. The elements could be sorted into groups with the help of dynamic groups. This way all objects could be defined using the attributes given in Revit.

Problems with RIB iTwo

After the initial successful transfer of the 3D-data to RIB with only minor errors, the refreshing of the model with new data information caused more problems. The main hindrance was that by refreshing the model information the geometries were changed, but the old existing data was not deleted, thus creating two buildings in each other. As later realised the error occurred due to wrong usage of the software due to inexperience. Unfortunately, there were also no tutorial videos or guides that could be used for the specific problem. Another problem was that for some few elements the quantity, surface or volume could not be calculated, the solution was to get the quantity volume and area directly from Revit.