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CARPENTER AND ROBOT: HOW TO BENEFIT FROM THE KNOWLEDGE OF CRAFTSMEN AND THE STRENGTH OF ROBOTS

Wolfgang Schwarzmann[1]

ABSTRACT: In this research project, the working process of carpenters using a CNC joinery robot was observed, documented and evaluated on the basis of a small building, the *'Werkraum Häuschen'*. Designed as a building made of traditional timber joints, the entire construction was produced on a modern CNC joinery system. Under aspects such as the utilization of mono materials, simplified disassembly and reuse, as well as the need for later deconstructability, the wooden knots proved to be functional and resilient. According to interviews with the craftsmen, not only the skills of experienced carpenters but also the advantages of a modern CNC-joinery machine contributed significantly to the success of the project.

KEYWORDS: CNC robot, craft, carpenter, tradition, human-machine interaction,

1 INTRODUCTION

The profession of carpenters has always been in a constant process of change parallel to our society [1,2]. While in former times purely manual work was significantly changed by the emergence of metal tools, steam power and later on electricity, today, a major driver in this process of change is computer-controlled joinery robots [3]. By opening up new applications, these machines offer additional possibilities from the construction and design perspective. While a lot of research projects start from a process optimisation perspective when considering new digital tools [4,5,9], the focus of this paper is on the merged potential of the craftsmen's knowledge and the opportunities offered by joinery machines. As described by Nonaka and Takeuchi, craft professions involve profound tacit knowledge [6], and therefore it is highly relevant to not only conduct research on new applications but also on the context of knowledge generation and manufacturing processes from a craftsman's perspective. In the context of this research, tacit knowledge and the associated perception of the craftsman is explored and discussed in relation to the contemporary technological developments of a cnc-joinery robot.

1.1 NEW SKILLS UNDER AN OLD LABEL:

With a history of more than 7,000 years, the craft of carpentry can look back on a long and dynamic history [1]. Besides the historical evolutionary stages related to steam engines and the introduction of electricity, digitalisation in the craft of carpenters can be considered as a further, fundamental moment of transformation [3]. While craftsmen once had to prepare raw tree trunks themselves, nowadays they can access an almost infinite range of electrically powered and digitally controlled tools. Today, modern joinery robots and corresponding CAD systems mean that much of the work that once had to be done by hand is now done by digitally controlled machines. Apart from these technological changes, wood has remained central as a building material over all that time. A rather similar situation can also be observed in the job description. Although the work of the craftsmen has changed fundamentally, we still refer to them as carpenters today.
This changing field of work for carpenters was already examined in connection with their working process [7], their tradition, and the role of the technologies involved [8]. In this paper, we examine the task of the craftsmen and how they experience their work alongside the joinery robot.

1.2 A MOBILE STRUCTURE MADE OF WOOD

As part of the exhibition Constructive Alps 2021, the *'Werkraum Häuschen'* was built at the *Werkraum Bregenzerwald* in Andelsbuch in autumn/winter 2021. The region of the Bregenzerwald in Vorarlberg, Austria, is known for its timber construction culture and its high regard for craftsmanship. A debate concerning modern manufacturing methods and traditional craft culture is particularly exciting in this region.
The *'Werkraum Häuschen'* (Figure 1) is a small, mobile building, constructed from solid wood. The intersections and corner joints were resolved as pure wood-wood joints. Fully erected, it measures 5.50m x 2.80m x 4.36m (l/d/h). The locally harvested, sawn and dried wood (within a radius of 18km) was processed on a joinery robot. The connections were designed and manufactured as dovetail joints, mortise-and-tenon joints or similar. In the manufacturing process, great care was taken to use traditional, i.e., once commonly used, timber connections, whereby these connections were now fabricated by a joinery robot. All parts were manufactured on a state-of-the-art joinery machine, a Hundegger 'Robot-Drive'

[1] Wolfgang Schwarzmann, Architecture University Liechtenstein, Vaduz, Liechtenstein, Institute of architecture and planning , wolfgang.schwarzmann@uni.li

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Figure 1: *The 'Werkraum Häuschen' a modular wooden construction kit, after completion, ready for the upcoming contributions of the craftsmen*

1.3 THE WORKING PROCESS AS FIELD OF RESEARCH

As an essential part of the qualitative research work, the construction process was documented with photos, video and audio, and then transcribed. In just one day, the structure was assembled and erected by 3 craftsmen (1 craftsman and 2 trainees) as well as the author himself (Figure 2).

Figure 2: *A carpenter assembling the wooden frame. The complicated connections in the frame are still visible.*

After approximately 3-4 weeks, all the craftsmen that had worked on the project were invited to participate in interviews. They were asked about the manufacturing process, sharing their insights concerning the challenges but also the positive qualities related to the robotically manufactured construction components. The interviews were supported by drawings of the construction as well as a time-lapse video of the construction process and photos of the assembly. It was intended to spotlight the assembly process once again. In addition to the 3 assembling craftsmen, the two CAD draftsmen responsible for the working plans but also for programming the joinery robot were interviewed. This wide range of audio and video material formed the basis of this research work.

1.4 A JOINT DESIGN AND PLANNING PROCESS:

Based on an initial meeting with a team of curators and carpenters, a simple CAD sketch was developed. This sketch already illustrated the requirements for the finished project without detailing the timber construction.

The basic principles of the concept sketch were:

- **Simple load-bearing structure:** the geometry of the building is formed by a simple load-bearing system made of wood. Similar to a shelf, the supporting structure is intended to form the framework for the contents.
- **Modularity:** Modules will be inserted into this supporting structure by the craftsmen. The individual wall, floor and ceiling modules should be insertable at any desired position.
- **Mobility:** The finished building should be just large enough to be transportable by truck. This building should be able to function in a variety of places. Wheels on the underside allow an uncomplicated positioning of the building.
- **Circularity and deconstructability:** All solutions for the project should be developed under the aspects of circularity and deconstructability. If possible, hybrid materials like glued beams or plywood should be avoided. The individual modules should be reusable for other purposes later.

2 METHODS

Based on these principles, several workshops and discussions were organised with the carpenters. Step by step, the craftsmen worked out the individual details. In the process, attention was paid to ensuring that the experience, the expert knowledge, and ideas of the carpenters could be implemented as effectively as possible while relying on the 4 basic principles.
The resulting sketches and CAD drawings, as well as notes from discussions were recorded and integrated as data for the project. Over the duration of approx. 8 weeks, a design was developed that could then be manufactured on a CNC joinery system (Figure 3).

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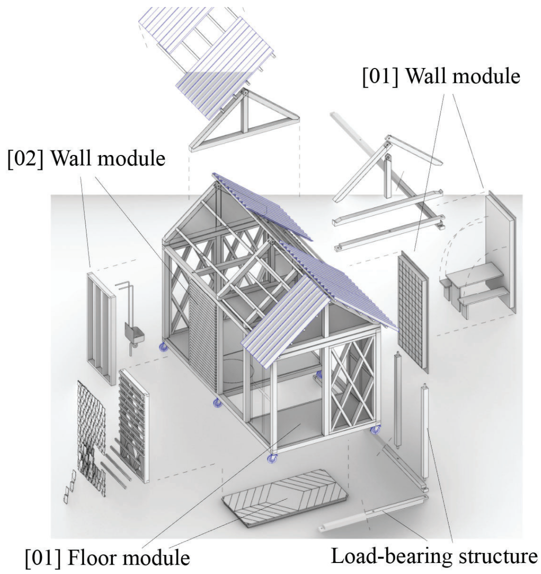

Figure 3: *Modular, dismountable and transportable; the small house was designed to work in different application scenarios.*

2.1 MANUFACTURING OF COMPONENTS AND CONSTRUCTION:

All parts of the supporting structure (columns, bottom plate, roof structure etc.) were manufactured on a 'Hundegger' joinery machine. The previously discussed construction details like dovetail, tenon, groove etc. were adapted and translated by an experienced carpenter to the technical possibilities of the machine. In order to be able to use mono materials and deconstructable connections, all the corner joints were designed as pure wood-wood connections. As a result, it was possible to omit further steel parts from the load-bearing structure. The stability of the construction was made possible by interlocking rhombic lattices that were installed as frames at each corner. At some points, the construction was stabilised with screws for safety and transportation reasons. The 6 wheels were also fixed with 4 screws each. The spruce wood was harvested in the region (12km distance) and stored and dried directly in the carpentry workshop (0km). A young carpenter operated the joinery robot and selected the raw wooden beams for their quality, as not all wooden logs offered the same properties in terms of straightness and stability. The finished beams were then delivered to the *Werkraum Bregenzerwald* (6km distance).

In a joint work process (1 carpenter, 2 trainees and the author) it was possible to erect the construction within one day. None of the carpenters who erected the structure at the *Werkraum Bregenzerwald* had been involved in the planning process before. This decision was intentional, as it meant that it was the first time for them that they came into contact with the project. This division between the planning and the construction process was made intentionally. Due to this separation, the craftsmen's comments during the construction were particularly interesting. They had to rethink the construction plans, the building parts and the construction process and develop their own approach to the project.

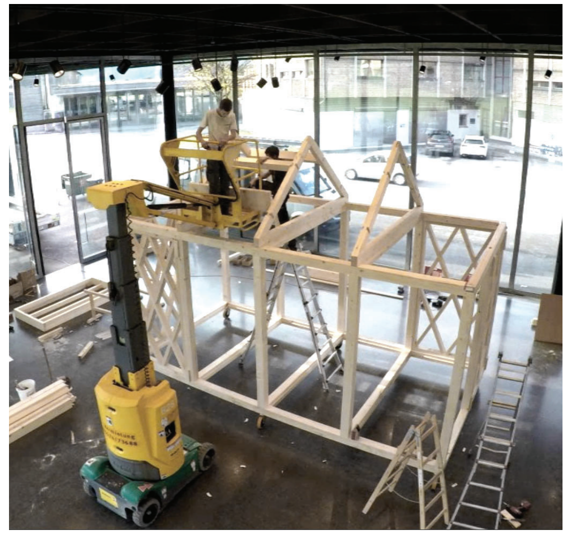

Figure 4: *The assembly of the wooden construction was completed within one day by 4 people.*

2.2 DEBRIEFING WITH CRAFTSMEN:

About 3 weeks after the completion of the construction, the craftsmen were interviewed in a semi-open interview to discuss and share their perspectives on the project. The interviews were supported by a video (duration 2:25 min.) showing the construction process of the building and by a selection of pictures illustrating the fabrication process (approx. 20 photos). The persons were interviewed in small groups and divided into 3 main work themes: (1) CAD and workshop drawing; (2) programming and application of the joinery robot ; (3) assembly and erection of the construction. The individual craftsmen were asked about their role as craftsmen in the process, how they used their expertise, and what the work process with a joinery robot meant to them.

Referring to the following research question, the collected data were transcribed, coded and analysed accordingly:

What are the perceptions of timber construction experts in the work process with a joinery robot in the development of alternative timber joint details.

3 RESULTS

Considering the collected data and the question defined above, 3 main phenomena could be observed:

3.1 THE RIGHT TOOL, AT THE RIGHT TIME:

One main observation was that the craftspeople always had to decide which tool would provide a good and correct solution at the right time. This situational problem-solving competence can be seen as a key component in the success of the project and ultimately as a crucial skill of their

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profession. Whether the tool selected was an electrically powered circular saw, a manually guided plane or a digitally controlled joinery robot was of secondary importance to the craftsmen. For example, it could be observed that although the joinery robot is capable of producing complex solutions quickly and efficiently, the interviews revealed that the correct positioning of an appropriate timber joint was based on the expertise and experience of the CAD draftsman.

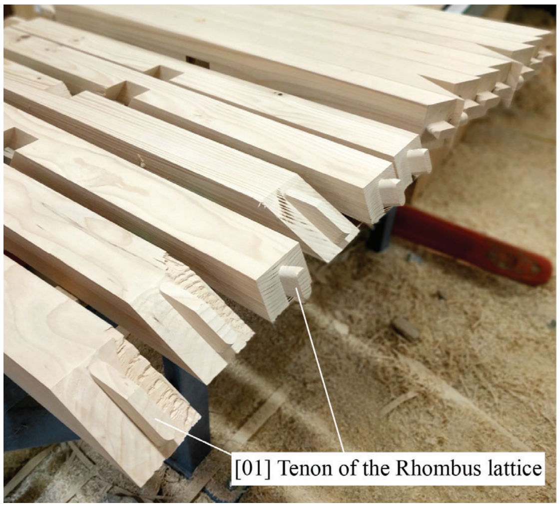

Figure 5: *Angled and sloping tenons are not a time-consuming challenge for the machine. However, most tenons still had to be cleaned by hand to ensure smooth assembly later.*

With his knowledge as a carpenter and a CAD draughtsman, this expert had previously designed the building in his head and simultaneously step by step on the computer. Thanks to his experience as a craftsman, he was able to imagine the subsequent assembly process in working-stages and thus could optimise it correspondingly. The joinery robot was then able to perform the job in a comparably short time. For the craftsmen, this computer-controlled production of the components was a significant reduction in their workload. However, as they explained in the interviews, the robot did not do anything that they could not have done themselves in a more manual process.

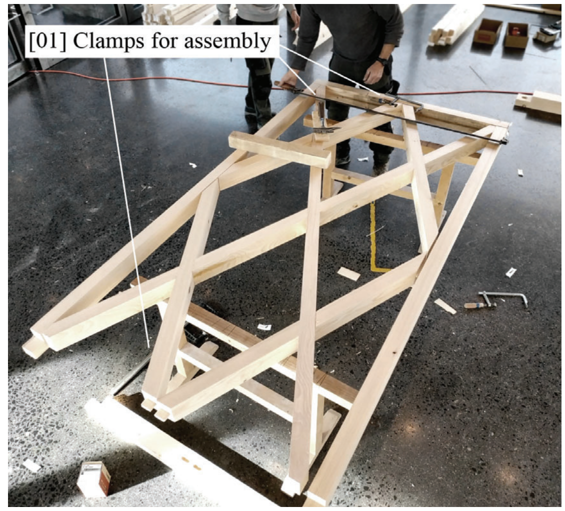

Figure 6: *At the right time, in the right place; the skilled application of screw clamps is crucial when it comes to precise assembly. The CNC robot is quick and accurate, but the assembly of the parts is still demanding.*

3.2 EARLY COMMUNICATION IN THE PROJECT PLANNING

Several rounds of talks were held with the project participants before the first CAD drawings for the joinery robot were produced. These preliminary discussions about statics, structure, construction, and design clarified and fixed fundamental details at an early stage. This preliminary coordination between the project participants demanded knowledge and experience from everyone involved. Problems that occurred later during assembly can be related to late involvement in the project or an inadequate flow of information. For example, a timber beam was installed in the wrong place during assembly. Except for 3 small boreholes, the column also fitted in the other place. Interestingly, the craftsmen already realised this irregularity during assembly and mentioned that the joinery robot must have made a mistake. Afterwards, they simply drilled some additional holes by hand. It was only at the end of the project that it turned out that two columns had been mixed up. This situation might have been avoidable with more accurate coordination, simpler drawings and a correspondingly more intuitive labelling. However, it was also impressive to see how the craftsmen solved the apparent machine error in just a few moments and then continued with the process.

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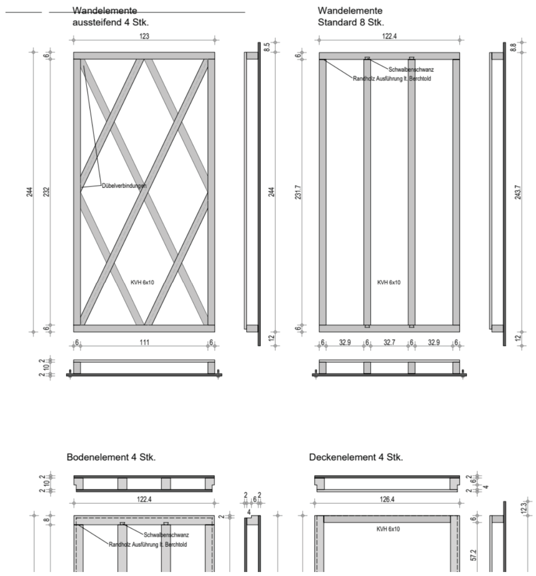

Figure 7: *Sketches, construction drawings, 3D plans; and in-between, there were meetings and discussions. The early and intensive exchange between all the project participants contributed significantly to the success of the project.*

3.3 MAN AND MACHINE COMPLEMENT EACH OTHER

As all the project participants mentioned, the craftsmen would have been able to produce the *'Werkraum Häuschen'* even without a joinery robot. The complexity of the project and the wooden details in the process are time-consuming in most cases, but in terms of production geometry they are not exceptionally complex. The project has shown the importance of the carpenter's expertise, both on the computer and in assembly. In addition to these cognitive skills, it was also the strength, speed and precision of the joinery robot that provided space for the valuable human resources. Because of the mechanical manufacturing, tenons traditionally designed as angular were realised in a round shape. Therefore, there was an adjustment of the timber construction geometry in favour of the machine production. Unfortunately, this geometrical solution could not be applied to all details. Since a joinery robot is not able to produce sharp-edged inner corners (Figure 8; '*[01] Remaining piece'*), the craftsmen had to rework them with a chisel and hammer and with an oscillation tool (Figure 9).

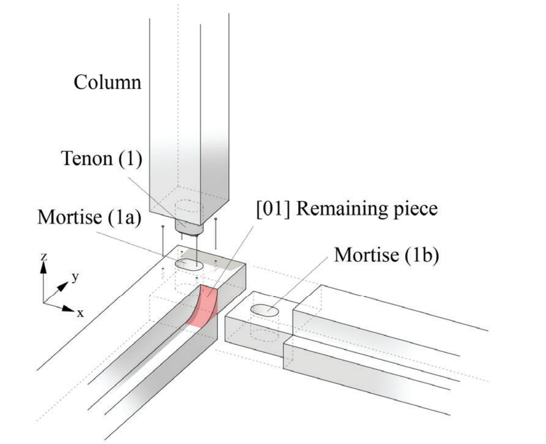

Figure 8: *Due to the technical limitations of the CNC joinery machine, the red corner had to be reworked by hand.*

Figure 9: *During assembly, the remaining piece was removed by hand with an oscillating tool.*

In this case, it would not have been possible to simply modify the geometry, as in the case of the tenons. The joint work process, i.e., rapid production on a joinery robot and completion by experienced craftsmen, proved to be an effective and favourable solution in this case.

4 DISCUSSION AND CONCLUSION

In this paper, the question was asked how carpenters perceive their work in relation to a joinery robot in an exploratory construction process, the *"Werkraum Häuschen"*.

Where do the carpenters see their human skills as a key strength, and what kind of work can be performed efficiently and effectively by a joinery robot? As the results illustrate, the carpenters' expertise in the areas of assembly and construction is essential, regardless of

whether they are working with a hand-held circular saw or a joinery robot. This knowledge is central in the project discussion, the creation of the CAD plans, and the production on the joinery robot as well as the subsequent assembly.
While in this case a purely manual production of the construction would have been too time-consuming and therefore too expensive, the joinery robot was able to produce the laborious timber joint details quickly and efficiently. Furthermore, the joinery machine can be seen as a physical extension of human capabilities. Traditional timber joints could be interpreted and translated in a new context, where the strengths and expertise of the craftsmen were shown to be a key competence. The joinery robot and the corresponding software package can simplify and speed up work processes, but the underlying skills of the people operating the machine remain a key resource in this process.
With regard to future developments in timber construction, the question can be asked how the profession of carpenters will continue to change, what role their knowledge and experience will have in the process, and where new necessities will arise.

5 OUTLOOK AND LIMITATIONS:

As the project review has shown, there are certainly further, more detailed options to be explored in the project. Due to the very tight schedule of the project, new wooden beams were used. Retrospectively, the use of already used wooden beams from, for example, a demolished building would have been a significant enrichment to the findings. Furthermore, a consequent expansion of the wooden joints would be conceivable. In a next step, it would be conceivable to replace the screws used with wooden solutions such as wooden nails or similar. Another point worth exploring would be to optimise the geometry in order to further benefit from the potential of the joinery machine. Due to the limited time available, the focus was placed on the joint working process of developing and implementing pure timber joints and the subsequent assembly process.

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