Internship Report

Development of a 3D model for the construction of a hull

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1 Introduction

In the context of the project *Formula Sailing*, which was conducted by students of the *University of Applied Sciences and Arts Ostwestfalen-Lippe* in Lemgo, the development and construction of a wooden boat was done. The project includes the participation at the *1001VELAcup*, which is a sailing competition where teams from European universities design and build sailing boats to compete in a later race. According to the competition rules the boat can be designed within a certain box rule. Some notes affecting the design are listed below:

- max width of 2100 mm
- max length 4600 mm
- no concave shapes below the water line
- minimum volume for buoyancy of 80 dm^3
- min 75 % (weight) use of natural building material
- no use of carbon fiber as building material
- multihulls are not allowed

For the competition prices can be archived by a successful participation at the race and for the design of the boat. The initiating team members of the *Formula Sailing*-Team have their background mainly based in wood sciences related subjects like design of wood based materials and manufacturing processes of the same. The aim of the team is to participate at the *1001VELAcup* with a sailing boat mainly consisting of wood based materials. Next to the work of the core team the development process of certain parts was included in the lectures for students of wood sciences as well as civil engineering and mechanical engineering.

2 Task

At the beginning of the project it was needed to create a basic boat model, which could be used for the further design development. The task was to create such a model with the help of taking measures from a reference boat and create a hull and the inner boat structure by using 2D and 3D software. The resulting model should be used to build the boat in small scale and used for further designs adaptions for the original boat.

3 Design method and reference boat

The common approach to build a boat is by using a building plan, which consists of the shape measurements of the frames for the inside structure of the boat. In advance the right type of boat needs to be chosen for the given use case of the boat. Most of the building plans were created and improved by the experiences of boat builders. Today it is possible to design a hull first and use computer aided design and simulation software to adapt the shape of the hull according to the own requirements. Still the approach of trial and error is used widely, because a simultaneous engineering process is still complicated to be used for the boat building process. It is important to find equality between the parameters affecting the hydrodynamic of the hull and the aerodynamic of the sail. Therefore the simultaneous approach needs to be done by a team of experienced people for the design of the different parts as well as the existing knowledge about how the different components of the boat are affecting each other is important. In addition the requirement of appropriated software needs to be given to simulate, adapt and test different settings for the sailing boat.

The members of the team *Formula Sailing* were not specially educated in boat building nor did they have any specific knowledge in designing and building boats or operating the same. For few members most experience was given by building and renovating larger sailing boats e.g. by using the method of stitch and glue as well as strengthen the structure with glass fiber fabrics. In addition the availability of a building plan was not given. For the design of the hull a process of reverse engineering was used to develop a rough model of the boat. Therefore the the hull of an available boat type *RS800* was manually measured. The measuring points were further processed to create a 3D model of the hull. Inside the hull the inside structure could be placed and derived for the production of the model boat. As software AutoCAD and Inventor was used for the 2D and 3D design. The design process was done parallel with the development of different features and functions of the boat e.g. a swiveling daggerboard, mast and gennaker pole. In addition the mast should be designed as prebent with a profile sail consisting of two layers. During the design process changes were to be expected within a short time to fit all parts within the boat.

4 Hull measuring and creation of new hull

The given hull of the *RS800* was placed upside down inside a measuring device which consisted out of a rectangular frame with distance indicators on the top for x and y horizontal direction. With the help of the distance indicators a grid of measuring points was established with a distance of 10 cm in each direction. At each point the vertical depth of the z direction was measured with a tape measure (see figure 1). In total a number of 530 points were measured.

The points were written down in a table according to their position and imported into

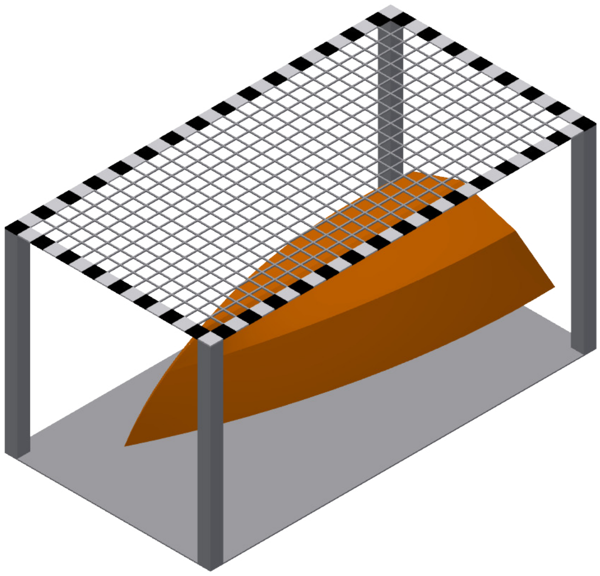


Figure 1: *Example measuring device with boat placed upside down*

the design software Inventor for further processing. The resulting cloud of points was showing a rough shape of a hull (see. figure 2). For further processing the measuring points were separated into different groups and optimized in terms of measuring failures and deviations. The separation was done for the characteristic shape lines which can be found on the outside of the hull e.g. the keel line, the board lines as well as the lines for the bug and the heck. With the help of a calculation software a three dimensional interpolation was done based on the measuring points for the chosen lines. For the calculation the points of the line from both parts of the hull were used. The best resulting lines could be archived by creating the same with a second degree polynomial. Thus was used for the left and the right side of the boat which is important to create an equal shape of the hull for a constant flowing behavior in the water. The calculated lines were imported again in the 3D software and connected with the help of surface forming functions of the software. Due to the own characteristics of the software for forming a free form surface, the resulting hull had convex shapes below the waterline, which needed to be erased. Therefore two vertical splines behind the bug line were added, which are connecting the board lines by passing by the keel line. Further adjustments were done to straighten the heck and the bug line.

The resulting hull can be seen in figure 3. Several free form surfaces were created and later joined with the help of the 3D program. This working step also included the smoothing of the connection points of the surface. To create a sharp keel line and receive a symmetric hull equally portside and starboard, the hull was created just on one half, which was mirrored in the later process. As a major change in reference to the original hull, the bug line was changed to a vertical line. This was done to reduce the

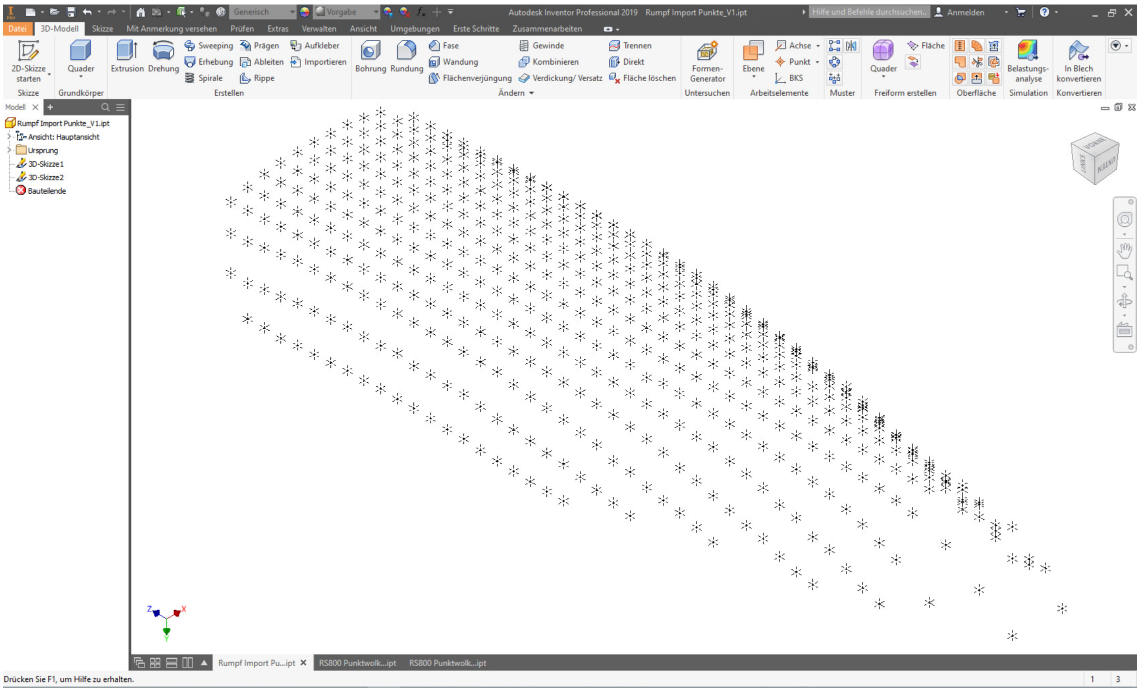


Figure 2: *Imported measuring points in 3D software*

length of the boat and stay inside the maximum allowed length according to the rules.

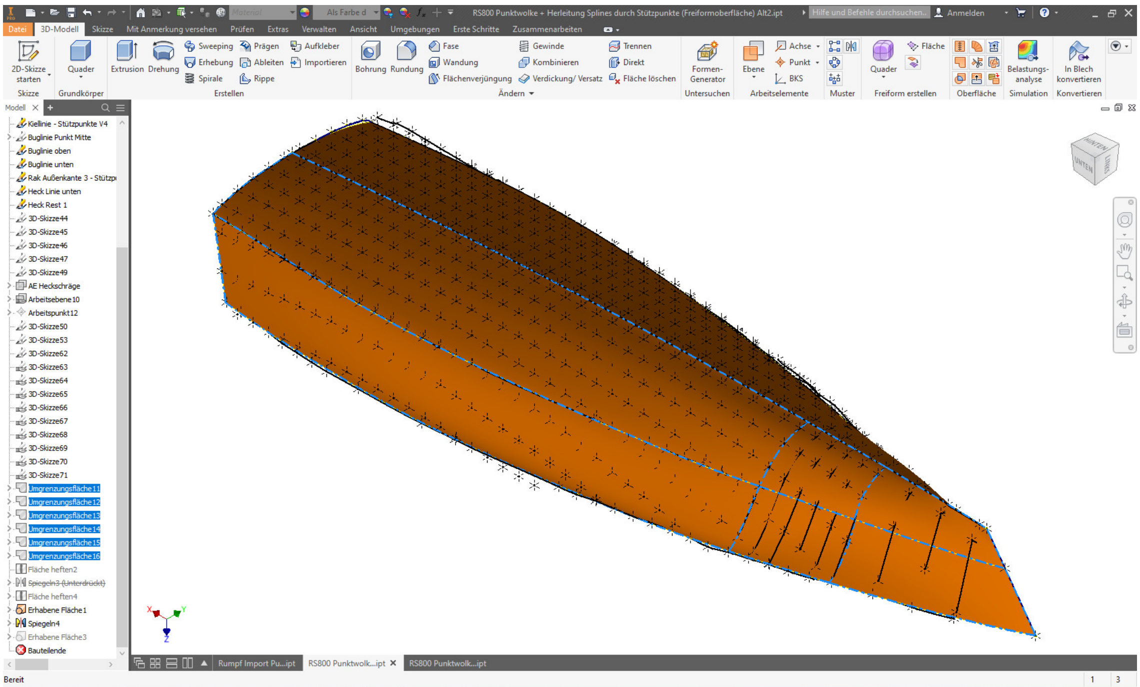


Figure 3: *Hull (orange) with measuring points (black) and outlines of the created free form surfaces (blue)*

5 Deriving the components

The completed hull consisted of one surface which was used to develop the main parts for the structure of the boat. In a following step a 2D drawing of the side view of the boat was used to plan the positions of different components e.g. mast, wands and racks (see figure 4). Those parts have the highest physical impact on the structure of the boat. The position of the wands was chosen rather narrow around the mast due to the limited space along the board line of the boat. The racks were positioned between the heck and the mast. In a next steps the positions of the frames were chosen. Below the mast one frame was placed which derives the vertical forces of the mast to the structure of the boat. The front wands of the mast were placed beside the mast, while the back wands were placed between another two frames which are located behind the mast frame. Those also function as structural elements for the daggerboard box. In the area below the foresail two thinner frames were placed, since this area has a reduced physical impact. For the bug one frame was chosen to absorb the force from the forestay, which is expected to be higher due to the narrow placing of the wands for the mast. In addition this frame is supposed to hold the swiveling device for the gennaker pole. In the area below the main sheet two frames were placed. These frames are essential for the stability of the deck. The deck was chosen to be parallel to the water surface in the area between the heck and the mast. In this area the main physical impact is to be expected due to people walking and also jumping on it. The floor ascents between the mast and the bug to guarantee enough air chambers for the buoyancy of the boat. The racks were planned to be held by the frames at the heck and below the mast.

Based on the 2D drawing the position of the frames was adapted in the 3D model. For each position a vertical layer was created on which the intersection line of the hull and the layer was drawn (see figure 5a and 5b). In total 9 layers were added in the drawing where the first layer indicates the bug frame and the 9th layer the heck frame. Due to the derivation process of the 3D program the resulted lines occur as splines. The splines were kept for the lines on the outside of the hull below the deck. The continuation of the hull to the board line were replaced with straight lines. Afterwards further adjustments were done to make the connections between the frames as well as to fix the position of the deck. For holding the racks the design was changed and the 4th, 5th and 8th frame were extended in their width as well as the ends were formed in a shape of a fish mouth connection to fix the position of the racks. Between the hull and the deck all frames were executed as massive material. In a later step cut outs were added to reduce the

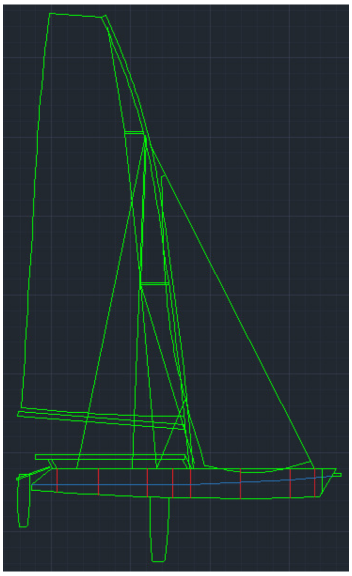
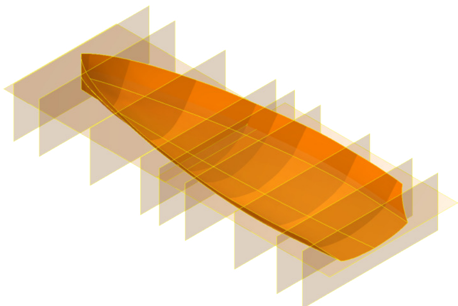
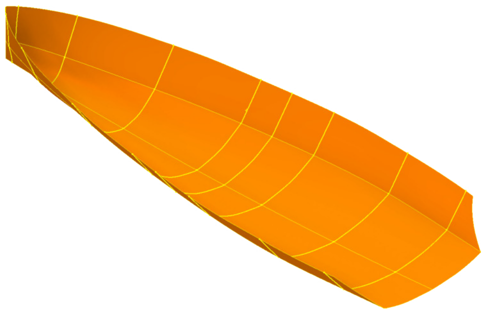


Figure 4: *Placement of the main parts of the boat as well as the frames (red) and deck (blue)*

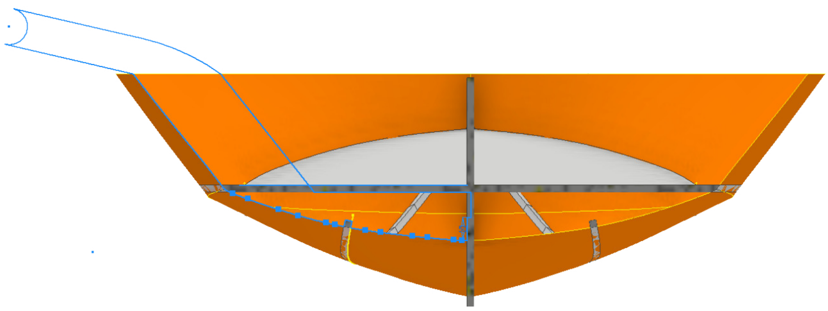
weight of the frame. For a better stability of the inside structure of the boat an additional frame was put between the keel line and the deck, running lengthwise from the bug to the heck. In addition two strips were placed on the frames, following the same direction (see figure 5c). Those reinforcements were needed to keep a stable shape of the boat before the planks were mounted in the later building process.



(a) *Surface model with construction layers for the position of the frames*



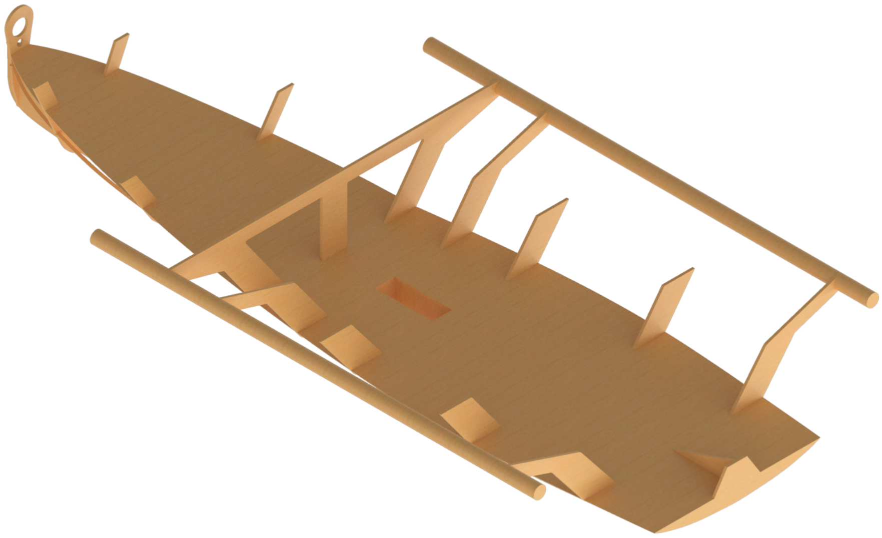
(b) *Derivation of the frame lines from the surface model*



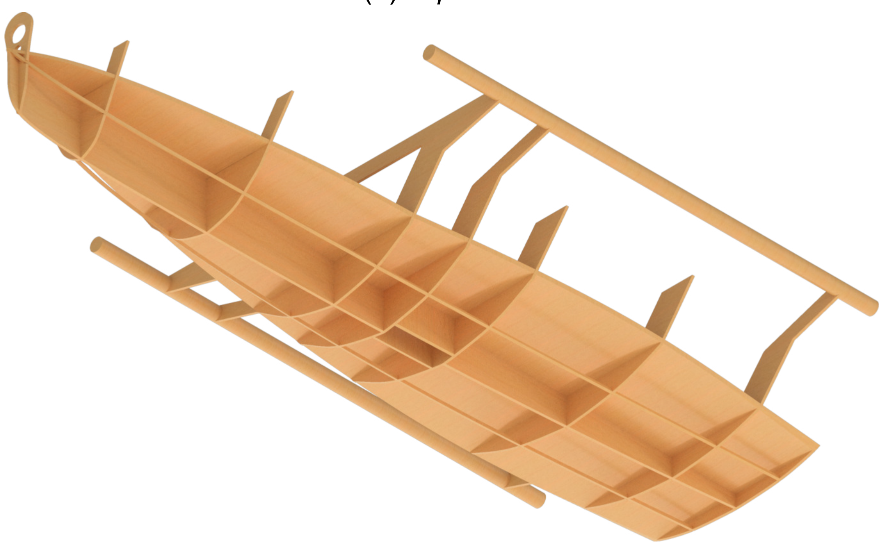
(c) *Drawing of the last frame to hold the rack with implemented deck and keel board*

Figure 5: *Developing the frames in the 3D model*

In figure 6 the whole assembled inside structure of the boat is seen in a top and bottom view. In a following design review the bug was designed to have a dull angle to form a nearly vertical bug line. The center of the heck line was lifted in crosswise and lengthwise direction to add a more stable construction for the steering gear. In the middle of the boat a cut out was established to hold the daggerboard box. Since the development of the daggerboard box was not finished at this station of the development process it was needed to enable a high variety to fix the sword box on the inside structure of the boat. Therefore the surrounding walls were designed to be used as screwing or gluing elements. In addition the structure has to withstand high physical impact while righting the boat or due to the influence of the daggerboard which can be varied in its angle of attack.



(a) *Top view*



(b) *Bottom view*

Figure 6: *Inner structure of the boat*

6 Further processing for production

After the inner structure of the boat was created and visualized the outlines of the given parts were extracted for further processing. In a next step the data was used to build a model boat in a scale of 1:5. Therefore mainly the drawings for the given parts were used and exported as a 2D drawing. For the deck two additional layers were used in the 3D program to copy the intersection line of the given hull with the deck and the frames. Afterwards the data was send to the 2D drawing program and processed in a further way. To build the model all inner parts were cut out from 2 mm veneer plywood with the help of a laser cutter. To prepare the drawing the thickness of all lines were set to a thickness of 0 mm and splines were changed to polylines. The used cutting plan can be seen in figure 7. The data format used for the laser cutter was *.dxf* which is also valid for other cnc maschines e.g. water jet cutter.

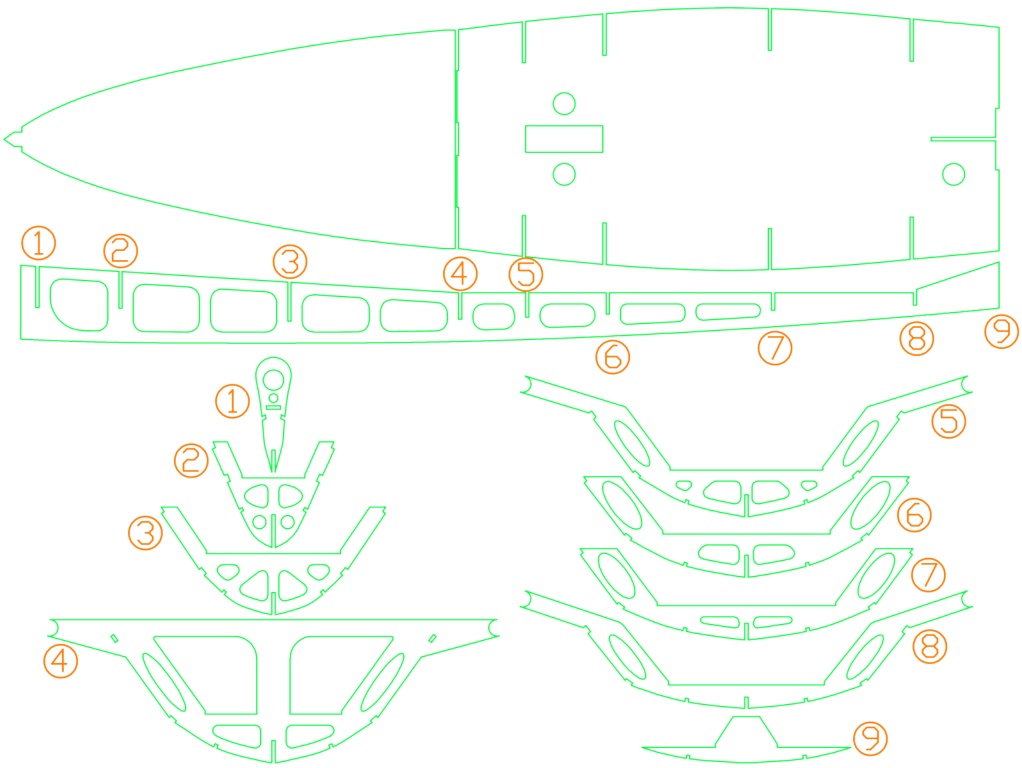


Figure 7: *Frames and deck for the model boat*

In a final step the cut out parts were assembled in the same order how original boat was planed to be assembled. First the inner structure was put together with the deck left out. Afterwards the planking was glued on the frames to higher the stiffness of the structure. In a last step the deck was assembled inside the structure. The thickness of the planks was chosen according to the planed final thickness of the planks for the later boat. The outer surface of the resulting model boat was slightly bent in the area below the deck and showed a straight surface in the direction of the board line. In the front part of the boat the bending of the planks in the lower part of the hull followed a light concave form, which could be straightened with the help of a filler (see figure 8). The model boat was presented at the fair *boot* in Düsseldorf, Germany, in January 2020 together with the freshly assembled inner structure of the boat (see figure 9b). As a result many new ideas for the features of the boat could be brought to the project group which were discussed and implemented in following design review of the boat.

Figure 8: *Model boat in scale 1:5*

For the further production of the inner structure of the boat the design of the frames in the former 2D drawing of the model boat was changed according to further development of the design process and scaled up to the original size of the boat. Afterwards the 2D drawings of the parts were exported to the 3D program again and made into solid parts by extruding the parts to their planed thickness for the boat. The parts were then virtually assembled to eliminate intersections as well as to detect and eliminate complications for the later assemble process. After the parts were optimized for the assemble process, the production of the parts was done with the help of a water jet cutter. As material marine plywood with thickness of 4 mm and 6 mm was used (see figure 9a). The assemble process was supervised and supported by the team members who were involved in the design process.

(a) *Cut out parts* (b) *Assembled inner structure*

Figure 9: *Processing and assembly of inner structure*

7 Result

With the used approach to design the hull for the boat it was possible to establish a basis for the boat, which could be used for the further development of the components and design. The design process for the model boat and the scale up for the original boat was done within a time frame of several month. That way it was possible to adapt to needed changes due to the progress of the development of certain boat parts. Therefor the process can be regarded as a slow simultaneous development. A disadvantage was given by the missing simulation of the hull according its hydrodynamic behavior which could just be tested with the built boat. The later progress of the building has shown, that the boat was able to float without sinking as well as the final shape of the hull was suitable to be used for the sailing boat.