Boathouse ZHS – Digital Design Method BIM

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GROUP O
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Boathouse ZHS

ZHS Munich is the central provider of sport activities for students and co-workers of the universities in Munich. ZHS is an acronym of the German words “Zentraler Hochschulsport”. Some of the highlights of the sport program of ZHS are the water sport courses, the most popular are among others: sailing, windsurfing and Stand-Up-Paddling. Within the course program, there is not only the possibility to exercise, but also the opportunity of building and crafting original prototypes of sport vehicles and testing them. The ZHS water sport is located on the Lake Starnberger See, southwest of Munich.

In summer 2018 the first TUM Craft Race at Starnberger See is intended as a highlight event in the water sport program of ZHS. A new boathouse is designed for not only this race but also for bigger range of sport activities, specially sailing.

Subject and Task
The ZHS boathouse should be designed within the course “Building Information Modelling (BIM)” using Revit 2017 combined with other design and simulation programs by teams of three members. The boathouse includes a workshop hall of about 200 square meter providing space for designing and testing of prototypes. The location of the boathouse should be near to the water, which is very practical with respect to the roofed parking place for boats.

At the Starnberger See, there is a huge and open space provided by the ZHS, so the location and design of the boathouse is free selectable. On the other hand, the location and design should be suited to the neighbourhood. On the ground of the ZHS there is space for sunbathing and other activities like swimming or other freetime activities. This area should not be effected by the boathouse. It is also to consider, that the boathouse should be easily reachable from the entrance and car parking space, in particular when boats are brought by cars to the boathouse.

The main challenge is the teamwork between architects and engineers providing the idea like in an actual design process. The application of digital design method should reduce time and work during the design and the project progress. The collaboration is required at very early phase and should therefore reduce clashes or even changes during and after the execution.

Figure 1 Starnberger See [bayregio-starnberger-see.de]
Digital Design Method BIM

Within the course “Building Information Modelling (BIM)” at TUM the suggested design method is digital in order to provide a possible exchange between the different softwares, which are provided by TUM. This project group will be using “Revit 2017” for modelling, “Sofistik” for structural engineering, “Solibri Model Checker” for model checking and “RIB iTwo” for quantity Takeoff. The main emphasis of this BIM course is the teamwork between architect and the engineers during the design, in particular the integration of changes from different team members around just one model and one design. Applications of the digital design method BIM should facilitate this integration of changes and coordination of different parties. Provided by Autodesk, the platform A360 is used for saving the only one central Revit Project-file. Every team member can work separately in the same or different time with only one model, so all changes can be considered by all team members. Revit 2017 provides possibilities for comments and communication for all changes or clash. From this, local project files can be exported into Sofistik for structural engineering calculation, into RIB iTwo for quantity take-off and into Solibri for model checking using different kind of exchange date formats, e.g. IFC.

Figure 2 BIM [deltalight.com]
Architectural Concept

Location
The chosen site for the construction is the north-east corner of the assigned lot, direct on the shore, currently already holding a small dock. The aim of the project consists in enlarging the existing structure while ensuring easy access with the car to the dock for further transportation of boats on-road. The direct connection of the Boathouse to the dock ensures easy parking and handling of the boat into the building. Furthermore, holding the position of the existing building, avoids negative effecting on the existing area dedicated to sunbathing and sport activities. Because an already built site has been selected, the mentioned existing building is to be demolished.

Space subdivision
The designed boathouse of group O contains four main areas: The workshop, the roofed parking facility for six Jolla boats facing the dock, the bar-restaurant with a terrace on the roof of the parking facility, the back of the building hosts the services on the ground floor, a small office for ZHS and a room hosting lecture, and computers on the first floor and a technical room and as well as an archive in the attic.

Workshop hall
The space dedicated to workshop is designed for direct access from the water. With a length of about 12m 2 boats can be placed with enough safety distance from each other. This allows the construction as well as the repairing of two boats at the same time. Right and left there is working space with a width of about 4m on each side. The distance between columns in this room is 6m, therefore the boats can be handled easily and the moving possibilities inside the workshop are multiple. The working platform for the boats is designed with a height of 10m so that the mast can be laid on during all the phases of the construction. Although the parking house is located directly between the dock and the workshop, after considering the frequency with which transferring operations need to be performed between the two rooms, no internal direct connection is planned, this reduces the internal traffic surface to maximize the quality of the working space.
The parking facility
In front of the boathouse, facing directly the water, a parking facility capable of hosting up to 6 boats is planned. Specifically the design of the internal space was created with respect to the type measurement and transportability of the boat type 470 “Jolle”. On the top of its roof a terrace offering a panoramic view on the Starnberger See is planned. During the sailing events like the TUM race it offers a unique observation point to the odiens. The terrace is reachable in three different ways: from the bar through an internal staircase, from the back part of the building through an internal staircase and an elevator and from the garden on the south through an external staircase. The use of the roof of the parking facility as terrace makes it the perfect place to enjoy the race on the water in summer 2018.

Roof
The roof is specially designed to work the best with the room below it in that area. The north side is highly angled to reach the height of 10m and allowing the handling of the boat with the mast mounted during construction, prototyping and repairing. At the same time the angle of the north wing of the roof ensure through big glass portions that only diffused light from north can enter the working space, this ensure a comfortable natural light for manual work. On the other hand, the portion of the roof above the bar presents small and repetitive windows, which distribute the intense light south as equally as possible in the big room.
Figure 6: North East view of the building concept

Figure 7: South West view of the building concept

Figure 8: Rendering, View from the terrace on the sailing race
Process management

Business Process Model and Notation (BPMN)
For the realization of a well structured Process during the design of the building, it is mandatory to create a concept of the different process, workflow and design steps. As mentioned in the lecture of the BIM course, we used for this concept a Business Process Model and Notation (BPMN) model. This model shows in a graphical computational modelling language all kind of activities and workflows necessary to create a building, such as the boathouse. After connecting all dependent workflows, it is easy to see the necessary exchange material, e. g. information- and model data, between the steps in order to have an uninterrupted flow. This model is also divided by the different participating actors during the design process, so you can see, who is responsible for several tasks and who needs to provide information or data for the next step.

The first sketch created at the end of November just contained roughly described workflow objects in order to get an overview over the whole process with its single workflow steps, relationships and possible durations. It starts with a researching process to the first BPMN workflow, in which the responsibilities are assigned. After that, the different actors will start their work in their professions and interact and exchange their data between each other until specific time steps, where the model will get evaluated for the further process. With a good evaluation, drop down application will start and the processes will finish in a final evaluation and presentation. Parallel to all these processes, every step is documented to keep track of all workflows and all changes made during the whole process for the final report. The model was created with a free online browser tool called “BIC Design Free WebEdition”. Out of this sketch, also a time schedule was created.
Figure 9: First Sketch of BPMN model

Figure 10: Time schedule
The next step in the design of the Process management model was to bring in more details, like specific activities in the workflow objects and the necessary exchange data, which is given in an extra lane at the bottom of the model. So, the final BPMN model looks like following figure.

Figure 11: Final Sketch of the BPMN model
Changes of the design during the project progress

The Process of the project started on the 27th of October with a brainstorming session and the assigning of the responsibilities. For the upcoming meeting, research about existing boathouses, the boat type and boat transport possibilities was done and sketches about the boathouse design were drawn. At the beginning of November, the sketches for the design were collected and a final design concept was chosen. The boathouse should have a mast high workshop and parking spaces, in form of one big cubical garage faced towards the waterside, both easily accessible from and towards the water. On top of the garages will be a terrace for relaxing and views over the lake. The main building should have a skeleton structure mainly made out of wood and a tent shaped roof made of glass. The building should also provide space for changing, management and lecture rooms and a bar / restaurant with an included show area for the prototypes. To start the modelling process, the site and the integration into the neighbourhood was checked and determined. For the upcoming presentation, further sketches and site plans were drawn, a structural concept and ideas were collected and process management maps and schedules were designed.

After the first presentation on the 17th of November, the modelling of the building started with Revit 2017. There were several struggles with the planned design at the beginning. Some of them were caused by the lack of knowledge about the modelling program and others by incomplete capabilities of the software, but most of them could be solved after the consultation of a tutor and some could be avoided by changing the design. E. g. the slightly tilted roof of the

Figure 12: First Sketches of Site plan and building
boathouse could not be shaped as one in Revit, therefore we separated the roof in different parts. This design was again replaced, because there was no possibility in Revit to create a roof made out of glass. With the first attempt of exporting the Revit data to Sofistik on the 19\textsuperscript{th} of November, there were also struggles referring to unrecognized materials or limited parameter recognition abilities of the two different softwares. The first structural design contained a skeleton structure made mainly out of wood, but Sofistik is not able to calculate the structural behaviour of wood, because of its dependency of the moisture content and other complex structural properties. So the skeleton material was changed to steel. Also the combination of loads could not be done in Revit itself, but could be solved in Sofistik.

\[\text{Figure 13: First digital model variant and first simulation attempts}\]

One big impact on the design had the evaluation of the traffic areas and the further involvement of the tractory curves of the boats on the 24\textsuperscript{th} of November.
The garage was stretched from a kind of cubical building into a longer building, also the height of it was reduced, because it was not needed. This also resulted in changing the slope of the roof and the width of the assigned bar / Restaurant area. The beams inside of the workshop were also shifted, so there is enough space to move and work around the boats.

These architectural changes led to recalculations within Sofistik and problems in the structural model, which needed to and could mainly be corrected in the architectural model in Revit around the 8th of December. For example, the stability of the two columns in the western part of the building were proofed as not sufficient. Our solution was changing these columns from steel to reinforced concrete to increase the stability. For the second presentation, the first drop down application and attempt with RIB iTwo started in order to get an overview of the program and some rough numbers for the Quantity Take Off (QTO). The Export into RIB iTwo worked fine with the CPIXML format, so there were no struggles in creating definition groups and a first QTO bill.

After the second presentation on the 15th of December and some advices from the lecturers, changes in the structural concept contained some reductions of the dimension of loadbearing structures, which were underutilised before. Because of that, the number of columns in the Workshop could also be reduced, so there will be more space around the boats. After this steps, a final ground plan of the model was found and had only some minor changes afterwards. Therefore a long period with iterative optimization steps of every concept started between the actors. Every change in one concept led to minor changes in the other concept, which was the trigger point for starting the collaboration on the cloud based server A360 on 22nd of December. With A 360, all changes were directly synchronized with the central model, which allowed us to work simultaneously on different parts of the model.
After that, within the exchange processes between the architectural and the structural concepts, also the drop down applications with the solibri model checker and RIB iTWO for the quantity take off started at the 5th of January 2018. As final steps, all actors tried to get the maximum optimization out of their own specialized concept with respect to all other participants, progresses and the whole project itself until we reached the final state of our model for the submission.

*Figure 15: South-East view on the final digital model for the submission*
Structural Concept

A skeleton structure was chosen to achieve a light construction and as many space as possible for the interior architecture. In the workshop, bar area and the garages in the front, all columns are made of steel. Because of the maximum height in the workshop area, the columns in this area were chosen with bigger cross section of the steel I-profile I400 to achieve high stability, other columns are designed with I300. To provide more space for moving boats in the workshop area a distance of 6m between the columns was chosen. Exceptions are the two highest columns made of reinforced concrete with a cross section of 25x25 cm in the building at the back due to the bigger span width of this area. This part of the building at the back is designed with three storeys for different uses, floor slabs are made of reinforced concrete with a thickness of 15cm, which are supported by reinforced concrete beams (25 x 50 cm) and columns.

Roof structure system
To make the roof terrace above the garages accessible, a load bearing roof made of reinforced concrete with a thickness of 15cm is chosen. The roof slab is supported by reinforced concrete beams underneath (25 x 50 cm) which divert loads to the steel columns. In the remaining areas the roof system is designed with the roofing supported by steel beams (HEA 260). To avoid the torsional buckling of the steel beams at the roof level, many secondary steel beams designed with a cross section of a pipe RO60.3x4 are set between those primary beams (HEA 260).

Building shell and the facade
The exterior and partition walls are made of reinforced concrete with a thickness of 20cm. They support not only the roof structure system, but also increase the stiffness of the whole building, in particular against the wind load. To enable a wide scope for the façade design in the bar area and the boathouse, columns are set at these sides instead of exterior wall. All reinforced concrete elements except the foundations are designed with a concrete strength class of C25/30.

Foundation system
An individual foundation system made of steel reinforced concrete with a strength class of C30/37 for columns and walls is designed. The individual foundation of the smaller columns (I 300) is designed with dimensions of 30/30/50 cm, the bigger columns (I400) with 60/60/50 cm and the strip foundation of the walls with 80/50 cm. The assumption of a sustainable underground will be investigated before the execution.
Analytic Model

Next to the self-weight of the structures considered automatically by SOFISTIK the dead loads of the roof and the floor covering are estimated for each area according to the European Design Code (Eurocode) DIN EN 1991-1 (EC1-1).

Dead load of

<table>
<thead>
<tr>
<th>Area</th>
<th>Live load</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof in workshop hall and bar area</td>
<td>0,10</td>
<td>kN/m²</td>
</tr>
<tr>
<td>Roof of the building at the back</td>
<td>0,30</td>
<td>kN/m²</td>
</tr>
<tr>
<td>Roof covering of the boathouse</td>
<td>1,5</td>
<td>kN/m²</td>
</tr>
<tr>
<td>Floor in the building at the back</td>
<td>0,60</td>
<td>kN/m²</td>
</tr>
</tbody>
</table>

The live load for each areas is estimated according to different categories of the Eurocode EC1-1:

<table>
<thead>
<tr>
<th>Area</th>
<th>Category</th>
<th>Live load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof terrace (boathouse)</td>
<td>Z</td>
<td>4,0 kN/m²</td>
</tr>
<tr>
<td>Floors (WC and changing room)</td>
<td>A2</td>
<td>1,5 kN/m² + 1,2 kN/m² (partition walls) = 2,7 kN/m²</td>
</tr>
<tr>
<td>1st floor (Bar area)</td>
<td>C1</td>
<td>3,0 kN/m²</td>
</tr>
<tr>
<td>1st floor (Workshop area)</td>
<td>E2.1</td>
<td>7,5 kN/m²</td>
</tr>
<tr>
<td>1st floor (boathouse)</td>
<td>E1.2</td>
<td>6,0 kN/m²</td>
</tr>
</tbody>
</table>

The boathouse locates in snow zone 2 and wind zone 2. The decisive snow load is 1,60 kN/m² for the flat roof and roof parts with small slopes. While the wind loads on the roof are very small or even transform to suction loads, and therefore can be neglected, the wind loads of 0,64 kN/m² on the walls and columns is estimated and put into the model.

The area loads on the roofs are estimated as line loads and applied on the load bearing constructions, as there was no possibility to put them on the sloped area of the roof.
During the first exports of the analytic model to SOFISTIK, wrong connections between some nodes were recognized at the view of deformation in SOFISTIK. Hence those connections in the analytic model in Revit needed to be repaired. During the first calculations there were errors due to the torsional buckling of the primary beams at the roof level. This challenge could only be solved by adding secondary beams. Afterwards there was recognized that no material for the steel reinforcement exported from Revit into SOFISTIK. Hence this material needed to be added later within SSD (SOFISTIK).
Analysis and Optimization
The decisive load combination consists of $1,35G + 1,5Q + 0,9W$, which results the highest stress in the outer columns in the bar area. The maximum deformation in the structure in this load case is about 4,7mm in z-direction, and 2,8mm at the columns in y-direction. Nevertheless, this deformation is smaller than the admissible deformation referring to the Eurocode EC3 for steel structures.

A hand calculation to control the results from SOFISTIK is conducted. The hand calculation is based on a single span girder with the same load and span length for the beam in the building at the back between two concrete columns. The chosen load case is $1,35G + 1,5Q + 0,75S$.

<table>
<thead>
<tr>
<th>Maximum of</th>
<th>Moment [kNm]</th>
<th>Shear force [kN]</th>
<th>Deformation [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand calculation</td>
<td>14,7</td>
<td>14,7</td>
<td>3,2</td>
</tr>
<tr>
<td>SOFISTIK</td>
<td>11,0</td>
<td>20,0</td>
<td>0,9</td>
</tr>
</tbody>
</table>

A small deviation in stress resultants could be observed, but not in the deformation. This deviation is caused by the non-linear calculation in SOFISTIK. On the other hand, two secondary beams, which are not considered in the hand calculation, change the static system and influence the behaviour of the beam. The assumption of idealistic boundary conditions in the hand calculation should be taken in account.
The small deformation and utilization of load bearing elements show possibilities for further optimization, in particular the reinforced concrete elements such as the cross section of the walls and the steel reinforced columns could be reduced, the high wall between the workshop and the boathouse, whose stability could be critical due to the great height, could be replaced by skeleton structure with columns and beams.

During the project progress the team was challenged by many problems, in particular the exportation from Revit to SOFISTIK and then the calculation with SOFISTIK. Some of these problems are not solved yet, but only ways to work with them. From the central Revit-Model from A360, it could not be exported directly into SOFISTIK, but only after the model was saved as a local one. After every change or addition of architectural elements the analytic model has to be controlled and repaired. Revit did not recognize the load transfer and connection between load bearing elements very well, sometimes even wrong.

The non-linear calculation with SOFISTIK with theory of 2\textsuperscript{nd} order shows unrealistic deformation of over 1m, while the stress resultant is correct. This problem was solved by using the theory of 3\textsuperscript{rd} order instead. Revit considers material, which is not included in the design code, such as strength class C24/29 of concrete.

Figure 18: Maximum of utilization
Quantity Take-Off

The quantity take off was realized with the program RIB iTWO, which was suggested by the BIM course. To transfer the model from Revit 2017 into this drop down application program, it was necessary to export the digital model into a CPIXML data format. This data format was created by the founders of RIB iTWO, with the intention of a smooth transfer from Revit to RIB. The Export can be intentionally done by a plug-in tool within Revit and transferred all objects into the Quantity take off calculation program. In order to take all objects into account, dynamic definition groups of building elements were created. The main advantage of those dynamic definition groups, is their ability to collect or delete elements dynamically after updating the model in RIB iTWO. This was done by using the CPI-Filter, which filters the objects according to their attributes. When all objects are collected within such a dynamic definition groups, we can use them as a reference for the quantity calculation. All necessary quantities can be calculated by entering a calculation formula into the calculation sheet, which also functions as a list of all elements, sorted by their material, attributes or usage. After implementing all calculation formulas, it is possible to print out a bill of quantities.

With checking the quantities on the bill, there were some mistakes recognizable. Some objects could not be calculated, as they were imported into Revit 2017 from an extern library called "BIMobject" (e.g. the façade system as the roof of the building or the external staircase). Therefor, these objects seemed to have no sufficient information about their dimensions or they were or could not be transferred correctly into RIB iTWO. Another possibility of this malfunction could be, that RIB iTWO could not calculate the area of the roof system due to its slope and therefor could not determine the area to be calculated. Some other elements also could not be calculated correctly, because they were changed from the standard catalogue structure into a selfcreated structure (e.g. external walls with insulation). All Attempts to solve these problems were not successful or could not be done in time, which makes the quantity take off incomplete. But most of the calculations worked fine and seem to be plausible.
Due to the non-existent basement of the building, it was not possible or necessary to calculate the excavation under the building by just creating a fictional excavation space. But it is still necessary to remove ground for an even and flat ground for the project. Therefor, the amount of removed material was calculated with Rhinoceros 3D by using different ground bodies, which were subtracted by each other and results in 6339 m³.
Clash detection report

During the design process, a lot of mistakes can happen unconsciously. Therefore it is mandatory to check the model with a model checker. In this project the Nemetscheck Solibri model checker was used to detect clashes within the model. This program scans and controls the model after a certain set of rules, which can be chosen by the user. The set of rules can contain regulations, e.g. no overlapping structures are allowed, length guidelines of certain elements need to be obeyed or distances have to be observed.

After a certain and reasonable state of the model, we used the model checker to find first clashes in the architectural concept and also tried to solve most of them. These changes also led to changes in the structural concept, so the model needed a new structural evaluation, which also brought changes with them. So if you want to check and change the model, a long chain of consequences will follow. Therefore it was hard to determine, when it is the right time to use the model checker. We decided to make it in the end of the modelling process and after we agreed on a final design of the architectural concept. Because of that, we had a lot of clashes to correct. The main clashes occurred, due to the level of development, which was for the limited time of the project not high enough. Also some clashes were detected, which referred to missing declarations or attributes from imported objects from an external library. Also some information about objects could not be transferred, even though the object was visually transferred. In the end, the model did not reach a clash free status.

Besides that, checking the model was also a time and work intensive, due to a missing connection of the model checker with the central model in A360. So in order to check the model, a local IFC file was needed, every time a check up was done. After this check up, the model was updated and checked again, which required a new IFC data model. This led to a lot of different data models, which consumed a lot of storage and worktime.

The big advantage of the clash detection is the easy transfer via the IFC data format. You can check the model, whenever it is necessary and the Solibri model checker also supports the communication between the different actors of the project with easy creatable, understandable and mailable presentations of the clashes.
Collaboration

Procedure
As it already could be seen in the chapter "BPMN" and "Project progress", the process of designing a building via BIM methods needs a well structured organisation of all actors and an universal information and data exchange. Therefor it is mandatory to determine one central exchange and communication base at the beginning of the process. This project started communicating via meetings and mobile messengers and the data exchange was realised by "dropbox" as the data exchange platform. After a certain progress the data exchange platform changed to one central and updatable model on Autodesk´s A360. As there were sometimes problems with the server of A360, back ups were still done on dropbox. Despite the communication possibilities, which were offered by the BIM methods, weekly meetings were still necessary to get on the same state of the project progress and to exchange important data between certain progress steps.

Potential and limitations of the digital design method
The greatest advantages and also the biggest challenge of the digital design method BIM is the collaboration during the whole progress using just only one model.

Using just one model for both architectural, structural design, energetic adaption and further calculations reduces times, work and storage space due to changes from different parties. Clashes could be detected and solved immediately, which can save not only much work but also costs later. The communication between all members of the project is supported by Revit through messages and comments linked directly to the changes or detected clashes. Therefore the progress could be speed up and the waiting time on changed and blocked parts reduced.

Still, this kind of collaboration with one model contains a big challenge for the architects and engineers. Certain knowledge and skills for working with these softwares are required, because one single change of one object could influence many others and causes more work and clashes.
Struggles with not transferred information can also occur, while exchanging and exporting the model data from Revit to other analysing and simulation programs, when not standardized element are used or imported into the model.
Within the used design method with Revit 2017 and SOFISTIK 2016 there are also limits of these software version. There is no link between European Design Code (Eurocode) and German codes (DIN) included in SOFISTIK 2016 yet. Therefore no design and calculation of foundations possible. Also there is no design for timber materials and steel elements with cross section class 4 regarding torsional buckling.

As it was not possible to connect drop down applications (Sofistik, Solibri, RIB iTWO) with the central model on A360, a lot of extra work needed to be done, which not only was time intensive, but also required a lot of data storage for the local data, which needed to be made.

With the central model on A360 it was possible to work simultaneously on one model, but this kind of collaboration was also limited due to the concept of borrowed elements or parts of the model. As long as there is the possibility to keep up a continuous communication about the blocked and updated elements, it is a good way of working together. Otherwise it could lead to long waiting times for admissions on working on blocked elements.
Final Design

Figure 21: Site plan and Ground Floor
Figure 22: First Floor

Figure 23: Elevation South
Figure 24: Second Floor/Attic

Figure 25: Section South-North: Bar, Workshop
Conclusion

This project showed, that using BIM methods has a lot of advantages, which lead to an easier way of collaborating with other actors of the project by saving time and exchanged data. On the other hand, was also clear how certain skills and knowledge are requires to start and execute a project with these methods. Also guidelines for the designing process and the way of exchanging data need to be set and observed. The potential in supporting and connecting different programs is already pretty high, but it still needs optimization especially when it comes to exchanging not standardized or complex elements from one program to another. It was also clear from our experience that the big amount of resources required at the beginning to setup the project data correctly are a good investment for long therm projects involving a lot of details and complexity, since BIM method are performing particularly well in menaging complexity and crash testing. But these problems can and will be solved in the future.