UNIVERSITÄT LIECHTENSTEIN

Digital transformation and crafts: How is the profession of the carpenter changing due to modern joinery robots?

Wolfgang Schwarzmann
FS180203

Doctoral Thesis

to obtain the degree of
Doctor of Philosophy in Architecture and Planning

University of Liechtenstein

Doctoral degree programme in Architecture and Planning

Supervisor: Prof. Dipl. Arch. ETH Urs Meister,
University of Liechtenstein, Liechtenstein

Co-Supervisor: Prof. Dr. Sascha Friesike,
Director of the Weizenbaum Institute for the Networked Society, Berlin
Professor at Berlin University of the Arts, Berlin

Working Period: 1 September 2018 – 19 October 2022
Date of Submission: 19. October 2022

Peter Zumthor fragte ihn:
‚Ist das eigentlich noch handwerklich, was du da machst?'

‚Ja, ich hoble doch das Holz.'
antwortete der Schreiner, während er ein Stück Holz durch die Hobelmaschine hindurch lässt.

Dialog in Zumthor, (2016, p. 80)

Acknowledgments:

Almost exactly 4 years after the beginning of this journey, I am happy to have reached my goal. Although mine is the only name written under this work, it should be mentioned how many other minds and hands have contributed to this result. Besides the fact that it would not be possible to accomplish such a project alone, it certainly would not be a pleasure to do so.

First and foremost, I would like to thank Andrea Schwarzmann, who has accompanied and helped to resolve my constant stream of uncertainties, arising questions and tasks in countless conversations. Apart from her deep personal support, she has significantly enriched this work, especially with regard to proper citations, the overall scientific work, and the sharpening of all my research questions.

Looking back, it is impressive how calmly Urs Meister has accompanied me as my first supervisor. Knowing that he always stands behind me and my work, I experienced this freedom as a great sign of trust in me as a person and in the way I work.

With his expertise on the current digitalisation hype, Sascha Friesike has repeatedly shed new light on my work and raised the corresponding debate to a much higher level. Apart from this professional contribution, he has challenged me again and again with questions as to where the results of this work should ultimately lead, and for whom it will be of added value.

Great thanks are due to Anne Brandl, who, as an incredibly strong and at the same time uncompromisingly democratic leader, encouraged me to take the next steps. It was her drive that led me to the FFF-Research project 'Digitale Meister', which ensured the financial security of this work.

I would like to express special thanks to Christoph Michels, who has enriched my thinking significantly and showed me how to explore Actor-Network Theory. His open manner and his non-violent conflict management have become a model of leadership for me.

Thanks also go to Johannes Herburger and Luis Hilti who, as PhD students and friends at the Institute, had the most direct and closest contact in emotionally moving moments of this project.

In numerous discussions and consultations, Martin Mackowitz and Robert Maier also drew my attention to new problems and even further solutions.
It was Peter Staub, among others, who saw the potential of this work in a two-page abstract during a job interview many years ago.

Thanks to my parents, Hildegard Bechtold, who has repeatedly shown me the true meaning of life with her calmness and composure and our limitations as human beings and to Thomas Bechtold, who, besides being an excellent chemist and researcher, outlined and accompanied my first publications from an intellectual, content-related and technical point of view. In this case it is probably a great advantage to have such a scientific expert in one's private sphere.
Furthermore, I would like to thank my siblings, Susanne Rinderer and Guntram Bechtold who, in countless telephone calls and conversations, embedded the threads of this work in the complexity of life and were thus able to motivate me.

Apart from these individual, personal mentions, deep gratitude goes to all the craftsmen and carpenters who have contributed to this work. This includes all those involved in the process such as Martin Winsauer as a woodworker and forestry driver, Matthias and Jakob Mayer as sawmill operators, Matthias and Michael Kaufmann as carpenters, and Belinda Rukschcio as managing director of the Werkraum Bregenzerwald.

I also want to thank my friends and my family for their support.
This work has been so extensive ... that I may well have overlooked someone in the short time available. I apologize if this is the case.

Abstract

The craft of carpentry is in a constant process of change. This dissertation focuses on the changing work processes between carpenters and joinery robots. These CNC-controlled machines open up enormous potential in terms of production speed, precision and the complexity of structural elements. At the same time, this technological evolution means a change for habitual methods and craft traditions. Previous process flows are changing in favour of the new, digital tools. Knowledge and proven practices that were previously central to the carpenter's education and profession are now being reprioritised. The question some craftspeople may ask themselves is where their own role is now to be found; what is the necessity of carpenters in the process?

In the context of this thesis, (1) the 'former' profession of carpenters is outlined, (2) a picture of the contemporary work involving joinery robots is drawn, (3) the question of manual labour in the process is discussed, and finally (4) an extended understanding of the interaction between humans and machines is elaborated.

The individual papers then answer questions such as how historical techniques can add value to the digital manufacturing process (P I.), what specific role an individual carpenter might have in this process (P II.), and how previously unprofitable construction principles can add a new, regional value through joinery robots (P III.). Finally, a comparison (P IV.) is used to discuss further technological developments in the sector.

Keywords: changing craft, carpenter knowledge, digital transformation, robotic fabrication,

Table of Contents

1 Craft in a Process of Change

1.1 Carpenters and the Digital Revolution

‚Manche Zimmerer sind oft aus der Tradition heraus noch nicht vollends in das Zeitalter der Digitalisierung aufgebrochen.' (Lindner, 2018).

Following this quote on holzkurier.com, the claim is made that: *'Some carpenters, out of tradition, have often not yet fully entered the age of digitisation.'* It appears that the craftsmen still have some catching up to do. While the above quotation argues that it is primarily a choice between 'tradition' and 'innovation', the same article later on raises the question of what this process of change actually means for a carpenter in terms of digitisation. However, for the author it seems clear that digitalization is changing timber construction. Over the last few years, buzzwords such as 'digitisation', 'innovation' and 'artificial intelligence' have made their way onto many covers and into many presentations. 'Innovation packages' and 'digitisation plans' have been proclaimed and announced by policymakers.

To avoid being left behind, seemingly everything needs to happen fast in this global competition. New technologies might offer new solutions that have to be introduced as soon as possible. Workshops on the topic of 'digitalization' are being held and expeditions to the Silicon Valley are being organized, in order to learn from the most successful companies. Ideally, after the flight home, the knowledge gained on site can be implemented directly in the company's own operations (Friesike & Sprondel, 2022, pp. 61–62). At least that is the business idea of the tour operators.

However, if we look at this desire for change and development in more depth, an increasing number of questions start to arise. What does this process of digitalization actually mean in a specific area such as the profession of carpentry? To what extent can new technological possibilities be implemented in a meaningful way in a craft profession, and is it really necessary to act as quickly as it may currently appear? Especially in an historically far-reaching profession such as carpentry, the question of ‘tradition’ and/or ‘innovation’, as well as ‘old’ or ‘new’ seems to arise. As mentioned in the quote at the beginning of this document, there seems to be a need to take a stand on what parts can be preserved and what parts must be replaced. But where does this underlying pressure to avoid missing the digital boat or the urgent need to replace established practices with new, seemingly more innovative alternatives come from?

Looking back, an interesting change in corporate culture can be observed using the example of the social media platform Facebook. Until 2014, the motto of the Facebook Group was *‘Move Fast and Break Things’*. At that point, their primary focus was the fast delivery of new features, which may not yet have been fully developed. Until then, it was a common practice to launch a product, a code, on the platform even though it was not yet fully developed. If necessary, the errors and problems that subsequently occurred were then fixed at a later point during operation. The primary benefit of this strategy was to rapidly achieve ambitious goals that had been set at an earlier stage. However, this accelerated pace of progress was at the expense of platform reliability, the workload of employees and a resulting unstable infrastructure (Baer, 2014). It was probably also due to this progressive growth policy that the company reached an overwhelming size without having sufficiently addressed fundamental issues such as privacy and the use of user data until that point. However, the need for those issues became increasingly prominent over the following years. One of the most prominent moments in these issues was in 2018, when Mark Zuckerberg, co-founder and CEO of Facebook, was questioned on them in front of the U.S. Congress. Although Facebook had already changed its internal slogan in 2014 to *‘Move fast with stable infrastructure’*, this event has had a strong impact on the global discussion about digitisation. Similar to Facebook, the media hype surrounding the digital revolution is characterized by an apparent high speed of change, radicality in decision-making, and proactive reshaping of conventional practices. This rhetoric is not limited to the actions of a single company. For example, processes that take place in the context of ‘digitisation’ or ‘digital transformation’ are often linked to correspondingly radical and disruptive changes. If one follows the proponents of this trend of change, all of our business models and companies would be transformed (Anderson, 2013, p. 21; McAfee & Brynjolfsson, 2018).

As one of the most powerful claims in terms of these supposed processes of change, Frey and Osborne (2017) published an estimate of which professions were likely to be replaced by computers in the coming years and with what probability. As part of their findings, almost fifty percent of all jobs in the U.S. were considered to be 'at risk' of automation. The work of these professions is expected to be replaced by computers or robots in the near future. The profession of carpenter was ranked in 398 place out of 702 and is thus on a comparable level to pharmacy aides or a home appliance repairer.

Although the findings by Frey & Osbourne have been further developed by others since then in publications arguing less risk, the fundamental question remains as to which professions will still exist in the future and where or to what extent computers or robots will take over a part of the overall process.

1.1.1 What influences a carpenter? Four Observations

In order to develop a deeper understanding of the complexity of the current situation of carpenters, it is important to ask where the craftsmen stand at the moment. As part of this research, a large number of carpenters and experts in the field were consulted. In doing so, four main points were mentioned repeatedly:

1. External pressure to innovate:

As described in the previous section, digital technologies are being promoted as the right path to a secure future. Funding and coaching opportunities from the chamber of crafts and the trade associations are intended to provide the necessary know-how, so that people and their companies can manage a development process that is as straightforward as possible.

As can be seen in the interview *'Aus Überzeugung digitalisiert'* by Holzbau Austria, every now and then an individual is highlighted as a leading thinker. In this example, a carpenter is interviewed who talks about his experience with digitalization. He describes fears and risks, but also advantages and new possibilities that have emerged through the use of a joinery robot (Lanz, 2020). While in the above example, the state of Salzburg provided an incentive with its so-called digitisation campaign, the region of Vorarlberg has written a 'Digital Agenda Vorarlberg'. On 59 pages, it outlines the next necessary steps in this transformation process (Amt der vorarlberger Landesregierung, 2018).

So, while the goals seem to be straightforward on a political scale, the question arises as to what can be done in practical terms within an individual company. Ultimately, these changes are intended to generate added value for the individual craft enterprises. Craftspeople, who are already busy in their day-to-day operations, like managing site projects and keeping their company on track, see the signals that something needs to be done, but it may still be unclear where and in what way the 'digital transformation' should be implemented in their company.

2. Questioning one's own tradition:

A large number of the carpentry companies that were visited can look back on a long company history. In most cases, a further step 'forward' was taken with each change of generations. New machines were purchased, joinery workshops were expanded or new ones were even built. All these actions followed an apparent thread, a line of tradition, and could be seen in connection to their craft and tradition. When asked how the history of their company or their profession should be continued with regard to digitisation, the craftsmen expressed uncertainty about making a wrong decision. For the craftsmen, this decision seems to be a radical break with previous ways of doing things.

3. Economic, solid basis:

Common to all the discussions were comments that carpenters can currently look forward to an exceptionally good order situation. As a result of the changing awareness in society to make use of renewable materials and accessing regional building materials, the business opportunities for wood craftspeople are very good. Subsidies favour building with wood and the acceptance in society is contributing to an increasing demand for corresponding construction methods.

Even though the global price fluctuations of building materials in 2021 have brought some uncertainty, everyone is well aware of the potential of timber construction. Accordingly, the order books of the craft enterprises are packed.

4. Demanding times in terms of manpower: ‚*Fachkräftemangel*'

The current shortage of skilled workers in the construction industry also means a challenge for carpenters (Dornmayr & Riepl, 2021). Although the interviewed companies are pleased with their increasing number of orders, in most cases they have to complete the projects with the same number of staff, and sometimes even a smaller number of people. In Vorarlberg, there are currently around 170 apprentices in training. Although this is a very positive development, it is more than necessary for the 150 carpentry companies in the region (Zeman, 2022). It also means that the number of apprentices is barely keeping up with retirements and job exits. Aside from this young professional issue, interviewees also repeatedly described the challenge of downtime (physical stress and health issues), age-related retirements, or simple career reorientation.

These four points, summarized as examples, are a selection of the topics described more than once by the craftspeople in the interviews. However, what seems to be particularly worth mentioning in the context of 'digitalization in the craft of carpentry' is the fact that the call for a 'digital' change seems to originate from outside the companies, but the practical implementation within the individual companies is faced by a certain degree of insecurity. This is a particularly important point, since the companies are basically experiencing a very good demand situation, but have too few hands - i.e. craftsmen. It would therefore be quite obvious to simply invest in new machines and CNC joinery robots. So, where does the scepticism come from with regard to technological innovations that would solve so many problems, or so it seems at first glance?

1.1.2 Might Technology solve the problem?

In his book 'The Craftsman', Richard Sennett describes the story of the French inventor Jacques de Vaucanson. In the 18th century, this inventive mind tried to develop things that could amaze people around him. His inventions included a mechanical duck that appeared to digest and defecate (but ultimately turned out to be a fake) and a mechanical flute player that could actually play music. Although this puppet was quite complex in its realization and could amaze people with numerous melodies, its performance skills were still far below those of a human flute player. Impressed by this technical marvel, the French King Louis XV appointed Vaucanson to manage French silk production at that time. Back then, the looms were operated by skilled workers in laborious and time-consuming manual work. The knowledge that Vaucanson gained from the development of the flute player allowed him to contribute to the further development of the looms. While previously the weavers had to perform their work with an appropriate level of dexterity and optical control, the new looms produced a better product even without these skills. For the workers who were on strike in those days, this development was rather unpleasant, of course.

As a result, it was possible to produce at lower cost and faster. The workers, who had previously been slaving away for very low wages, now had to give up their jobs completely. The frustration was accordingly directed against the inventor and the new loom (Sennett & Bischoff, 2008, pp. 119–122). In this brief example, Richard Sennett illustrates how technological progress can, under certain circumstances, take over, improve and even replace parts of people's tasks. The new looms were also capable of producing more complex patterns with greater accuracy. For Sennett, this example marks the beginning of the substitution of machines for craftspeople. Historically, however, this debate can also be illuminated by other events.

For example, the process of writing books by hand was replaced someday by the printing press (Giesecke, 1998, p. 63). The letterpress, in turn, was then replaced by the cylinder press, and later by digital printing and photocopying equipment, with each of these transformations discarding existing skills and adopting new approaches. Of course, these technological changes have in turn given rise to new professions associated with the machines.

While for some people the invention of a loom already meant the loss of the art of manual weaving, in the example of Vaucanson it was the further development of already existing looms into automatic machines that ultimately displaced manual work from the process. In the final stage, it was the use of punched cards, among other things, that made people's manual work completely replaceable.

Are carpenters now in a similar situation to the weavers of the 17th century? To what extent do these historical examples have relevance in carpentry trades today, or is there a difference to the current situation?

As described on the basis of the four points above, the craft of carpentry is facing various challenges. On the one hand, there is the question of how to meet the increasing demand in the construction industry. On the other hand, it should be possible to handle a rising number of orders without a corresponding increase in skilled workers. As one further point, new developments under the buzzword of 'digitalization' are being pushed by politics and business, while the question of the craftsmen's culture, their profession, remains unclear.

If we follow the solution patterns of workforce optimization in a craft business from the past, rationally speaking, the most obvious and efficient solution is to invest in a new machine. Depending on the configuration, this machine will quickly and reliably be able to handle parts of the manual work once performed by craftsmen.

While modern planing machines and digitally controlled sliding table saws can optimize certain activities of carpenters, for the past 25-30 years a new combined tool has been making its debut in the joinery workshops (Jeska et al., 2015, p. 60). So-called joinery robots combine a multitude of processing options of various tools. Computer-controlled and supervised by machinists, wooden parts are milled, drilled, slotted and also marked. In most cases, this substantial investment simultaneously replaces the purchase of other machines such as a circular saw, a tapping machine or a slotting unit. Work previously performed on several smaller, stationary machines can now be carried out on a single, large joinery system. In most cases, the decision for such a new machine is driven by other processes taking place in the company, such as the takeover of the company by the next generation or a structural change in the company's management. Because of the associated need to keep the business running for the next 20 to 30 years and the need to be technologically up to date, craft businesses are taking the step towards robot-assisted joinery. From this point of view, the acquisition of such a robot is 'only' a question of the firm's economic starting position. How long does the machine have to work in our company in order to pay for itself? What orders can we offer? Is there a corresponding need in our region to be able to work efficiently with such a machine? etc.

While these economically driven aspects may be discussed rationally, such an investment implies further, perhaps much more substantial, consequences. The question of how a craft profession changes as a result of new technology is at least as substantial as the optimization of individual activities or a company's economic success . Such investments not only replace existing tools, but also fundamentally rearrange the manufacturing processes in a carpentry shop. Work processes are reorganized, orders are calculated differently in view of the machine's technical possibilities, and jobs are rearranged. The specific reasons why craft businesses decide to do this are always on an operational and individual level and therefore have different origins. However, the main reason is the desire to optimize the workflow and reduce the craftsmen's workload. One fundamental aspect of the carpenter's profession, therefore, is not taken into account. The main focus of this thesis is precisely this often unconsidered, secondary change, and essentially revolves around the question:

How is the craft of carpentry changed by making use of a CNC joinery robot?

Further sub-questions are raised in order to clarify this wide-ranging discussion:

- How does the craftsmen's knowledge in combination with the capabilities of joinery robots lead to new solutions?
- Does the introduction of a joinery robot imply an erosion of traditional working methods for the craftsmen?
- What is the newly arranged role of the worker, and what part does the machine play?

Figure 1. Man and machine working on the same piece of wood; from 'Orbis sensualium pictus', the robotic arm was added 'digitally' in 2020.

An artistic print by Johann Amos Comenius (1658, p. 130) summarises and illustrates the range of tasks a carpenter had to perform at that time.

We can see three people working with axes and parts of a truss structure at one side. The picture shows how a tree is cut down and levelled, and its final destination in a building. Furthermore, several tools and some details have been added to the working men. It is also possible to spot a marking cord, a few workhorses, the broad axe of the craftsman, as well as a dowel in the construction and the scrap pieces stacked up for drying. In short, in 1658 Comenius started an attempt to outline the profession of carpenters on a single print. In the context of this thesis, I have taken the opportunity to add a robotic arm to his wonderful art work. To me it seemed appropriate for this thesis to pick an exceptionally old picture of the profession and enrich it with the appearance of a very modern technology.

The black-and-white printed graphic thus represents the most traditional values of manual carpentry. The bright orange robot arm can be seen as representing the modern, technological part of this research.
In general, the joinery robots used by carpenters on a daily basis do not necessarily look like the orange robotic arm shown here. This arm, which is typical for the automotive industry, exaggerates the picture with its high recognition effect as a robot arm. Its movements, some of which remind us of human actions, blur the boundary between humans and machines and question where a line between the two can be drawn.
In the following chapters, the technologically induced change in the craft of carpenters is analysed and discussed on different levels. The main focus of this research, therefore, is not on the development of new applications for the machine in wood construction, but on observations of the change in craft practices already happening in the context of robotic automation in carpentry.
Here, the emphasis is primarily on the joint performance of craftsmen and their joinery machines. The study therefore looked specifically for carpentry companies that could already look back on a certain amount of experience with joinery robots. By means of company visits, interviews and discussions with people involved in the process, their tasks, their attitude towards joinery robots and the question of their own performance in the process were examined.
Selected projects were carefully examined for the work of the craftsmen and the performance of the machine. It soon became obvious that a binary separation between people and machines is not tenable. The results from these observations were then interpreted as a collaborative effort between the carpenters and the joinery robots. The actual work process of all the forces involved was tracked and documented as a key finding.

In the first section, a clarification of the terminology is provided. This will shed light on the question of how the process of digitisation in carpentry can be understood, why a robotic arm with a milling head is not necessarily the (only) solution, and that carpenters may have already been in a state of digital transformation for longer than the media hype wants us to think.

The next section addresses the question of 'whether this is still craftsmanship at all'. Thereby, the debate concerns what characterizes the core of craftsmanship, where it differs from industrial production, and how manual work is changing in our society. As an example, the activities of a carpenter are compared with the performance spectrum of a joinery robot. By explicitly focusing on the example of 'joinery work', in German the so called 'Abbundarbeit', the different approaches in carpentry will illustrate the technological change. This work of 'joining wood' can be done with a specially constructed joinery robot as well as without a robot. The results of the working methods are of course different.
In the third section, the link to an ongoing discussion in society regarding 'man or/and machine' is examined. Which of the two is doing the work, and what kind of work? On the basis of the actor-network theory, the profession of carpenters is analysed and finally considered as a complex network between human beings, machines and other elements. It appears to be of particular relevance that since the very first records people have always worked with tools in order to expand on human capabilities.
The accompanying articles respond to the questions raised in this thesis. Based on the findings in the articles, it will be shown how old craft solutions can be revived using the latest building materials and machines. For example, how historical joining techniques can encourage the use of modern timber construction materials such as beech (in German, *Bau Buche*) with a joinery robot (*Paper I.; How new technologies can promote the reintroduction of traditional knowledge in the profession of a carpenter*), how a carpenter's expertise and enthusiasm have further developed the company's own joinery robot (*Paper II.; Traditional Knowledge on Modern Milling Robots*) or how an already almost forgotten, regionally typical design could be reactivated (*Paper III.; The Renaissance of Structural Ornamentation*). That there is still further development potential in the joint work process of man and machine is illustrated in the final part, comprising a comparison between the Maker community and carpenters (*Paper IV.; What a carpenter can learn from 'Thingiverse'*).
Although this thesis deals extensively with the overarching question of the craft of carpenters, it must be said that my numerous conversations with the craftspeople provided huge enrichment to the work. While the attempt for a

uniform definition of ‘the craft of carpenters’, i.e., a clearly marked profession, is often sought in this context, the individual descriptions by the carpenters showed how broadly their profession needs to be interpreted. As a result, it should be mentioned that the various perspectives of the individual carpenters are very diverse and broad. Accordingly, it is difficult if not impossible to sharply define the profession of ‘the carpenter’.

1.2 What is 'digitisation' in the craft of carpentry?

As described at the beginning, it is often said that companies must engage with the latest technological solutions in order to avoid falling behind. However, before it can be said whether carpenters are actually lagging behind in their craft, their current position with regard to 'digitisation' needs to be clarified.

1.2.1 Moment of translation; from analogue to digital

The process of digitisation in general simply means the translation of a book, a piece of music, a thing from an analogue to a digital form. For example, a vinyl record that preserves a piece of music in analogue form can be digitised using a microphone and a computer. In this process, sounds that were previously grooved into a vinyl record are played back through a record player. The sound waves are then recorded by a microphone and a computer and stored on the computer in the form of digital data. A significant advantage of this digitised form of storage is the immense amount of data that a digital storage medium is able to hold. While a vinyl record must always remain a certain size for technical reasons, the digitised version of the music can be stored on a much smaller hard drive or USB stick (Friesike & Sprondel, 2022, p. 11). In addition, a digital storage medium may also contain other data formats such as images or videos and provide them again at a later time. Digital data therefore only require a fraction of the space that their analogue counterparts used to take up. As with any translation process, this transformation from analogue to digital involves a certain amount of change. It is only in theory that translation processes are absolutely free of losses. If a word, a thing, an object is transferred from one form to another, therefore, this always means a certain process of change or a modification of the word, the thing or the object. While the transmission ratio between two gears works mathematically without losses, such as 1:3, i.e. 10 revolutions to the left means 30 revolutions to the right, the transformation process in the real world unavoidably results in corresponding system losses. Inaccuracies of the gears, rolling resistance of the bearings but also the air resistance of the individual gears mean that a certain part of the energy received in the system is wasted, mostly in the form of frictional heat or downwind. Ultimately, it is precisely these transmission inaccuracies that bring the engine oil in our cars to an operating temperature of 90°-100°. While these transmission inaccuracies can be calculated and measured quite straightforwardly in a car gearbox, it is more difficult to do so in the case of a less tangible phenomenon such as the translation between different languages.

For example, a sentence may translate effortlessly into another language, but in the new language it no longer carries the same force or even the same message. On French motorways, the saying *'La vitess ou la vie'* urges travellers to keep to the given speed. If this sentence is translated directly into English, its previously French lightness sounds more like a slogan from a Hollywood thriller: 'Speed or life'. This problem of translation was countered on German roads by an appropriate adaptation in the form of 'travelling instead of speeding' (in the German language form: 'Reisen statt Rasen'), which ultimately focused on the content and not the exact wording and was pursued with intuition instead of technical precision (Henschelmann, 1999, p. 21). It is precisely this challenge of translation that becomes very vivid and comprehensible in such an absolute field as written language. However, the requirements for a reliable, meaningful or literal translation already require a deep understanding of the source and target languages. Under certain circumstances, specific knowledge of culture, country or politics is also necessary in order to ensure the quality of the final product. Although the process of translation may seem straightforward on a technical, rational level, the actors involved in the process must always be aware that any translation is, to some extent, a process of change, of transformation. While everyday phrases are seldom affected by such imprecision, the problems of translation can be experienced in complex, human works such as poetry or prose. These culturally unique constructs, which are highly fragile in terms of style, can only be translated into other languages to a limited extent or perhaps not at all. It may then be easier to learn the language of the source product in order to grasp the content in the original formulation. But the problem of translation still remains. It merely shifts from the word written on a page to an intellectual and spiritual form in the mind of the individual.

If we recognise that such transformations are unavoidable, we first have to ask what aspects need to be preserved in this process of transformation. To be able to portray such a moment of transformation in the craft of carpenters, it is first necessary to clarify the initial situation. Then the questions can be asked which key aspects should be kept during the moment of translation, and how these aspects can be adequately retained in the resulting output.

1.2.2 Before this translation; How did carpenters work until now?

In order to assess the current translation moment of carpenters, it is first necessary to outline the past working methods of these craftsmen. With a documented history of more than 7000 years, the craft of carpentry can look back on an extensive historical background (Gerner, 2002, p. 8). A precise date for the beginning of this craft is not appropriate, since the craft of carpentry developed in a slow, and very subliminal, evolutionary process from the work of farmers. Together with the ability to lay loose stones on top of each other in a structured way, wood and stone represent some of the oldest building materials of all (Gerner, 2002, p. 14). Even before one could speak of a service and trade in today's sense, it was necessary for people to be able to erect and maintain buildings of their own. Thus, farmers constructed their first buildings to meet their own needs. Because of this need to be able to build and maintain their own house, the farmers developed their own specific knowledge of how to work with wood as a building material. In the process, the techniques and working methods were practised, trained and passed on more or less in isolation and informally handed over to others (Zwerger & Olgiati, 2012, p. 54). The specific knowledge of manual work was thus passed on to others directly and informally through collective work. The growth and development of larger settlements and towns led to the profession of craftsmen working with wood as a building material becoming more and more in demand. With the increasing complexity of wooden constructions such as roof trusses, sacred buildings or bridges, the need for experts with specific knowledge concerning the material wood increased. Therefore, it became worthwhile to hire master woodworkers from abroad. On site, workers were recruited to help, who in turn were able to expand their own knowledge of timber construction (Zwerger & Olgiati, 2012, p. 55). This increasing expertise in timber as a construction material led to other professions such as woodturners, coopers, wainwrights and joiners or cabinetmakers emerging over the years (Gerner, 2002, p. 10). Compared to other crafts, the dimensions of the structures to be erected and the associated complexity of the parts posed a particular challenge for carpenters. For example, in the actual manufacturing of a building, the construction timber used to be delivered directly to the building site and was then processed there. The timber beams were laid on the ground as they would later be used in the building and then individually processed to fit with one another. This unique and typical activity for carpenters is generally referred to as 'the joinery process'; in German better known as 'Abbund' or the joining of timber pieces. Due to the fact that the beams were chopped out of round wood by hand, each piece of wood was affected by certain inaccuracies. Thus, it was necessary to fit twisted or slightly bent beams to the corresponding counterpart. After a wall had been completely tapped together and was still lying on the ground, the individual pieces were marked, disassembled and then once again assembled piece by piece as the final, vertically rising structure (Gerner, 2007, pp. 89–90). According to the dimensions of a building, large construction sites were necessary to serve as joinery areas or later as a joinery workshop for the craftsmen. Very complex components were first drawn on the ground, or on a wooden floor as drafting geometry, and then copied onto the individual beams (Ulm, 1983, pp. 124–125). This process, described as hand joinery, was one of the main activities of carpenters for many centuries. However, as the precision of the available wooden beams and planks increased, the intermediate step of placing each piece individually on the floor became no longer necessary. Whereas previously each piece had to be picked up manually several times, the so-called geometric or mathematical joinery process made it possible to calculate the dimensions of the components or to sketch them on a geometrically reduced scale. One advantage of geometric joinery is the simultaneous optical verification of the planned draft. A great advantage of mathematical joinery is the theoretical, absolute accuracy as the component lengths, angles etc. were determined mathematically. However, due to the often very complex calculations involving angle functions, the ultimately possible complexity was tied to the craftsmen's mathematical ability (Schneider, 2022). Not only for these reasons, for a long time, drawing boards and hand drawings in actual size, i.e. on a 1:1 scale, were still the most reliable solutions.

As a logical next step, computer-assisted joinery developed from mathematical and graphical joinery. Since the mid-1980s, the craft of carpentry has undergone considerable change (Jeska et al., 2015, p. 60). With the increasing performance of computers and the related CAD software, it has been possible to combine the beneficial qualities of the different joinery methods. For example, plans drawn in CAD programmes have an absolute accuracy that equates to mathematical joinery. Working on screens also brings simultaneous visual control of the parts displayed on the monitor. While in the past, the size limitations of the floor meant that craftsmen had to plan and manufacture a building in partial segments, this kind of fragmentation is no longer necessary on the computer. The digital floor plan is basically only limited by the performance of the computer.

Theoretically, the later printed blueprints on the plotter could be joined together seamlessly. Therefore, it can be said that the opportunities offered by computers and CAD programmes have already moved elementary parts of a carpenter's formerly manual labour into the digital toolbox. Based on my observations in the workshops, I was still able to discover the massive drawing tables used to create hand-drawn plans. But as the craftsmen explained, these tables were either preserved as mementos or intended as an introduction to drawing plans for the trainees. There was no longer any evidence of the large-scale production of hand-drawn plans in any of the workshops. The process of joining wood, once very time-consuming and correspondingly essential for craftsmen, has already been translated into a digital solution to a large extent.

While in the past it was necessary to lay out individual, crooked and curved beams on the floor, nowadays the delivered construction timber is quite accurate in its shape and can be processed immediately after its delivery. Timber is usually ordered on a project-by-project basis, delivered 'just-in-time' and is completely used up, leaving only a few offcuts. Furthermore, complex geometries are first created on the computer and no longer have to be laid out on the workshop floor and then cut down. While the craftsmen used to start their work from the raw material, i.e. the individual tree trunk, the wood is now ordered according to the project and processed straight from there. Both the starting point from the raw material and the actual working method of the craftspeople have already changed, therefore, and have become much more straightforward.

1.2.3 When was 'the break' in the traditional craft of carpenters?

Looking back from today's perspective at the craft of carpentry, one may ask when the break or the change from the historical to the modern carpenter happened. From today's perspective, this once manual analogue craftsman seems to have switched one day to electric machines and then to digitally controlled tools.

As illustrated by the joinery process, the craftsmen's hand movements have changed fundamentally over time. However, in my understanding, the transformation steps that happened in the process should be understood as a very slow and continuous evolutionary processes rather than as significant steps or thresholds.

If one intends nevertheless to subdivide the evolutionary process in the craft of carpenters into a certain technological classification, the doctoral thesis *'Ein architektonisches Periodisierungsmodell anhand fertigungstechnischer Kriterien, dargestellt am Beispiel des Holzbaus'* prepared by Christoph Schindler provides an impressively complete and coherent argumentation (Schindler, 2009). In his work, he illustrates the technological evolution process by means of three waves that are essentially based on the relationship between material, energy and information. The first wave is introduced as 'hand-tool technology', the second wave as 'machine-tool technology' and the third wave as 'information-tool technology'. Essentially, with these three levels he distinguishes between working by hand with hand tools such as hammers or an axe at the first level, working with steam, water or electrically driven machines from around the 19th century onwards, and then working with the integration of computer-controlled machines. The study conducted by Schindler covers a time frame of more than 3000 years. Under this aspect, it is understandable that the waves described contain an accordingly large number of individual phenomena and developments. Although I view his attempt to divide the history of carpentry into three sections as only partially appropriate, I deeply appreciate his unbelievably detailed and consistent line of work and argumentation.

1.2.4 In translation; How do carpenters work today?

If one had to summarise the job description of carpenters in just one sentence, one could define their profession as the craft of making and erecting buildings and structures from wood (Brockhaus, 2019). From a global point of view, however, it is difficult to define a uniform profile of the profession of carpentry today. These differences in the individual job descriptions can also be traced back to the historical roots of the profession in the various regions.

If we look at the development of carpentry in America, the relatively late settlement of the continent by European colonial empires must be taken into account. The related events and injustices between indigenous American people and European settlers are a great humanitarian tragedy. However, if the focus is placed on the craftsmanship of carpenters alongside these events, after some initial log buildings the balloon frame and the platform frame can be seen as the primary construction typology used in America. These two construction methods therefore proved to be suitable solutions for the great demand for housing from around 1850 onwards. The possibilities of steam-driven machines as well as the potential of rational and industrially produced steel nails substantially drove the success of these construction methods. Simple and quick in their implementation, the skills required for these methods also developed with the craftsmen, who were then able to cope with the large volumes of orders with a relatively straightforward repertoire of carpenter's solutions. One interesting point is that in the 1930s, this construction principle returned to Europe, where it became more established as post and beam construction or the now widespread timber frame construction. In contrast to the American version, however, in Europe the quality standards with regard to precision, prefabrication, load-bearing capacity, etc. were further developed to a higher quality (Kolb, 2010, pp. 60–65).

While the craft of carpentry has a relatively short history in America, a far-reaching tradition can be found in Japan. Known for its extraordinarily elaborate and fine solutions, Japanese timber construction stands globally as an absolute top-level achievement in the craft of carpentry. The Japanese temple Hōryū-ji in the city of Ikaruga can be seen as proof of this incredible precision and craftsmanship. Today, it is the oldest wooden building in Japan and was erected as long as 1300 years ago. (Kumano, 2022, p. 268). The position in society of the carpenters working at that time is hardly comprehensible with our modern understanding of the carpenter's craft. For example, at that time the traditional craft techniques and the corresponding expertise were passed on by priests as being the most skilled carpenters (Graubner & Grunder, 2016, p. 40). In strictly organised and vertically structured hierarchies, which also had a further horizontal subdivision, countless sub-groupings and skills were trained in the craftsmanship of carpenters (Zwerger & Olgiati, 2012, p. 59). Following the argumentation of Seike (1990, p. 11), Japanese carpentry can be described as the most highly developed craft in timber construction and timber jointing details. Traditionally deeply rooted craftsmen can still be found in Japan today, working on a few selected, and often pricy buildings. However, it must be said that besides this culturally admirable tradition, a more contemporary type of timber construction has also developed. The small building sites, narrow access roads and the need for a fast construction time on site have led to impressive developments, especially in terms of prefabrication. In Japan, single-family houses are often prefabricated from steel-frame elements and can be erected within a few hours. (Bock, 2015). Besides these steel construction kits, the emergence of buildings made of wood, such as the Muji House or the 'Shawood'-product line that was developed as a separate product family by Sekisui House AG, could be observed over the past few years. (Wada, 2022). These highly specialized and very large-scale house-building factories, however, are only partially comparable to European carpentry. Knot details and technical solutions are manufactured efficiently and rationally, and the employees' tasks require only little knowledge of construction and wood as a building material. The production is more like a prefabricated house factory in timber construction than a carpentry company in Europe.

In addition to this highly standardised house production, however, there are also other, small-structured carpentry businesses. For example, the ‘Onjuku Beach House’ designed by BAKOKO Architects was built by a carpentry workshop with only two workers. The fact that almost all the wooden joints were realised as solid wooden knots makes it impressive from a craft-driven perspective. Formally, the joints can be seen as a modern interpretation of traditional Japanese wooden knots. However, the individual knots were not made by hand, but by a specialised joinery centre. The wooden parts were manufactured using the so-called ‘Precut technology’ system, which is processed on CNC robots and then delivered directly to the construction site. The carpenters’ task is then to assemble the parts into a single structure. A few single, custom-fit pieces were measured and matched on site by the carpenters. The logic of the wooden knots used here correspond to the traditional Japanese wooden joints, but had to be adapted to the technological conditions of modern CNC milling machinery. The tenons and knots are therefore manufactured as a round solution instead of the angular ones that were once common (Golden, 2017, pp. 63–68).

In the contemporary craft of carpenters, however, a somewhat similar, technology-driven adaptation of traditional construction principles can also be found in Switzerland. For example, the ‘Leis’ house built by Peter Zumthor was ‘knitted’ from wooden beams.

Figure 2. Individual beams of the ‘Onjuku Beach House’; Well visible: the machine-made joints (csxlab, 2012)

In this building, the architect, known for his minimalist philosophy, adapted the logic of a knitted building to a new, modern construction. Similar to the ‘Onjuku Beach House’, the beams were manufactured on a CNC joinery machine. In this case, the dimensions of the rooms depend on the maximum lengths of the tree trunks, because the wall can only be as long as a tree trunk (Zumthor, 2006, p. 10). Glued or butt-jointed beams would not have been an option for the architect. For the carpenters, this combination of traditional construction techniques and modern design language meant a particular challenge, as all the construction parts had been left visible. Together with the craftsmen, details were developed that gave the natural changes of wood as a building material sufficient space. For this reason, it is only natural that a knitted house will slowly but steadily settle by several centimetres over the following years (Zumthor, 2006, p. 11).

Figure 3. Carpenters ‘knitting’ the ‘Leis’ house; photo c by Walter Mair Photography (Maier, 2009)

From a global perspective, incredible diversity and variety can be found in the profession of carpentry. For the purposes of this research, the focus has been on German-speaking countries in Central Europe. This scope was chosen as there is a certain geographical, historical and cultural overlap in the understanding of the profession of carpentry in these countries. Although even within this geographical zone there is no unified definition of what the profession and training of carpenters must include (Zwerger & Olgiati, 2012, p. 57), at least country-specific regulations and assessments outline a picture of these experts in wood construction.

In Germany, Austria and Switzerland, the education of this profession begins with a 3-4 year dual training programme. The trainees learn the basics in workshops as well as at a vocational school. Later, they will be able to take a final exam to become an apprentice or, later on, a master craftsman. (Wirtschaftskammer Österreich, 2022). The core activity of carpenters involves all work related to wood as a building material. Besides the skill to manufacture roof trusses, wooden houses and particularly complex constructions such as bridges or observation towers, these craftsmen are also experts in the production of complicated formwork for concrete construction (Lohmann, 2010, p. 1398). According to the definition of the Austrian Economic Chamber, the craftsmen mainly work with wood and wooden materials as a building material. Depending on the project, however, other materials such as mineral insulation, plasterboard or even plastic panels may also be used in the building process. A wide spectrum of building materials is used, and an equally wide spectrum can be observed in the configuration of the projects. While some craftsmen may specialise in certain parts of a building, such as wall panelling, terrace flooring or roof trusses, others act as general contractors and offer customers turnkey houses at a fixed price. The profession therefore has impressive scope at both the material and service levels. Looking at the tools used by carpenters, an interesting differentiation is made in a listing by the Austrian Economic Chamber. The chamber differentiates among electrical tools on the basis of three levels, which are manual, semi-automatic and fully automatic machines. If the list is interpreted precisely, then the boundaries between circular saw, band saw, planing machine, but also joinery machine and CNC-controlled joinery line must always be differentiated in each individual case. (Wirtschaftskammer Österreich, 2019, p. 2).

While a somewhat imprecise three-way division is pursued in Austria, starting from the tool, the situation in Switzerland is narrowed down to only two basic categories. If one looks at the current training plan for carpenters of the State Secretariat for Education, Research and Innovation of the Swiss Confederation, the field of activities of the craftsmen describes the process of joining wood in two ways: There is a distinction between '2.1 Joining wood construction mechanically (CNC)' and '2.2 Joining wood construction conventionally'; (in German: *'2.1 Holzkonstruktion maschinell Abbinden (CNC)'* sowie *'2.2 Holzkonstruktion konventionell abbinden'*) (Staatssekretariat für Bildung, Forschung und Innovation, 2013, p. 4). The following figure 4 shows a section of the abovementioned document:

Tätigkeitsbereiche / Handlungskompetenzbereiche	***Tätigkeiten / Berufliche Handlungskompeter***			
1. Vorbereiten der Arbeiten 4	1.1 Masse aufnehmen 9	1.2 Werkpläne und Listen erarbeiten 1 5 6 7 8 9 10 11	1.3 Betriebsmittel, Arbeitsmittel sicher bedienen, warten und instandhalten 3 5 8	1 v
2. Abbinden von Konstruktionsteilen 4 5 9 10	2.1 Holzkonstruktion maschinell abbinden (CNC) 8	2.2 Holzkonstruktion konventionell abbinden		
3. Vorfertigen von Bauteilen 3 4 5 11	3.1 Vorgefertigte Bauteile (Wand, Dach, Geschossdecken) herstellen 1 7 6 10	3.2 Installationen in der Vorfertigung einlegen 1 7	3.3 Futter für Dach und Wand vorfertigen 1	3 h

Figure 4. In the education plan for vocational training as a carpenter in Switzerland, a distinction into two categories is made between 'mechanical' and 'conventional' joining techniques (Staatssekretariat für Bildung, Forschung und Innovation, 2013, p. 4)

In the written explanations of this illustration, it is added that the young craftsmen must independently mark out the timbers on the basis of a CAD plan in '[...] conventional joinery'. For the actual processing of the elements, '[...] suitable joinery machines (e.g. large, stationary joinery machines)[...]' or also '[...] portable and stationary joinery machines [...]' are to be used (in German: '*[...]*

geeignete Abbundmaschinen (z.B. grosse, stationäre Abbundmaschinen)[...]' and *‚[...] tragbare und stationäre Abbundmaschinen [...]'.*) (Staatssekretariat für Bildung, Forschung und Innovation, 2013, p. 18).

It is interesting to note that timber constructions that are 'mechanically joined' are generally to be processed on a CNC machine. On the other hand, portable or stationary joinery machines can be used for 'conventionally' joined timber elements. Following this distinction, machine joinery is only performed when a CNC joinery machine is used. Work with a stationary joinery machine, which is operated without the computing capacity of a computer, is therefore not 'machine-made', which leads to a certain confusion around the word 'machine' or 'machine-made'. While both cases make use of large and stationary machines, a clear differentiation is made between the two modes of operation, 'mechanised' and 'conventional'. The exact translation of the Swiss definition is only possible to a limited extent, since even in its original language, German, the meaning and distinction is not entirely logical.

In addition to this Austrian and Swiss approach to the question of how the lines between craftsmen and joinery robots are defined, a different approach can be observed in Germany. In German legislation, no distinction is made between manual and mechanical production or between traditional and modern approaches. In the current Regulation on Vocational Training in the Construction Industry *(Verordnung über die Berufsausbildung in der Bauwirtschaft)*, under the focus 'carpentry', it is only mentioned that the young craftsmen must be able to complete a joinery process. The tools and equipment required for this should be selected autonomously by the craftspeople. (Bundesministerium der Justiz, 1999). Even if the German version cannot contribute to a deeper clarification of the situation, it elegantly avoids the conflict by pointing out that the craftsmen should act upon their own judgement and use the appropriate tools.

Although carpenters and joinery robots do their work in all three countries, it is interesting to see that these definitions sometimes express a diverse understanding of the interaction between craftsmen and joinery robots. These different understandings of the country-specific definitions can also be observed on a smaller scale. Within the framework of this research work, it has been shown repeatedly that the craftsmen's individual perceptions of their own profession are also highly heterogeneous. For example, some carpenters only defined working with hand tools (e.g. axe and chisel) as real craft, while others also included electric circular saws and cordless screwdrivers in their understanding. Depending on which carpenters and workshops were contacted, they also described working with a joinery robot as an activity that involves craftsmanship.

In contrast, my own definition of the craft of carpentry is quite short. The absolute and central competence of these craftsmen in my view is an internalised expertise in the development and production of wooden structures. The required skills involve both the planning and the manufacturing process of a building. It does not matter whether they work with a chisel, a chain saw or a CNC joinery robot. What is central, is the ability of the craftsperson to know exactly what is happening and why at any point in the process.
This knowledge also implies that in the case of a tool's technical failure, the working process can be shifted and continued using another technological solution. If a chisel breaks off, work can continue with a router or, under certain circumstances, even a chainsaw. If the control of the CNC joinery system fails, the beam can also be finished with a cordless drill or a router. Of course, these moments of change always mean a re-evaluation of the goal to be achieved. The focus, however, remains on the fact that the process can continue. From this point of view, carpenters have to retain an overview at all times in the production process. They may need to be able to intervene actively, to develop and implement an appropriate solution on the fly. The tools used in the process are therefore merely extensions of the mental capabilities of these timber construction experts.

1.2.5 The joinery robot; Established parts in a new combination

A very detailed and complete illustration of the development of work and tools in the craft of carpentry can be found in the PhD *'Ein architektonisches Periodisierungsmodell anhand fertigungstechnischer Kriterien, dargestellt am*

Beispiel des Holzbaus' by Schindler (2009, p. 194). Using a wide variety of examples, he illustrates how the craft of carpenters has developed in waves according to the tools used. His thesis begins with the very first woodworking tools, such as a simple axe made from a flint and a wooden stick, and ends in the modern day with the most advanced CNC joinery equipment.

Thus, Schindler argues that the logic of the wood saw, i.e. the removal of wood chips in a straight-line working direction, has evolved again and again over the past centuries. Following his line of argument, this logic still finds its daily application today in the form of circular saws and milling heads. In this context he mentions that the solutions used today were not invented in a single day as a brilliant flash of genius, but must be understood instead as a technological evolutionary process. Schindler's work supports the approach that technologies overlap in their developments and new solutions emerge as a combination of things that already exist (Schindler, 2009, p. 223).

While Schindler argues this conclusion in his work primarily on the basis of a historically far-reaching chronology of the carpentry craft, similar developments can also be observed in other more contemporary phenomena. For example Flath et al. (2017), show that the design evolution process on a relatively fast-moving internet platform such as 'Thingiverse' also frequently builds on already pre-existing solutions. On the platform 'Thingiverse', users can download digital models for 3D printers, modify them, print them and, if they wish, upload them again. An interesting feature of the website is that it is able to illustrate the evolutionary progression of a design. If a design, a 3D file is based on a previous solution, the history of the development can be traced back, in a similar way to a family tree. Under the concept of 'remixing', Flath et al. (2017) explain what role pre-existing models play in such a process and what common forms of recombination can be observed. For the authors, 'remixing' means that already existing things are brought together in a new combination so that something new emerges.

A similar evolution can be observed using the example of the saw. Basically, the working principle of this tool has not changed significantly over the centuries. Over the centuries, however, countless small evolutionary steps have led to a wide variety of applications and areas of use. What once began as a simple, straight steel strip now has countless applications in band saws, circular saws, gang saws etc. Seemingly new solutions, thus, usually arise from the recombination of existing things. Previously established and sometimes outdated solutions are not necessarily wiped out in the process, however. They generally slowly fall behind in their significance, which leads to a corresponding reduction in use in the long term. As a final consequence, such solutions are retired as time goes by (Schindler, 2009, p. 223).

Such a combination of existing technologies, which was new at the time, can be seen as the starting point for joinery robots. Joinery machines or joinery robots equipped with a corresponding computer control system are large stationary machines that are produced especially for carpentry workshops. These combined machines cut, mill, drill and mark the timber for the craftsmen. These work steps are referred to as 'timber joining', or in German *'Holz abbinden'* (Lohmann, 2010, pp. 2–3). Starting in about 1950, several woodworking aggregates were combined to form a combination circular saw and milling machine. With the availability of newly developed electric motors, control units, saw blades and milling heads, a level of performance was achieved that made this combination possible in a compact way. These stationary machines, which were still quite large, already made it possible to process a considerable amount of timber in timber house serial production. Compared to today's joinery machines, however, the flexibility of this form of wood processing was still severely limited, as the individual aggregates had to be adjusted and set individually in a partially manual operation (Schindler, 2009, p. 194).

In general, there are several manufacturers of such special machines on the market. The manufacturer and the available machine are selected according to the craftsmen's individual preference and financial possibilities. In the context of this thesis, the focus was put on the machines of Hans Hundegger AG, as they claim to have the greatest penetration of the worldwide market. In discussions with the craftsmen, the products of this company were described as cost-benefit efficient and as providing good long-term service. At the end of the 1970s, Hans Hundegger began to modernise his parents' sawmill business and began to build his own machines for this purpose (Hans Hundegger AG, 2022).

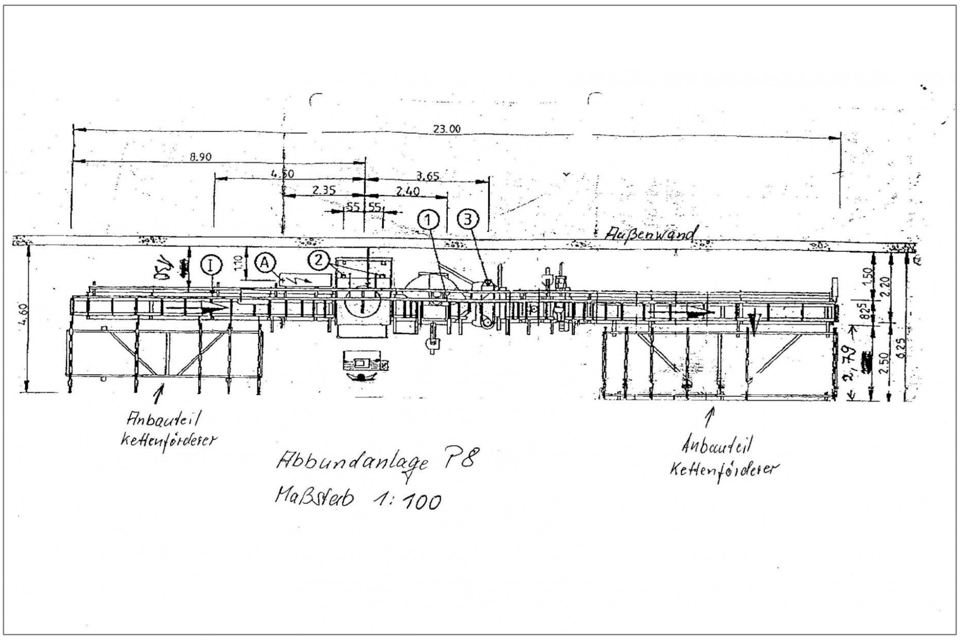


Figure 5. Drawing of a joinery machine, Hundegger P8, which is offered for sale online for 20,000€ after approx. 27 years of service (Gaitzsch, 2022).

Subsequently, among other things, he and his team developed the first joining machine that was made in a comparatively large quantity. By 1992, the so-called 'P8' joinery machine had already been produced and sold 150 times (Schindler, 2009, p. 194). While the first joinery machines of the 1950s still required manual adjustment of the individual aggregates, Hundegger machines made increasing use of digital technology in the form of monitors, servomotors and, later on, computers and even fully integrated digital interfaces.

According to Hundegger, the company has now become the global market leader with its CNC-controlled joinery machines. By 2017, approx. 2750 joinery machines had been manufactured and delivered worldwide. (Hans Hundegger AG, 2022).

If we look at the development of joinery machines, which has already been going on for more than 30 years, we can also observe a corresponding process of technological change. The first joinery machines were a line-up of woodworking aggregates (up to 12), which could be operated from a central control panel. One disadvantage was that only one of the 12 units usually worked on the workpiece, while the others either repositioned themselves or were in a resting position.

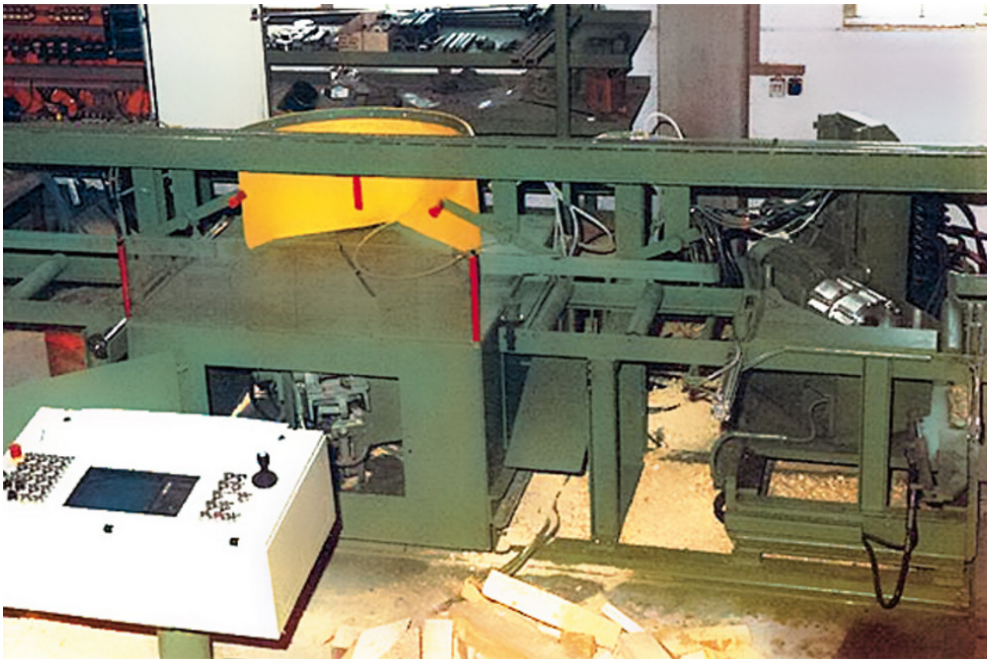


Figure 6. One of the first 'digitally' controlled joinery machines. Clearly visible: The monitor and the control panel for operation (Hans Hundegger AG, 2022).

Due to this line-up of several units, the required space was relatively large. Today's systems generally have fewer aggregates, which can produce much more complex components thanks to automatic tool changers and extended movement options.

Although the spatial dimensions of the joinery robots have not become smaller, the variety of possible solutions and the maximum processable diameters have increased significantly (Lohmann, 2010, p. 3). Compared to the first joinery robots, over the years the size and amount of processed timber have also increased rather than decreased. While the first joinery robots usually worked on simple beams and poles, today's machines are able to work on large glulam products as well. In general, joinery robots are customised in their exact configuration to the needs of a craftsman's workshop. Although the starting point for a new order is a standard series product, when it comes to investment sums of several hundred thousand euros and correspondingly complex production, a precise and customised solution is needed for the woodworking business. For example, material intake and discharge, maximum piece length or waste piece disposal are adapted to the local conditions and needs of a carpentry workshop.

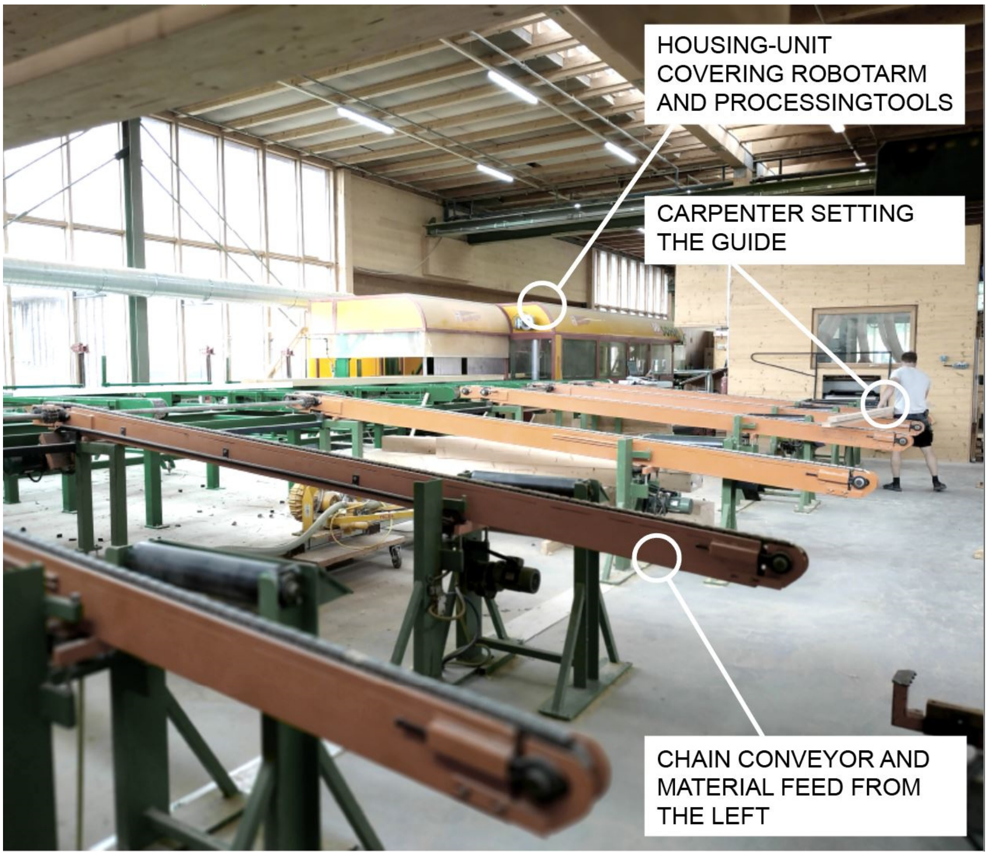


Figure 7. On this very large joinery machine, a chain conveyor transports the timber to the machine.

After delivery, the machines are assembled directly in the joinery hall of a carpentry shop from multiple prefabricated parts. In most workshops, these machines then serve as a new, more centrally located woodworking centre for the carpentry shop.

A Hundegger joinery machine usually works with a pre-mounted roller table, over which the unprocessed timber is pulled into the machine by a horizontally movable clamping gripper. The logs or beams are thereby fed in one by one, processed and discharged as a finished component.

Once a joinery robot has pulled in the first piece of wood, the subsequent processing steps are carried out fully automatically and without human intervention. A spacious hood with the appropriate extraction system ensures a clean workplace and the necessary overview around the machine.

Figure 8. The joinery robot's milling machines are located under the yellow housing. Material is fed in from the left and then expelled on the right.

In order to provide the carpenter and/or the machinist at the joinery robot with an overview even during a running machining process, further devices are provided. For example, the ongoing processing step can be followed digitally on an additional monitor as well as the transparent window on the joinery robot.
After the machine has processed a wooden beam, the component is marked by an inkjet printer or an automatic labelling machine. Now the processed and labelled wood can be removed from the roller table and stored aside for further assembly. Well-organised storage of the individual parts, which can sometimes look very similar, is essential for the ongoing work process.

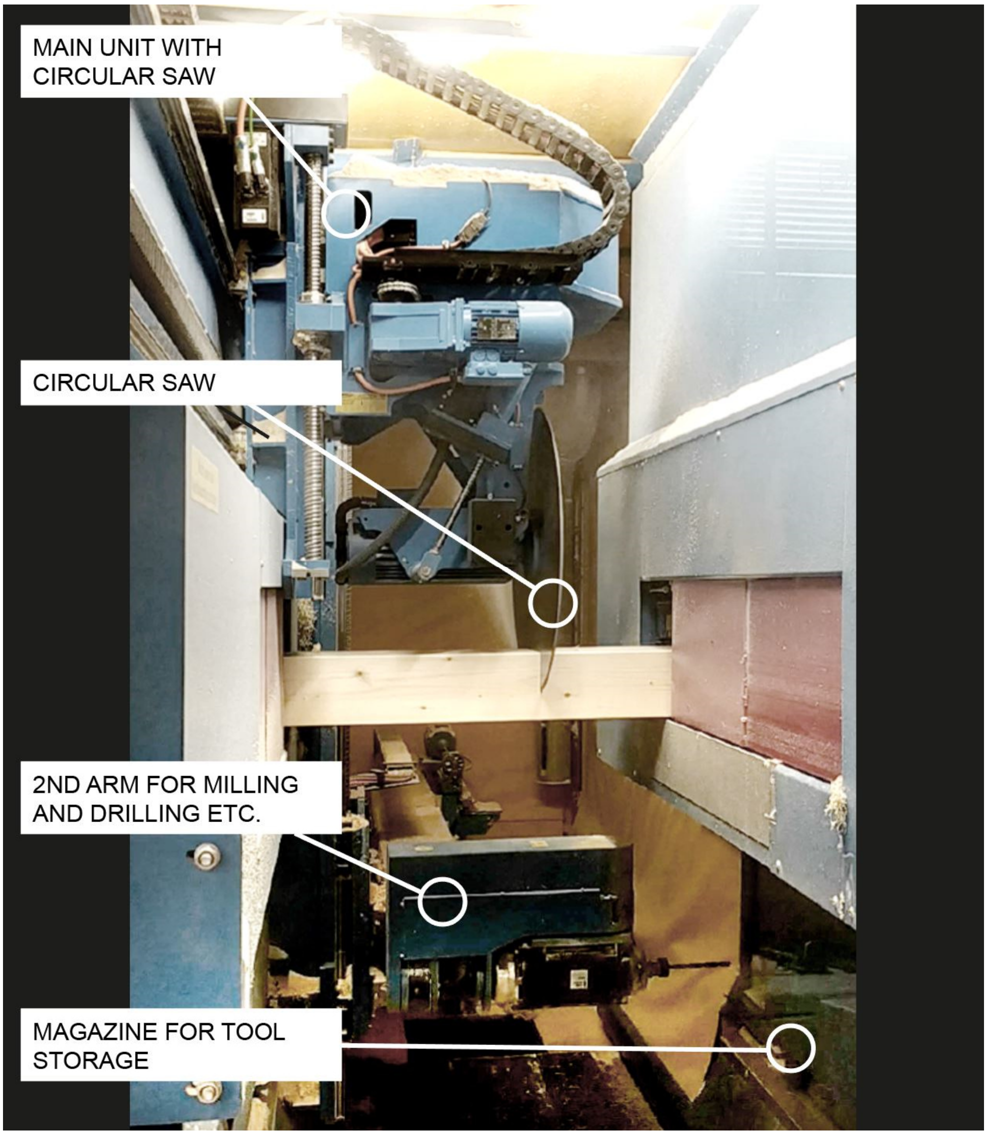


Figure 9. The large circular saw of the joinery robot. At the bottom, a drilling tool can be seen, while on the right, a tool magazine is located, where other milling and working tools are stored.

In daily work, joinery machines are designed for beam-shaped raw materials such as straight wooden planks or glulam beams and by default they can process lengths of up to 10m. While the first joinery machines were operated directly from a control panel, today's joinery robots work with prepared, digitally processed data sets. The timber demand lists and the corresponding processing steps are sent digitally from the CAD workstation in the company's office to the joinery robot located in the workshop. Afterwards, the person at the control panel has to feed in the correct timber profiles for processing and, once the processing has been completed by the machine, unload the finished components. The individual processing steps, such as angular cutting, drilling, rebating, etc., are performed fully automatically by the joinery robot (Verband HIGH-TECH-ABBUND im Zimmererhandwerk e.V.). The machinists I have met (in this case they were always male workers) are trained as carpenters and were then instructed as machinists in a corresponding training course on joinery robots. They therefore have a comprehensive knowledge of timber as a building material and at the same time the manual skills of a carpenter.

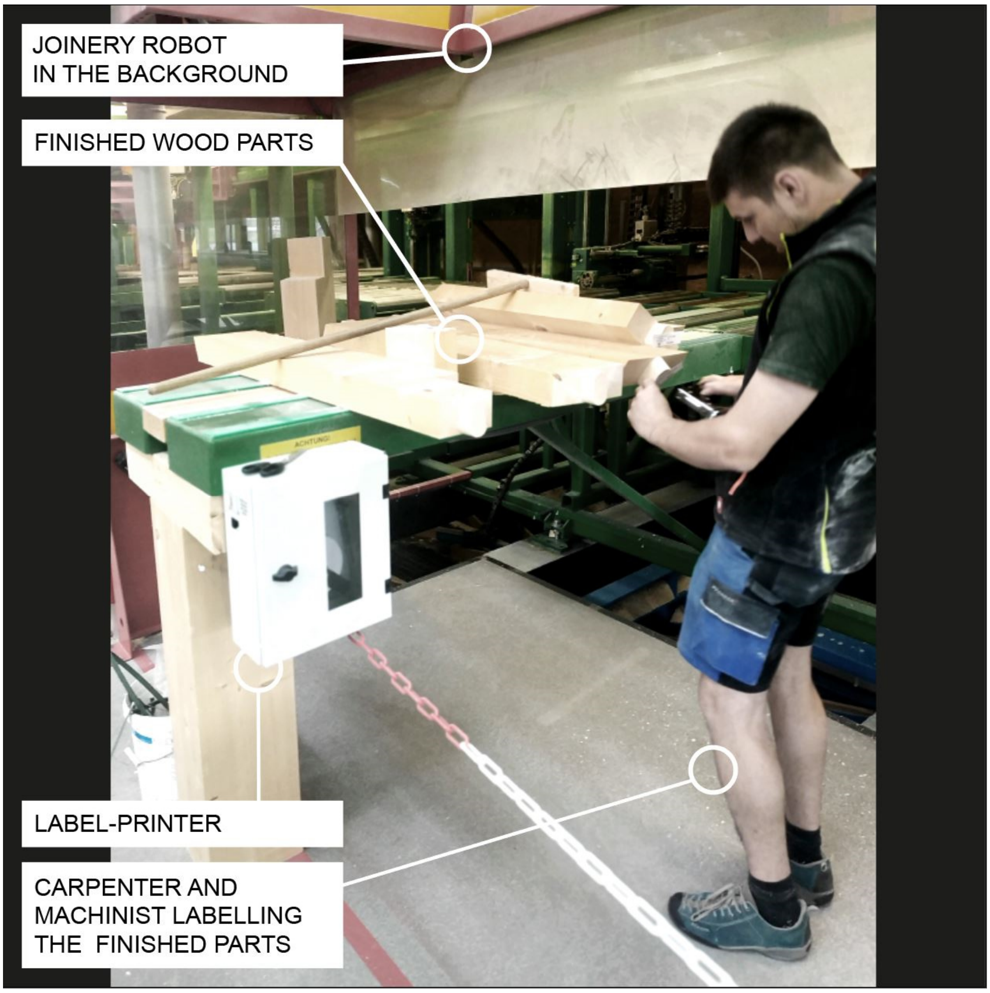


Figure 10. Trained as a carpenter, now in charge of the machine. The craftsman cuts the tags with scissors and then attaches them to the element.

Joinery robots or CNC-controlled joinery machines are fully automatic in their operation and designed for an accordingly optimised and rational process, which in the words of the ‘Holzlexikon’ could even be described as ‘manless production’ (Lohmann, 2010, p. 3). However, as the numerous conversations with the craftspeople revealed, the responsibility of the people who are present at the machine is a vital part of the manufacturing process. The craftsmen mentioned, for example, that the presence of a trained person during the running work process makes sense for (not only) safety reasons. Under certain circumstances, untypical noises or smells can occur while the machine is in operation, which would alert a person and prompt an immediate intervention. For example, due to the natural characteristics of wood as a building material, chips or even entire slats can sometimes break off during processing and possibly disrupt the operation.

As explained by the carpenters, skilled craftsmen with conventional electric machines are comparable to the joinery robot in terms of both speed and precision for simple constructions such as a rafter roof. However, as soon as more complex shapes and geometries are required, for instance a hipped roof, a hip rafter or a dovetail joint, the machine is faster than the craftsmen. The time and effort required to mark complex pieces, turn them and process them using hand-operated machines is too great. As described at the beginning, these robots designed specifically for the craft of carpenters have already been in use for several decades. However, the chunky safety hood and the relatively discrete operation of the machines give this technological change a very unspectacular look. At the same time, entire buildings can already be sent in digital form from the CAD workstation directly to the joinery robot. The analogue steps in between, such as keeping a wood-joinery list or selecting the necessary machines for processing, are substituted for by this digital solution. The craft of carpentry, therefore, has already been in a deep, digital transformation process for longer than one might assume at first glance.

1.2.6 Reflecting on a somewhat misguided image of the future:

If one browses through online magazines or other channels of the timber construction industry, it will quickly become obvious that the topic of digital change is given a high priority. In this context, attempts are being made to provide readers with information on developments currently taking place around digitalisation, Industry 4.0 and sometimes also BIM. To give an example, the online presence of the *'Holzmagazin; Die Plattform für den modernen holzbau'* (Wood Magazine; The Platform for Modern Wood Construction) is considered in the context of this work. Designed as a printed magazine for architects, craftsmen and planners in timber construction, this magazine is published 8 times a year with a print edition of around 14,000 copies. In addition to this print edition, articles are also published online on the holzmagazin.com website. According to the editors, this site receives more than 22,000 hits per month. For some time now, the *holzmagazin.com* website has also dedicated a separate special section to the topic of 'digital timber construction', 'Digitaler Holzbau' in German (holzmagazin.com, 2021). Here, the headline already seeks to make a clear statement, as it claims that in digital timber construction, the future has already begun.


holzmagazin Die Plattform für den modernen Holzbau

architektur technik branche innenraum abo ePaper mediadaten firmen

SPECIAL Digitaler Holzbau zur Übersicht

THEMENFOKUS

Digitaler Holzbau 1: Die Zukunft hat begonnen

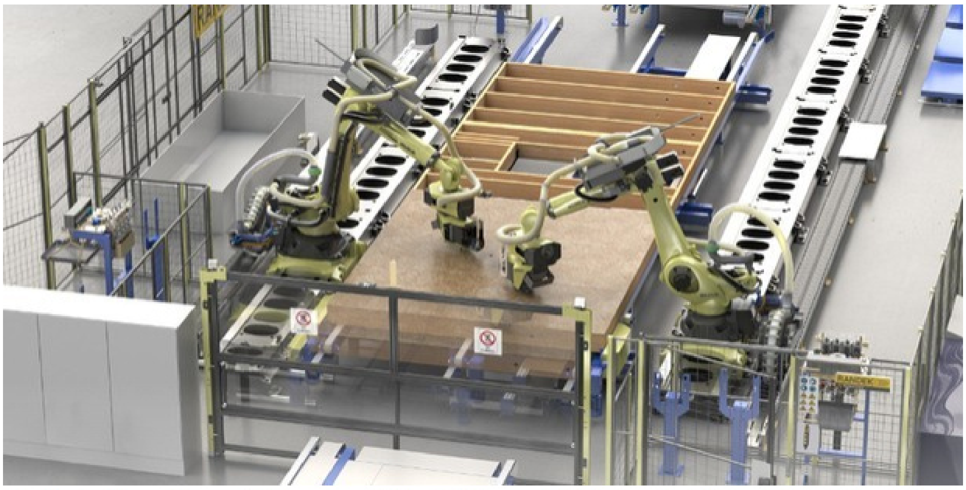
Mittwoch, 24. November 2021

Wer sich nicht auf das digitale Zeitalter einlassen will, ist heute schon abgehängt. Wir zeigen, wo überall digitale Prozesse voranschreiten.

SERIE: Digitaler Holzbau

Figure 11. The topic of the 'digital' in timber construction can be discovered in numerous channels. To some extent, the way in which the individual themes are addressed and discussed is very diverse (holzmagazin.com, 2021).

While this announcement still allows for the possibility of a positive vision, the subheading already clarifies that there are actually no other options left but to embrace this digital transformation, as it says that *'...those who do not want to embrace the digital age are already being left behind today' ('Wer sich nicht auf das digitale Zeitalter einlassen will, ist heute schon abgehängt').* Apparently, there are only two options for the people reading: One is to fully embrace the digital age, whatever this means; the certainty of soon being left behind is in the other prospect. The first paragraph under the title *'Digital timber construction 1: The future has begun' ('Digitaler Holzbau 1: Die Zukunft hat begonnen'),* portrays a fossilised image of an old-established carpenter who no longer understands the world and mourns his work by hand, and sees it only as work done by computer. On the second page, the title *'Digital timber construction 2: BIM is the future' ('Digitaler Holzbau 2: BIM ist die Zukunft')* offers an indication of how to escape this digital trap. An illustration shows how two robot arms assemble some panel material and build a prefabricated wooden element. No humans are visible in this visualisation.



Von der Fertigung bis zum Abriss – der digitale Zwilling merkt sich alles. Grafik: Randek ZeroLabor Robotic System / Randek AB

Auch gibt es imposante, bereits realisierte Bau-Projekte und Best Practice Beispiele, die den Weg weisen. Meist handelt es sich dabei allerdings um Projekte großer Unternehmen mit entsprechender Infrastruktur und weitreichenden Ressourcen.

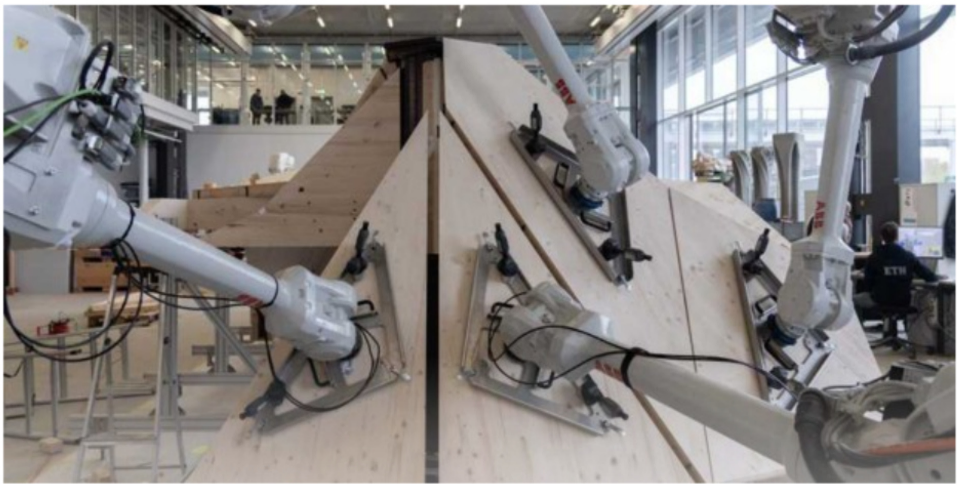
Ist dieser Weg mit BIM (Building Information Modeling) also auch für kleinere Unternehmen

Figure 12. The digital future of timber construction? Similar to an automobile plant, robots put together parts of a building (holzmagazin.com, 2021).

Below the illustration, it is said that the digital twin remembers everything and is thus considered more efficient than humans.

Another, at least as interesting comment from the series can be observed on the third page under the heading *'Digital timber construction 3: The robot in the workshop is a strong buddy' ('Digitaler Holzbau 3: Der Roboter in der Halle ist ein starker Kumpel')*

- **Digitaler Holzbau 3: Der Roboter in der Halle ist ein starker Kumpel**
- Digitaler Holzbau 4: Auf den digitalen Hund gekommen
- Digitaler Holzbau 5: Die Vermessung des Alltags



Vier Robotarme nehmen im Gleichtakt Holzplatten auf und platzieren sie gemäss Computerentwurf im Raum. (Bild: Pascal Bach / Gramazio Kohler Research, ETH Zürich)

Wie sie im Automobilbau gang und gäbe sind, ziehen sie nun in die Hallen der Zimmerleute ein: Roboter. Diese bescheidenen, fleißigen, aber seelenlosen und arbeitsplatzvernichtenden vielarmigen Gesellen können emotional und sozial und kollegial beschrieben, bewertet oder

Figure 13. Robots as a metaphor for innovation and progress; image taken from the online article of holzmagazin.com (2021)

In this picture, you can see four robotic arms that are placing polygonal wooden panels next to each other. Tidy, white painted and in a somewhat sterile setting, the robotic arms are working in a well-lit, transparent space. While the title speaks of ‘the robot’ in ‘a workshop’, which in the larger context of the article probably refers to the joinery hall of a carpentry shop, the photo shows the four robotic arms operating in the workshops of ETH Zurich. The picture thus shows an experimental set-up of the kind that can only be observed in an academic research institution. In this context, it is worth mentioning that this institution is specifically focused on robotic manufacturing and therefore can only have limited intersections with a carpenter’s workshop at all.
However, the use of robotic arms shown here and the headline chosen for it suggest to the reader that such robotic arms may already be part of the daily work of carpenters, especially as there is also a reference to a ‘strong buddy’.

Thus, the article conveys only a partially correct picture of current technological developments in a carpentry workshop. It paints a picture that stands for progress, technology and, in a broader sense, also for ‘digitalisation’.
This stereotypically developed representation uses a story that has been shaped partially by the automotive industry. Aitchison (2017) shows in his work ‘A House Is Not a Car (Yet)’ that the construction industry and the automotive industry have fundamentally different approaches and that they cannot copy each other so easily. For example, he states the sheer difference in size between a car and a house as a significant difference. According to him, a building should be compared instead to the cost of a lorry, some earthmoving machinery or even an aeroplane. Another significant difference Aitchison describes is the geographical dependence of a building. While a car may only drive on paved roads (around the world, in hot or cold climates, but in almost all cases on asphalt, gravel or sand), the global variations of the building site can result in unforeseen extra costs. While one building might require almost no ground preparation, the structurally same building in very close proximity might require several times that amount of foundation work. Besides these geographical uncertainties, there are other cultural, social, political aspects that influence a building’s design- and manufacturing process. In contrast, a car is never designed or planned in relation to its surroundings. For its entire life, it is intended to function as a mobile and moving unit without any geographical dependencies. (Aitchison, 2017, p. 14).
As the previously mentioned example of the website *holzmagazin.com* illustrated, there are different and maybe also distorted perceptions of how technology is used in the craft of carpentry. When you enter the workshop of a modern carpentry company, you probably won’t discover a robot arm. So, the question arises as to why the timber construction companies do not make use of this technological solution. The often-used image of this flexible and speedy robot arm would significantly improve the success of a craft such as carpentry.
However, in the everyday life of the craftsmen, it may be that a carpentry workshop is already more technologically advanced than it appears at first glance. This point is important, insofar as there may not be a white or orange painted robot arm at all, but the complexity of the building components, the

processing speed and the precision in the production are already at approximately the same level. The robots used in carpentry companies therefore have a different visual appearance to what we know from the automotive industry or illustrations dealing with Industry 4.0.

Nevertheless, it can be said that robots already found their way into the workshops of carpenters 20-30 years ago. As described in Section *1.2.4 In translation; How do carpenters work today?*, these machines have gradually conquered a place in joinery workshops in an evolutionary process. However, this process has been much less spectacular and 'disruptive' than the media might portray. This means that robots, i.e. electrically controlled and partly autonomously acting machines, are already making their contribution in the carpentry profession, but they might not necessarily have the same appearance as in the automotive industry. Interestingly, in articles on technological change in the construction industry, a comparison with the automotive industry is often attempted. The automotive industry represents an ideal to be achieved in terms of cost efficiency, automation and quality standards with regard to manufacturing. However, as shown by Aitchison (2017), there are fundamental differences between the real estate and automotive industries. According to him, the frequently made comparison between the two industries may be used only to a limited extent as a learning model. The orange or yellow robot arms used in the automotive industry have a strong symbolic association with technology and progress, as they seem to be able to do the job quickly, accurately and flexibly. Nevertheless, the technical circumstances of a production line such as the one used by car manufacturers can hardly be compared to the requirements of a carpentry workshop. Joinery robots that are already in use in the timber construction industry perform their work in a far less remarkable way. Hidden under a protective hood, they might work more slowly, but are for sure as powerful and reliable as the countless robots of the car industry. So, from an automation perspective, carpenters already possess solutions that transfer significant parts of their previously manual work to robots. However, the appearance of these solutions does not necessarily match the media-effective images from the automotive industry or from university research institutions that one might be expecting. However, under the aspect of 'digitalisation' in the craft of carpenters, it can be said that robots have already been performing substantial parts of the manual work once done by a carpenter for several years now.

1.2.7 Is the profession of carpentry more fragmented today than it was in the past?

From the current perspective, it is not easy to answer this question. One thing that can be stated quite clearly is that today, many different skills and profiles are required in a carpentry workshop. For example, there are trained carpenters and technicians who draw CAD plans, others who operate a joinery robot, others who manufacture and produce the wooden elements, and still some others who finally erect the building on the construction site. In addition to these tasks, there is a need for people who are familiar with wages and taxes, but also with personnel management and insurance issues in relation to modern timber construction. Furthermore, due to today's technological developments in prefabrication, it is crucial that building materials are scheduled on time and that transportation activities are organised in advance. Depending on the size of a company, all these tasks have to be covered by 2 or 3 people in a small workshop, or each of these activities is assigned to a single person in a big workshop. While in a small workshop almost all the people are involved in the various tasks, in a large workshop very different profiles might be necessary. In addition to this diversity of employees in a company, there are also the buildings, which are constantly becoming more complex and demanding. While 60 years ago a detached family house built of brick could be built with one massive brick wall, in modern timber construction it is not uncommon to have 10 or more layers of different construction materials in an outer wall. Corresponding to these different layers, there are also various standards, working techniques and technologies that have to be followed. However, a straight comparison to the craft around 200 years ago is only of limited value in providing answers to the question of the complexity of the carpenter's craft. In earlier times, it was still necessary to straighten the logs by hand or to be able to independently assess the quality of the wooden beams needed for construction. What from today's point of view seems like an exhausting and monotonous job, or what now is regulated by building standards and guidelines, required a considerable background of experience and knowledge. For example, one crucial question was which side of a round tree trunk would be on top or at the bottom in the later construction process, as this could directly affect the stability of the building. The craftsmen also had to be able to imagine what dimensions and lengths could be processed out of a log while it was still in its round shape (Opderbecke, 2013, p. 24). Only when the beams had been shaped with angular profiles could a corner connection with the next, neighbouring piece of wood be carved and then produced. To a certain extent, the craftsmen of the past therefore required many more imaginative skills than those required today with the help of CAD drawings and dimensionally precise profiles. The same could be said for the subsequent manufacturing process of a building. For instance, hip rafters had to be correctly calculated and marked out. In the event of a mistake, the lost timber beam would have been a far more devastating loss compared to today's working practice. Besides these skills required in manual work, the profession of the carpenter has also been divided up in different ways depending on the various cultures. In Japanese timber construction, when working on sophisticated buildings such as temples, it used to be common to assign up to 6 or even more hierarchical levels of carpenters (Zwerger & Olgiati, 2012, p. 59). The top level, usually covered by priests, therefore had different responsibilities to a craftsman who was only responsible for wall cladding or wooden columns (Graubner & Grunder, 2016, p. 40). It was probably also this extremely structured hierarchy that ultimately contributed to the impressive results of Japanese timber construction. Whether the profession of carpentry has become more fragmented over time, or whether the complexity required of it has increased, must be considered and discussed individually. It can be said that the craft of carpentry has always required a very extensive and broad knowledge of the people involved, regardless of whether the trees had to be straightened by hand or the vapor barrier had to be glued on correctly.

1.3 Is that still *'craft'* at all?

1.3.1 'Craft' as a flexible concept illustrated by the example of the planing machine

While the observations so far have illustrated mainly the technical development process and the resulting change in the profession of carpenters, the question of the role of the craftsmen in this process has still remained unexamined. In an exhibition conceived by Peter Zumthor in 2016, the architect showed the range and diversity of craftsmanship in our society. One part of the exhibition was entitled *handmade*, in German *'Handgemacht'* and featured a video of an interview between Zumthor and a joiner. While the craftsman is pushing a piece of wood through a planing machine, Zumthor asks if what he is doing is actually still craftsmanship. The joiner confidently answered with a yes and explained that he was, after all, planing the wood. (This dialogue is also cited as the introduction to this paper in the first section; in German: *Zumthor 'Ist das eigentlich noch handwerklich, was du da machst?' Der Tischler antwortete ‚Ja, ich hoble doch das Holz.')* (Zumthor, 2016, p. 80). As Zumthor mentions in the corresponding exhibition documentation, he intends to show 'without any ideology at all' what craftsmanship means in today's world. But it has to be said that the question posed in the interview as to whether this is 'still' artisanal already implies a certain attitude towards what can be described as artisanal. In an undertone, he communicates that something else, another activity, must have been more 'artisanal' before than is now the case in the video document. His statement, which is actually formulated as a question, thus implements an attitude taken by Zumthor towards craft work. The work otherwise done by hand by the joiner seems to be reduced to only setting the machine, switching it on and then feeding a piece of wood through the machine. Parts of the actual work performed by the joiner, however, remain unconsidered, such as deliberating how the wood should best be fed into the machine or whether the board is suitable for the coming work process. While the carpenter in this dialogue only briefly explains that he is 'just' planing some wood, the brief verbalisation of the activity is accompanied by a much more extensive set of thoughts than it might seem at first glance. This question-answer example forms an introduction to the far-reaching discussion about a change in manual work. The word ‘still’ in Zumthor’s question suggests a loss, a loss of what Zumthor personally might call craftsmanship. This example stands for the discussion of the ‘right’ or ‘real’ craftsmanship or, subsequently, how much ‘hand’ there must be in handicraft or craftmanship. But it also opens up the debate about the newly arranged relationship between craftsman and workpiece.

Depending on the era and the stage of technological development at which one takes a look at production methods, one can always observe moments of insecurity on the part of craftspeople in relation to their own profession. What was the question in the dialogue between the carpenter and Zumthor about a hand-held plane in comparison to a planing machine can be observed equally at a previous stage of technological development. In 1942, for example, Herman Phleps already criticised a loss of manual skills due to the hand plane. While the wood previously had to be straightened with a drawknife, i.e. using a simple steel blade with two handles, a hand plane did the same job in less time and with more precision. In the view of Phleps (1989, p. 43), however, qualities of the natural material and skills of craftsmanship are lost through this efficiency-enhancing step in the evolution of woodworking. The drawknife, for example, requires the craftsperson to realign the tool with each new pull. In each subsequent stroke, the natural differences of the raw material wood are noticeable to the person working. So, in the next pull, the characteristic of the material can be taken into account again, and the alignment of the drawknife can be adjusted. In contrast, according to his description, the work and the result with the hand plane is already predetermined. Compared to the draw knife, the hand plane does not allow any immediate changes during the work. The fixed clamped blade and the nature of this tool therefore add a level of abstraction to the process of straightening. Phleps summarizes:

‚Je mehr man aber dem Werkzeug an selbstständiger Leistung aufbürdet und anvertraut, um so loser werden die Bindungen zwischen dem Handwerker und dem Werkstoff‘ (Phleps, 1989, p. 43).

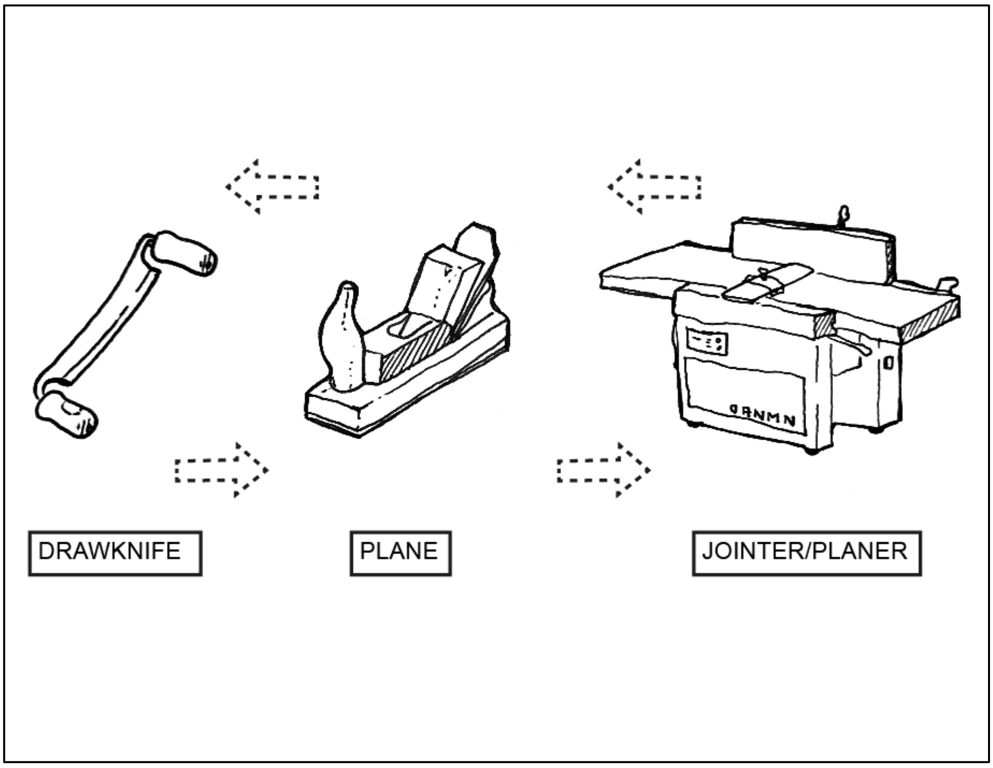


Figure 14. A rough plank can be straightened with a drawknife, a hand planer or an electric planer. The activity is always referred to as 'wood planing'. In this sense, the tool used might not be important to mention.

What Phleps had already expressed in 1942 as an unfortunate loss of bonding between the craftsman and the material is addressed again in the interview conducted by Peter Zumthor. The underlying and always constant goal, which is to straighten a piece of wood for further processing, has not changed at all. However, the tools used and the associated hand movements of the craftsmen have changed fundamentally over the years. While the blade of a drawknife is pulled across the board by muscle power in individual movements, the electrically driven blade shaft of a planer rotates with up to 8,000 revolutions per minute. For the joiner interviewed by Zumthor, however, the perception of his own profession remains fully intact at its core, since he is still planing a piece of wood, as he stated *(Zumthor, 2016, p. 80).*

1.3.2 The changing craft of joining wood

While this excursion has been based on the work of a joiner planing a piece of wood, the question remains what changes can be observed in relation to joinery robots and carpenters. As explained in the previous section, joinery robots are stationary machines that can autonomously process wooden pieces. The profile of these machines is therefore specifically customised to automate activities that were previously performed manually by carpenters. From this perspective, the only remaining task for a carpenter is the digital planning of a building and the subsequent assembly and erection of the structure. So, through the use of a joinery robot, have carpenters lost an essential aspect of their craft?

One possible answer to this question depends essentially on what is to be called the craft of carpenters. It therefore depends on whether we are talking about craft in the sense of manual work, i.e., the purely physical activity, or whether craft is understood as a subject-specific profession.

If one considers only the carpenters' manual work, i.e., work that is done with the hands, it can be said that the joinery robot has already taken over large parts of the profession. With the machine, activities that were previously carried out by hand, such as marking out the wood or then cutting it with the circular saw and adding the corresponding cerves or tenons, can be done by the machine without any problems. In most cases, the machine can perform these tasks even faster, more accurately and, in the case of complicated components, more reliably. If the profile of a carpenter is limited to this purely physically performed work, it can be said that a robot has already taken over numerous work steps here. However, if we look at the holistic process that is necessary to develop and erect a wooden structure, it can be said that the joinery robot is just one more technological step in the constantly changing profession of carpenters. In a similar transformation process, drawing tables for planning timber constructions were replaced one day by computers and plotting machines. At least in the carpentry shops I know, projects are now only designed and planned on computers in a digital way. So here, too, a change in working methods can be observed in the example of the creation of plans. However, the actual contents of the digitally created and machine-plotted plans have still been preserved and show important information as general plans, installation plans or detailed drawings. Regardless of whether work is done in an analogue way or also digitally, it needs a project-specific cognitive process. This means that the need for mental work remains the same: The person drawing needs experience in timber construction and knowledge of standards and construction guidelines, and in addition, they need an understanding of the subsequent assembly process.

All these underlying conditions must be taken into account and brought together in the best possible way when drawing plans. 3D programmes and CAD tools can facilitate the drawing process, but the responsibility of the person doing the drawing remains. As was stated by an apprentice during an interview, the joinery robot is only as 'smart' as the person drawing at the CAD workstation. If the person at the CAD workstation is inexperienced or careless, the best joinery robot will not be able to compensate for this deficit. In this sense, the machine can be seen as a digital extension of the mental abilities of a CAD draughtsman or draughtswoman. Similar to the way a computer mouse contributes to the digital extension of human abilities at the computer, a joinery robot must also be understood to a certain extent as a digital extension of human abilities. The knowledge and active participation of all the people involved is therefore central to the success of these work processes. Many craftspeople (CAD draughtsmen, joinery robot technicians and also classic carpenters) pointed out the importance of a close and targeted exchange of information on a project. This begins with an initial project meeting in the office and continues with regular, short dialogues during the ongoing production process.

1.3.3 The ability of combining knowledge and skills;

If we focus on the process of joining wood, i.e., on the marking, cutting to length and fitting together of wooden beams in the carpenters' craft, a transformation process can be observed based on the different methods of joining. Depending on what source one follows, three or four different types of joinery can be identified. According to Schneider (2022) and Loeffelholz (n. d.), traditional joinery, graphic joinery, mathematical joinery and computer-assisted joinery can be differentiated. In discussion with the instructors of the carpentry department at the vocational school in Dornbirn, I was told that they only distinguish between traditional, graphic and drawn and computer-assisted joinery in their lessons. This information also corresponds with the three distinctions made by Batran et al. (2021, p. 69). Which method of joining will be used on a project depends on the technology available, the knowledge of the craftsmen, and an approach that is suitable to the project. The choice of the appropriate type of joining is mostly made by a skilled craftsman. As mentioned by Batran et al. (2021, p. 69), a 'good carpenter' can also be identified by this decision, as he or she can accomplish a project in the appropriate and therefore most straightforward way. The method finally used may even compensate for some human labour, but the intellectual effort contributed by the craftsman will not be replaceable in any of the three or four different ways of joining wood.

In traditional joinery, the pieces of wood are laid on the floor piece by piece and cut to length (Lohmann, 2010, pp. 2–3). As already described in section *1.2.2 Before this translation; How did carpenters work until now?* this was the earliest method of joinery and, due to the limited technological possibilities at the time, the only choice. The inaccuracies of hand-hewn timber and the large number of different cross-sections involved meant that carpenters had to work directly, piece by piece, with the wooden beams that had to be joined (Gerner, 2007, pp. 89–90). For traditional buildings such as a timber-framed house or a barn, the time and effort was acceptable in relation to this method of working. One major disadvantage of traditional timber joinery is the time-consuming work and the amount of space that is required (Krauth, 2003/2018, p. 62).

In the case of drawn or geometric joinery, on the other hand, the timber construction is first drawn and then manufactured according to a scaled-down drawing of the design. After manufacturing, some parts are put together for a trial fitting, but a complete laying out of the construction as required in traditional timber framing is not necessary (Schneider, 2022). One big advantage of drawn or geometric joinery is that it allows a visual check at the same time. However, the possible accuracy is limited by the accuracy of the drawing.

Mathematical joinery is generally based on the mathematical calculation of lengths and angles (Loeffelholz, n. d.). The accuracy of mathematical joinery depends in general on the number of decimal digits used or the range of the angle functions that were applied. Ultimately, the capabilities of mathematical joinery are dependent on the mathematical skills of the calculating person. The more complex a building or a geometry becomes, the more complex the angle functions and calculations will be. However, it can be said that there is always a certain remaining risk, as an accidental calculation error can occur under certain circumstances. As indicated above, there are three or four different types of joinery mentioned in the sources. If one only mentions three methods of joinery, the methods of drawing and calculating in timber joining are combined in a hybrid form (Batran et al., 2021, p. 69). In the case of particularly large and complex structures such as clerical roof structures or bridges with a respective length, the various methods of traditional, mathematical and geometric timber joinery are used in combination (Schneider, 2022).

With the emergence of the computer and CAD programmes, computer-assisted joinery finally became common practice in the craft of carpentry. With software specially designed for carpenters, such as CADworks or SEMA, a planned construction project is drawn in 2D or 3D. The possibilities of computer-assisted joinery combine the strengths of all the other joinery methods. In this way, the construction can be visually checked via the monitor as a 3D model or as a plan drawing. The preciseness of the drawing is mathematically guaranteed by the computer through constant calculations in the background and no longer has to be calculated and checked by the craftsmen themselves (Doelling, 2016). The building is drawn in true size, but as a digital model. Similar to traditional joinery, every corner can be checked in detail for its geometry. Although the beams that are used no longer need to lie on the floor in real size, their digital representation can be examined and processed to an equal extent and with the appropriate effort. Another significant advantage of computer-assisted joinery is the more or less unlimited project size. The digital drawing board can theoretically be extended without limit. The resulting data volumes require only a relatively small amount of memory and can be transferred to a USB stick or emailed without delays. In the subsequent manufacturing process, computer-aided joinery in combination with a joinery robot offers further benefits in terms of efficiency. Thus, the data exchange between the CAD workstation and the joinery robot is synchronised in the best possible way. Data from the digital 3D model is exported and can be processed directly on the joinery robot. The creation of hand-held trimming lists, the marking of the wood and the calculations of the steps for further processing of the components is handled by the software and subsequently by the trimming robot. In contrast to traditional, mathematical and geometric joinery, the advantage of the digital model in computer-assisted joinery is again significantly increased by the integration of a joinery robot (Batran et al., 2021, p. 69).

If one compares the different methods of timber framing, it is evident that the manual contribution of the craftsmen has been reduced step by step. In traditional joinery, each piece of wood was laid out individually and marked in accordance with the neighboring piece, whereas in geometric or mathematical joinery, a large part of the former manual work was already done at the drafting table, on the pocket calculator or in one' s head. The dimensions of the various beams required for the next steps were planned in advance by drawing or mathematically defined by using extrapolated distances. Not until this theoretical step has been completed does a beam, a piece of timber, enter the workflow as physical construction material. Thus, the process of joining wood has once again undergone a significantly stronger division into an advance planning phase and a subsequent manufacturing phase. This observed separation between the construction and planning process is further increased by an additional level of abstraction in the computer-aided joinery process. As 2D or 3D models, the wooden beams will only be arranged digitally and later automatically cut and trimmed with the help of a joinery robot. In order to further increase efficiency, the joinery process was divided into different phases and slowly developed from working on the wooden beam directly to an advance planning process with a subsequent manufacturing process. Work steps that previously had to be done directly on each piece of wood shifted from the joinery yard or the carpentry workshop to an office environment. As a result, the historical image of the carpenter, once traditionally joining wood, has more or less disappeared from our region for quite some time now. Even without a joinery robot, blueprints are only drawn on a digital basis. In the same way, wood is now only processed just-in-time and more or less straight from the truck.

Interestingly, the word for *'joining wood'*, in German *'Holz abbinden'* has always remained the same throughout all of these periods of change. Even though the activities, procedures and contents have changed fundamentally, a 'joinery' robot seems to be 'just' a robot joining wood, and decades ago a traditional wooden building was also constructed from joined wood. Work process elements have been changed, replaced or have completely disappeared, but nevertheless, the craftsmen interviewed in this research always clarified that they are still joining wood and that the process of joining is a core activity of their work. From a technological point of view, however, it can be said that when using the phrase of 'joining wood' today we are describing something completely different to what craft people did a hundred years ago. For the craftsmen, for the training manuals and for the overall craft process this subliminal but constant transformation of the activity seems to be of secondary importance. Likewise, the fact whether a company owns a joinery robot or not was not a determining factor in these dialogs.

Figure 15. Carpenters in the joining process. Both the left and right images show carpenters in the joining process of wood. However, there is a gap of more than 400 years between the two images; right image: (Wilhelm, 1668).

It can therefore be said that the expression 'joining wood' has remained as a descriptor for the work of craftsmen, but the work steps and processes associated with this concept have undergone a radical transformation. In the same way, the range of the skills mastered by carpenters has also changed significantly in comparison to former times. Whereas in the past they had to hew logs themselves and arrange them in relation to each other on the ground, nowadays aspects such as vapour diffusion or heat transmission have become crucial issues for these craftsmen. If we compare these changes with the definitions of carpentry in Austria, Germany and Switzerland, the German version in particular carries an important message. Following the German definition, an integral part of the education of carpenters is the ability to select and use tools and small equipment by themselves (Bundesministerium der Justiz, 1999).

It is therefore up to the individual craftsperson to choose the right tool for the corresponding task. This remark, which is somewhat open, does not make any decision with regard to the use of tools, whether these are a hammer, a circular saw or a joinery robot. Instead, it claims the necessity for situation-related competence to act from the craftsmen. In other words, it is up to the experience and judgement of the craftsmen to decide which technological solution to choose. As already summarised, the various forms of joining wood differ above all in terms of the hand movements required in the process. In the case of computer-assisted timber joinery and under the implementation of a joinery robot, at the latest, a high degree of automation of work previously carried out by hand can be observed. For the profession of carpenters, this technological step means a partial reduction of manual activities. However, this relief on a physical level is not a necessarily a substitute for the specialist knowledge that is still required in the overall process of working with wood as a building material. The manner in which a project is handled, what work steps have to be taken and how, thereby remains as a key competence that cannot be covered by a joinery robot. For example, a craft workshop may own a joinery robot, but the specified task can be completed with plans simply drawn by hand and accomplished with portable power tools. This solution may be appropriate for a particularly simple construction or a renovation project. A simple hand-drawn sketch, the necessary measurements and the expertise of the craftsmen may be sufficient to be able to complete a project quickly and correctly. In this case, the direct work on a building can be a significant advantage, as existing structures can be immediately captured and measured, and a solution can be added. The stationary nature of a joinery robot and the need to first construct components using a 3D scanner or manual measurements that later have to be digitised can be far more time-consuming for such tasks.

The question of how and with which tools a project is effectively executed remains a key competence of the craftspeople. Even if new technologies have removed some of the manual work, the relevance and necessity of the craftperson's experience and knowledge remains central to the process.

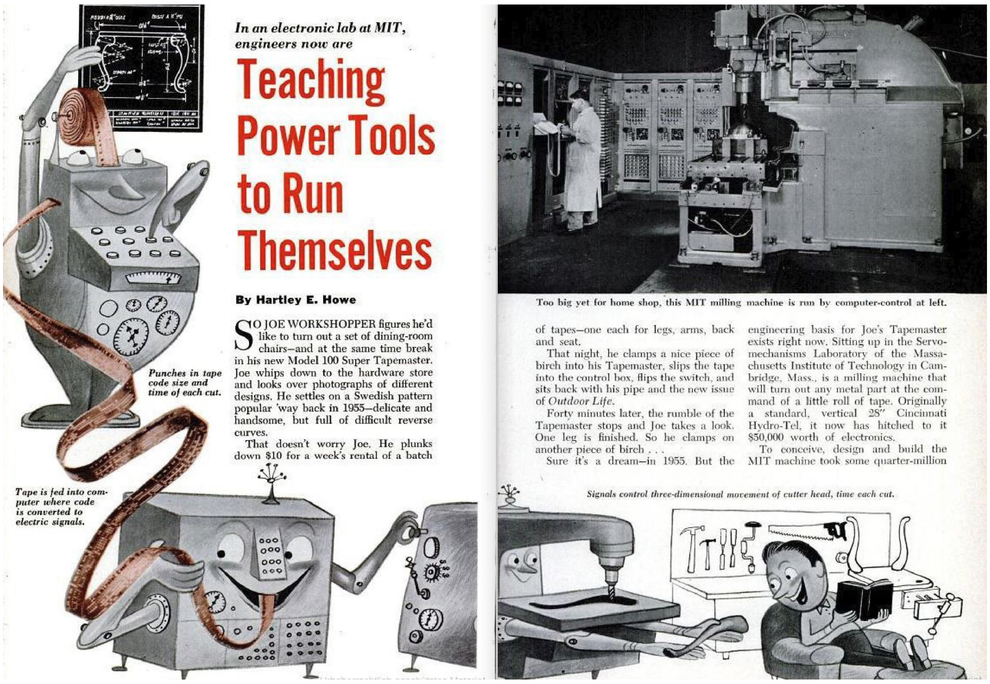
1.4 The craftsmen and their machinery

As illustrated in the previous chapters, it can be said that the work of carpenters is in a constant but gradual process of transformation. While conducting this research, this transformation process revealed uncertainties among carpenters regarding their own profession and their future responsibilities. The question of 'the real craft', of the actual profession of carpenters, was raised repeatedly, and the importance of a corresponding level of expertise was stressed. What resonated in numerous conversations, however, can also be observed in social media activities. For example, in a post by a carpenter's workshop from the Bregenzerwald, it was explicitly pointed out that for the construction of an alp building, there was no involvement of CNC machines. According to their words, they consciously worked exclusively with hand-held electric machines. This work of course includes cordless drills, hand-held circular saws and chainsaws, as well as the use of a remote-controlled overhead crane in the workshop. By giving priority to the tools that are used, the focus should move back to the handicraft. In this short article, the aim is to create an image that is once again in line with a personally defined tradition of the carpenters' craft.

Figure 16. Social media post of a carpentry company describing the intended decision not to use CNC machines in favour of so-called 'real' craftsmanship (Kaufmann, 2019).

As also observed by Schindler (2009), for some craftspeople the new complexity of CNC joinery machines has resulted in the feeling that they are losing control over the production process.

This question about one's own role in the process and the uncertainty about new technologies in one's profession is nothing new and has existed in our society for a long time. In the 17th century, the example of the loom showed how 'replaceable' the work of craftspeople can be (Sennett & Bischoff, 2008, pp. 119–122). In a similar way, in 1955, Popular Science magazine illustrated how robots might soon be making furniture. The owner of the machine, Joe Workshopper, sits in his armchair while three obviously amused machines read a punched tape card for him, interpret it and make a table leg from this information. The accompanying article introduces readers to the potential of punched tape cards and how they will simplify manufacturing processes and enable the exchange of data in the future (Howe, 1955, pp. 106–107).


In an electronic lab at MIT, engineers now are

Teaching Power Tools to Run Themselves

By Hartley E. Howe

SO JOE WORKSHOPPER figures he'd like to turn out a set of dining-room chairs—and at the same time break in his new Model 100 Super Tapemaster. Joe whips down to the hardware store and looks over photographs of different designs. He settles on a Swedish pattern popular 'way back in 1955—delicate and handsome, but full of difficult reverse curves.

That doesn't worry Joe. He plunks down $10 for a week's rental of a batch of tapes—one each for legs, arms, back and seat.

That night, he clamps a nice piece of birch into his Tapemaster, slips the tape into the control box, flips the switch, and sits back with his pipe and the new issue of *Outdoor Life*.

Forty minutes later, the rumble of the Tapemaster stops and Joe takes a look. One leg is finished. So he clamps on another piece of birch . . .

Sure it's a dream—in 1955. But the engineering basis for Joe's Tapemaster exists right now. Sitting up in the Servomechanisms Laboratory of the Massachusetts Institute of Technology in Cambridge, Mass., is a milling machine that will turn out any metal part at the command of a little roll of tape. Originally a standard, vertical 28″ Cincinnati Hydro-Tel, it now has hitched to it $50,000 worth of electronics.

To conceive, design and build the MIT machine took some quarter-million

Punches in tape code size and time of each cut.

Tape is fed into computer where code is converted to electric signals.

Too big yet for home shop, this MIT milling machine is run by computer-control at left.

Signals control three-dimensional movement of cutter head, time each cut.

Figure 17. Three seemingly friendly CNC machines get their information from punched tape technology; they make a table leg for Joe Workshopper (Howe, 1955, pp. 106–107)

This positively connoted and amusingly illustrated way of automating manual tasks was taken up just a few years later by the German magazine ‘Der Spiegel’ in a very contrary illustration. On the cover of issue no. 14 from 1964, a worker with a spanner in his hand is kicked aside by an oversized robot. Similar to the previously described illustration from ‘Popular Science’, a humanoid-looking apparatus is controlled by a punch card system. Equipped with 6 robotic arms, the machine appears to perform many times the work of a small, single human. In contrast to the robots in ‘Joe Workshopper’, this oversized robot communicates a rather uncomfortable future with its frigid expression (Spiegel, 1964).

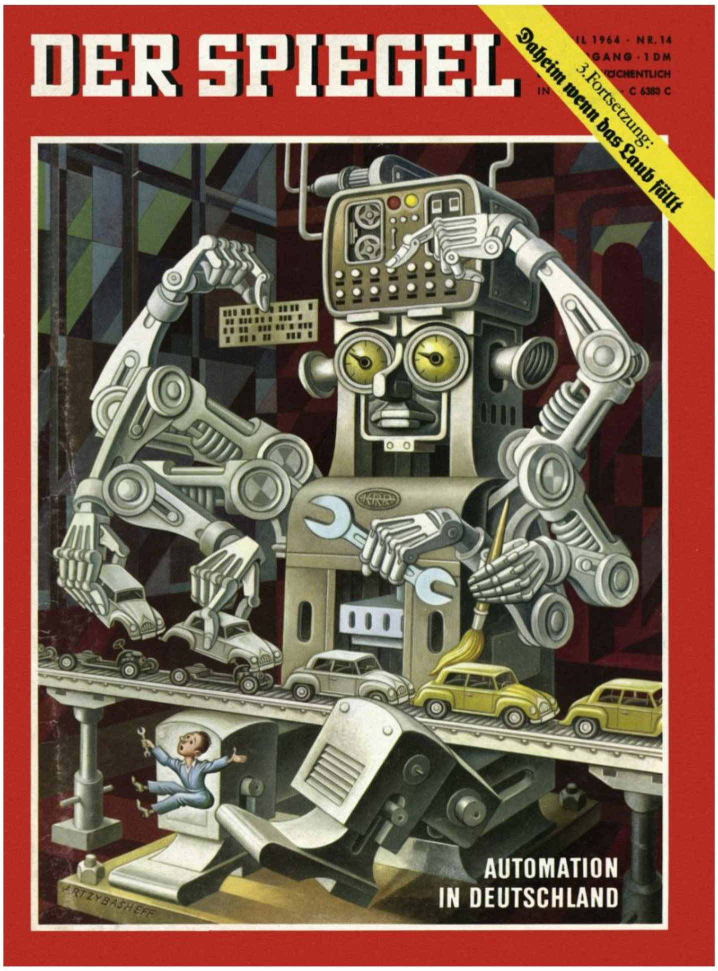


Figure 18. Man replaces machine; The cover of the magazine 'Der Spiegel' shows how a robot knocks a human off his workplace (Spiegel, 1964).

At almost regular intervals of about 25 and 50 years, 'Der Spiegel' published an issue with a similar focus under the heading of technological substitutions for human labour. Thus, in 1978, under the title 'Fortschritt macht arbeitslos' (Progress makes people unemployed) and in 2016, an issue under the title 'Sie sind entlassen' (You are fired), the discussion about the complex interaction between robots and humans was picked up and embedded in the current state of society. While this dichotomous debate can only answer the questions about humans and/or machines to a limited extent, an alternate way of looking at these complex relationships may offer a suitable perspective.

The fact that this seemingly sharp division between humans and technology is not so simple in today's world can be observed in the craft of carpentry. For example, the interviewees in this research repeatedly tried to clearly distinguish 'manual work' from 'mechanised' or even 'robot-supported work'. The problem with such a distinction, however, is that the boundaries are always highly individual and therefore rather fluctuating. For example, depending on the individual person, only a hammer and chisel are considered as 'manual work', but sometimes this definition also includes a hand-held circular saw or a cordless drill. Hammer and chisel are tools that are still quite obviously driven by muscle power only. Hand-held circular saws and cordless drills, however, already get their power from the electric grid or a rechargeable battery pack and are therefore only 'guided' by the craftspeople. For some craftspeople, however, it was also 'manual work' to have beams milled on a CNC joinery machine and then to join them together by hand. Following this discussion, even an axe and a chisel can be seen as an artificial, i.e., as a man-made extension of the craftsman's physical capabilities. As described by Pallasmaa (2015) in the book, 'The thinking hand', when an experienced person picks up a tool, the separation between human and tool becomes impossible:

'The tool has grown to be part of the hand, it has transformed into an entirely new species of organs, a tool-hand.' (Pallasmaa, 2015, pp. 47–48)

1.4.1 Human or machine? Hybrid craft as a unity!

The observations made within this thesis have shown how fluid the boundaries are between the manual craft and machine- or computer-assisted manufacturing. This rejection of a clear separation between man and machine is in line with Actor-Network Theory. This theory does not consider carpenters and machines as separate entities, but instead defines a profession like that of the carpenter as a dynamic and constantly rearranging network of things, actors, and the intermediate relationships between them, i.e. the networks (Belliger & Krieger, 2006, p. 14). By doing so, the individual actors, such as a single carpenter, but also a joinery robot, a hand-held circular saw or even the company, are to be understood as nodes in this network. Depending on what phenomena are observed and discussed, the considered network expands or shrinks in terms of actors. Likewise, the network will be expanded or reduced according to the question posed, thus realigning the relationships of all the nodes relevant to the observation. From this point of view, the craft or profession of carpenters is a constantly changing network of people, machines, and building materials, but also the company itself, the government and the interactions that happen among all these entities.

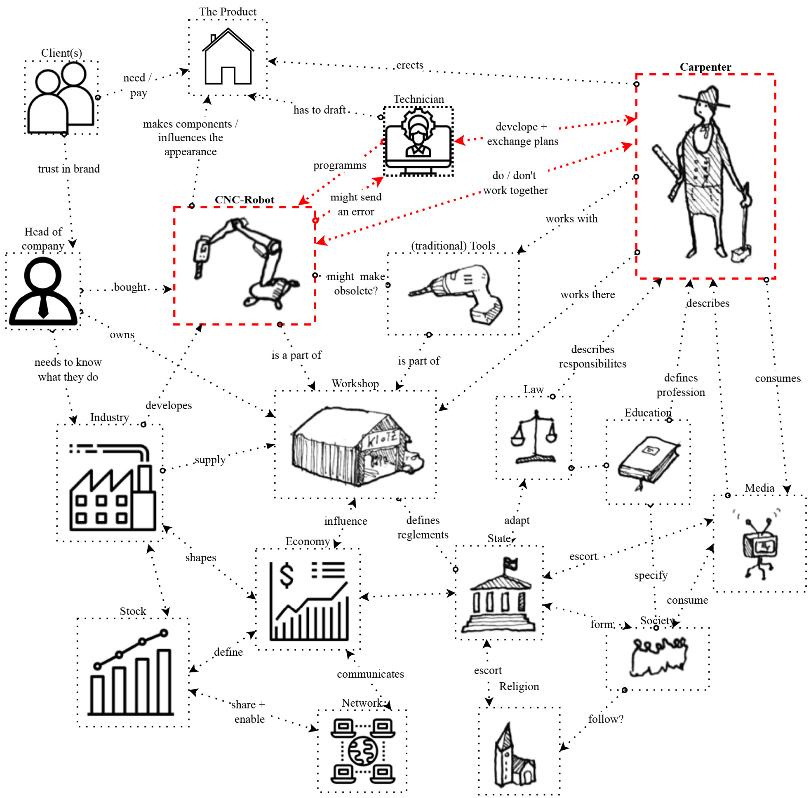


Figure 19. One of countless possible illustrations of the actors involved that could help to define the profession of carpentry.

1.4.2 Expanding human capabilities

As noted by Bruno Latour, one of the founders of Actor-Network Theory, a fundamental mistake in our unclear differentiation between humans and machines lies in an already existent lack of clarity in communication. For example, a newspaper may report that 'a man was flying' or 'a woman was conquering space'. On closer examination, however, it is indisputable that a man cannot fly as such, but that it takes the interplay of a wide variety of factors and things, such as an aircraft, its engines, a ticket counter, an airline and also an airport to lift a man into the air (Latour, 2006, 490). In order to describe in a more concrete way the understanding of these alternative explanations of the interaction between us as human beings and the objects that surround us, Latour uses a simple but very striking comparison. Based on the appearance of a human being together with a handgun, he illustrates the complex reciprocity between subject and object, or how the two parts mutually result in something new, something different. If one simply follows the argumentation of the gun industry, then a firearm in itself is not a risk to mankind. A person who basically has good intentions is no threat either with or without a weapon. This is the case, for example, with a sport gun user at the shooting range or an antiques collector. In contrast, a potentially dangerous person who may have the intention to commit murder represents a significant risk, both with and without a firearm. Whether the killing of a person is ultimately committed with a firearm or maybe a knife, it is, according to this first line of argumentation often used by the gun lobby, always initiated by a human being. However, this standpoint can be opposed to the fact that someone may only commit murder because of the firearm, which is understood as a technical extension of human capabilities. With a handgun, the act of killing is simply reduced to pulling the trigger of a pistol. Due to this mechanical and relatively simple activity, the ergonomic fit of a firearm, and the effortless automaticity of firing a projectile, people's capacity to kill is expanded. A person who might have only wanted to threaten or seriously injure others is now empowered to kill. It is therefore possible for people to kill others who, for example due to their physical constitution, their mental readiness or even their emotional willpower, would not otherwise have been able to kill someone. The sheer simplicity of a mechanically shot bullet and its consequences may be far more serious than it was originally intended. Thus, it requires a fundamentally deeper commitment to eliminate your opponent when using just a knife, a baseball bat or even your bare hands than with a gun (Latour, 2006, pp. 485–490). For Latour, however, this rather simplified approach, a reduction of the situation to only two opposing standpoints, is not sufficient. He states that a person with a weapon in his or her hand is a fundamentally different, new entity to the person without a weapon just a short time before. This new entity, which Latour calls hybrid gun-human or also human-weapon, has a fundamentally different baseline to an insufficiently precise description as presented by the gun lobby. In the two positions described above, a human being is fundamentally good or fundamentally bad; however, he or she wants to kill someone through the technical extension of human abilities, achieving a previously unintended, new state. A person who is not dangerous in and of themselves, who wants to use a pistol, for example, as a form of intimidation, may commit murder if the circumstances are unfavourable. On the other hand, it is also possible that someone could get hold of a pistol through an unfortunate coincidence and only kill another person as a result of exaggerating his or her abilities through the use of a weapon. For Latour, at the moment of picking up a weapon, a process of change occurs, which creates a new unity out of the two actors, the weapon and the person. It is therefore ultimately and in view of that fact needless to ask whether it is the human being or the weapon that has committed a murder. The terrifying result of such an act is certainly a product of the joint capabilities of both entities involved (Latour, 2006, p. 488). If this understanding of the interaction between humans and weapons/machines is transferred to the debate on craftspeople and tools conducted in this research, it can be discussed on a historically independent level. The quote by Peter Zumthor at the beginning of this paper referring to a joiner who is planing a board on an electric planer now reveals a possible answer to the profession of a craftsman from a new perspective, as he still describes himself as planing a piece of wood. Latour's understanding of the impossible separation of the capabilities of humans and machines respectively shows that neither the carpenter nor the electric planer could straighten a board by themselves. As described within the comparison of a human and a gun, ultimately, we can see a newly created entity of a joiner-planer or a machine-joiner that acts on a piece of work with the combined forces of the two parts. Neither the planing machine nor the joiner alone would have been able to plane the board. It is this temporary accumulation of the capabilities of both components that creates something new. This symbiosis of human abilities and machine strengths can also be illustrated in the joint working process of carpenters and joinery robots. Nowadays, it would be difficult for carpenters to handle the sheer number of orders if they worked by hand only. Simultaneously, the parameters of the machine also create new conditions relating to how orders are handled and processed. Thus, it can be said that the profile of a carpentry workshop with a joinery robot will be different from that of a carpentry workshop without one.

1.4.3 Approaching new technologies

What results, ultimately, from this new hybrid craft potential of people and machines, and to what extent this new combination of existing technologies and skills changes or even replaces existing approaches, must be considered using a case-by-case approach. As described in the previous sections, it can be said that joinery robots in the craft of carpentry now have the technological readiness and usability for everyday applications in carpentry. The craft of carpentry is therefore in the middle of a further technological change process. According to Barley (2020), this technological change can be categorised on two different levels: the substitutional and the infrastructural. Substitutional changes are those that seem at first glance to be already very promising and rewarding. This could be an old, slow machine being replaced by a new, faster one, a ball-point pen taking the place of a graphite pencil, or MP3 files taking the role of CDs or vinyl records. In most cases, these changes are evaluated on the basis of parameters such as production costs or process time. Such a substitutional change, however, does not necessarily imply a fundamental change in the way people use things or perceive their environment, or how our society itself functions (Barley, 2020, p. 7).

In contrast, infrastructural change through technology is much more difficult to observe, even though the associated changes have much deeper consequences. Thus, according to Barley (2020, pp. 10–11), a transformation called infrastructural change means both a change in the basis of what people do in their work and a fundamental change in how they do it. In his book *'Work and Technological Change'*, Barley (2020) illustrates this technological change very clearly with the following example. The introduction of snowmobiles for a part of the ethnic group of the Sami, the Skolts, seemed at first glance to be only a substitutional change. This group of people lives in villages on the border between Norway, Finland and Russia, where they used to live as a large community by rearing and selling reindeer. With the emergence of new snowmobiles in the 1970s, they were able to herd their reindeer more easily and quickly. Whereas previously the laborious process of herding the reindeer had to be done on foot over several days and weeks, with the snowmobiles the same work could be done in a fraction of the time previously required. Apart from the acceleration of the work, the physical strength required was now also greatly reduced. A previously laborious activity could now be done more quickly. However, within a very short period of time, the snowmobiles not only motorised their sleds, but also fundamentally changed the way they worked with the reindeer. The engine noise, the extension of the working radius, but also the financial maintenance costs associated with the machine meant a fundamental change in their daily life. The humming noise of the engines and the high speed of the snowmobiles changed the animals' herd behaviour. The powerful and long-lasting snowmobiles also required regular maintenance, fuel, and ongoing investment in equipment. While in former times 'only' muscular strength, time and food were needed for the work, the snowmobiles meant additional costs for the process. Within a few years, the village community and their livelihood changed. Therefore, initially, the acquisition of the snowmobiles was motivated by so-called first-order effects as defined by Sproull and Kiesler (2001, 1991). First-order effects are consequences of a decision that are made primarily for economic reasons. They are aimed at effects such as reducing the time required for production, improving product quality or simplifying the work to be done.

However, as the example of the Skolts has subsequently shown, the 'second-order effects' after Sproull and Kiesler (2001, 1991) were much more profound and meant a substantial, infrastructural change in the people's former habitual methods. The way the Skolts performed a job, and thus how they structured their daily lives, changed fundamentally (Barley, 2020, pp. 10–11). As observed in the example of the Skolts, the emergence of new technologies has the potential to restructure even deep-rooted principles of a society and therefore might lead to profound changes. While nowadays, in our society decisions are more often made in favour of 'first-order effects', the consequences of 'second-order effects' can rarely be predicted or even induced intentionally. However, these are usually the changes that contribute to a fundamental transformation of our society, our environment and our surroundings. The craftsmen who were observed in this research usually chose a joinery robot out of 'first-order effects'. This means that the machine can do the same work in a fraction of the time compared to a carpenter. In addition, a joinery robot can be operated in two- or even three-shift cycles. During these extended working hours, a carpenter or technician is then also necessary for supervision and support, but the output ultimately achieved exceeds the capacities of a single person in many ways. Furthermore, the machine usually does not need a break between jobs. In the interviews conducted, however, repeatedly there were findings that can be described as 'second-order effects' according to Sproull and Kiesler (2001, 1991) which entail more profound consequences for the profession of a carpenter. For example, some craftspeople complained that practices of craftsmanship that were previously fundamental to their profession have already been completely lost or that the carpentry workshop is now only a place of 'fitting pieces together' because of the joinery robot. The craftspeople thus observed or described changes partly in relation to the joinery robot that has transformed some of the core practices of their profession. The question of whether these consequences ultimately contribute only to a substitutional transformation, i.e. one that facilitates the work process, or to an infrastructural transformation, i.e. one that fundamentally changes the profession of carpentry, needs to be studied on a case-by-case basis. The results of the joint working process can be very different, depending on how the people at a carpentry company implement the joinery robot.

One of the carpentry firms visited during this research intends to specialise in the prefabrication of timber frame construction. According to their vision, the planned investment in a new joinery robot is intended primarily to increase the speed of the joinery process and of the assembly. The company also wants to prefabricate elements for other companies and therefore it will operate as a subcontractor. In this specific case, the entire workshop and its organisation will be rearranged and realigned in order to take advantage of the automation potential provided by the joinery robot. The resulting personnel and organisational changes will most likely lead to an infrastructural change for the craftspeople in the company. Compared to the previous way of working, tasks will be reassigned, processes structured in a fundamentally different way and the company's profile will be realigned. Partly consciously, partly unconsciously, this carpentry workshop will undergo a fundamental change by comparison to its previous profile. In this case, the realignment will make it quite feasible to observe how and what this means for the working methods of the individual carpenters.

In contrast to this very radical reorientation, a joinery robot can also merely mean a substitutional change for a company. According to one of the carpenters, the decision to purchase a joinery robot was motivated primarily by a great curiosity about the machine. Although the company has already been working with the joinery robot for more than 6 years, the joint work process between men and machine is still rearranged for each new order. Besides conventionally manufactured wooden elements, the company also 'knits' solid wooden houses as log houses from single trunks. Although the craftsmen's workshop has a joinery robot and this would be the most efficient and economical way of working for most of their projects, not every log construction is made on the robot. For example, a log house made of obliquely cut wooden trunks was recently produced. Because of the geometry, this timber would not be workable for the robot. Instead of switching the construction of the building to conventional, straightened logs, the carpenters decided to handcraft the building, without using their joinery robot. According to the carpenter, this decision was not economically justifiable, but for the carpenters it was motivation enough to try something different again. After weeks and weeks of rather hard, manual work, the carpenters were able to complete this unique project. The carpenter explained that it had been a great enrichment for the craftsmen to once again erect such a building purely by hand. Nevertheless, after completing this project, they were also very happy to continue working with the joinery robot in their daily work. The craftsmen of this company try to use the advantages of the joinery robot in a selective, project-specific way.

As these two brief descriptions of different working methods have illustrated, at some point it is still up to the craftspeople to decide which tool will produce the desired result. Each of the papers compiled and submitted as part of this research point to a specific case and concentrate on the working methods of an individual workshop in and around Liechtenstein. In doing so, craft enterprises were specifically selected that could already look back on several years of experience in working with the joinery robot. The projects realised and the working processes of the companies were closely observed and documented. As an integral part of the work, interviews were conducted with the craftsmen and those involved in the project, always focusing on the question of the implementation of the joinery robot. The articles on the following pages always present a single case, one phenomenon that is answered within the framework of this research work.

The first publication, '*Paper I.; How new technologies can promote the reintroduction of traditional knowledge in the profession of a carpenter*', shows how a CNC joinery machine and a clever carpenter could reinterpret an old construction principle. Whereas in today's timber construction, glued laminated beams are a product used every day, these technologically advanced timber products were not available in the past. In order to be able to bridge wider spans, carpenters made interlocking beams that functioned statically as a composite. As a composite, they could transfer much greater loads than the individual beams were capable of. Very precise work, a lot of time and experience is necessary to produce a stable and fully loadable interlocked beam. With the development of glue-laminated beams, this special joining technique became obsolete, as wooden beams could be produced in all shapes and sizes. Accordingly, the logic of interlocking wooden beams soon disappeared from the repertoire of craftsmen. However, the fact that this particularly resilient and stable connection logic makes sense again in modern timber construction is demonstrated by a new timber structure built by the architect Hermann Kaufmann in Germany. Due to the availability of the new building material 'Bau-Buche' and the client's request to use as much wood as possible and as few steel parts as possible, the carpenters used a modern interpretation of this interlocking logic. In this example, the logic of the sawtooth connection, the 'zig-zag joint' was used in the corner connection. However, this solution was only made possible by the strength of the modern machine joinery system (precision, efficiency, speed) and the carpenter's know-how.

The fact that this process of approximation between craftsman and machine involves a certain amount of time and effort is shown in the second publication: '*Paper II.; Traditional Knowledge on Modern Milling Robots*'. This craftsmen's company has had a joinery robot for several years. When buying a new joinery robot and the necessary software, a broad spectrum of 'standard solutions' for joining corners is already included in the bundle provided. This is intended to enable the craftsmen to start working quickly and in a targeted manner with the new infrastructure. While these pre-programmed solutions might already cover a large part of the daily tasks, this was not enough for the carpenter involved in this case. Specifically, he wanted to build a house out of solid wooden beams, as a modern block house construction. For this construction, the necessary corner joint, the dovetail, is a key point.
This corner detail must fulfil a wide variety of needs such as structural stability, ventilation, assembly and manufacturability. Especially with regard to ventilation, i.e. air tightness, the standard pre-programmed solution was insufficient for the carpenter. Over a period of several weeks, he developed an improved corner joint together with the machine manufacturer, which was based on historical construction techniques. In doing so, they integrated an additional groove, a so-called 'wind comb' inside the corner joint, in order to be able to meet the standards of the craftsman. In a similar way to how craftsmen once used to individually adapt their hand tools, in this case the carpenter (together with the manufacturing company) adapted the joinery robot's performance to his own requirements. His ideas and solutions were based on his expert knowledge

of historical constructions. The joinery robot manufacturer provided him with support for the technical implementation.

The fact that craftsmen can also revive historical and regionally anchored construction principles through the possibilities of a joinery robot is shown in the publication '*Paper III.; The Renaissance of Structural Ornamentation*'. In the context of this work, the appearance of *first-order effects* and *second-order effects* according to Sproull & Kiesler (2001, 1991) can be observed. In the example of this case study, a new wooden workshop was built. For structural reasons, it was required that parts of the side walls had to be closed for stabilisation purposes. In a first proposal, the plan was to close the side sections with a CLT panel. In order to provide sufficient light in the workshop, the carpenter offered to cut round openings in the panel. However, this solution was not sufficient for the clients. It was not until the subsequent discussion process between the carpentry firm, the structural engineering office and the client that the planned panels were replaced by a wooden lattice that could be made from individual rods. To the surprise of everyone involved, the production of the wooden lattice was almost the same cost as the previously planned CLT panel, despite the complex geometry and the additional effort in assembly. This decision resulted in several significant advantages. The final solution was implemented using regionally available timber beams, which minimised the carpenter's dependence on industrially manufactured timber construction materials. Transport routes were shortened, delivery times were improved and the regional network was strengthened. While the craftsman's company acquired the joinery robot primarily for the efficient and fast implementation of simple building components, far-reaching changes for the entire process flow could be observed in the context of this construction project. As a result, the manufacturing of the rhombic latticework only became affordable again with the help of the joinery robot. If one compares this transformation process with the previously mentioned snowmobiles for the Skolts in *1.4.3 Approaching new technologies*, the consequences of this technological change for the carpenters and the regional construction industry seem to be of a positive nature from today's point of view. However, it cannot be denied that the task, the profession of the craftsmen has also changed here as a result of the joinery robot. What seems interesting in this example is the fact that the ‘push’ towards the traditional construction principle was initiated primarily by the clients, not by the carpenters.

The fact that the constant evolutionary process in the craft of carpentry will continue to raise exciting topics in the future is discussed in the publication *‘Paper IV.; What a carpenter can learn from ‘Thingiverse’’*. Here, a comparison is made between the ‘maker community’ and their 3D printers on the one hand and carpenters with their joinery robots on the other. In the maker community, it is common to obtain and exchange designs, 3D files and inspirations via platforms such as Thingiverse. These 3D file templates are either printed directly or individually adapted and redesigned. After the editing process, the data can be uploaded and thus made accessible to the community again. The result is a lively global exchange of challenges, ideas and solutions. In comparison to this observation, carpenters first plan a building on the computer as a digital 3D model and then, after the joinery process on the robot, the files are usually only stored in the project archive. Therefore, no further discussion or work process follows using the digital data. Of course, the different ways of working in the two communities can be attributed to different backgrounds such as legal, economic or cultural aspects, but there seems to be great potential for innovation here, especially since the digital data is already available in both communities.
With regard to the craft of carpentry, it can be said that the coming years will certainly bring further significant changes, especially since the phenomenon of joinery robots has only been established for a relatively short time. As described at the very beginning of this paper, the growing number of projects and the corresponding demand for buildings made of wood are positive indications for an exciting future. In this context, it can be expected that the potential of joinery robots can and perhaps will make an increasingly important contribution. However, what these changes ultimately imply for the profession of carpenters cannot be summarised comprehensively in such a diverse profession. As Barley writes in his book, the major challenges of technological change are not technical, but rather social, economic and political (Barley, 2020, pp. 23–24). After almost

40 years of intensive research on work, technology and organisations, he only allows himself to make one clear statement:

You almost never get only *what you expect and sometimes you do not even get that.* (Barley, 2020, p. 26)

The craft of carpentry has always been in a constant process of change. In this process, carpenters should be understood as experts in wood as a building material. Within the context of this continuous change, it is important to develop an awareness of the corresponding translation processes in order to be able to respond to them if appropriate. As stated in Germany's version of the description of carpentry as a craft, it is ultimately up to the craftsmen to decide on the use of the right tools in relation to a task (Bundesministerium der Justiz, 1999).
This key problem-solving competence might not be replaced in the near future by joinery robots, artificial intelligence or other things associated with digitalisation. In any case, the use of new tools and technologies opens up new possibilities which - *as is often the case in life* - should be met with an approach that can be described as critical curiosity (Friesike & Sprondel, 2022, p. 32).

2 Paper I.; How new technologies can promote the reintroduction of traditional knowledge in the profession of a carpenter

Title:	How new technologies can promote the reintroduction of traditional knowledge in the profession of a carpenter
Authors:	Wolfgang Schwarzmann
Contribution:	Showing how nowadays traditional construction methods are used in a new context by joinery robots
Status:	Published in the Proceedings of 'Space and Digital Reality: Ideas, Representations/Applications and Fabrication' Conference, as part of the Tallinn Architecture Biennale TAB 2019

HOW NEW TECHNOLOGIES CAN PROMOTE THE REINTRODUCTION OF TRADITIONAL KNOWLEDGE IN THE PROFESSION OF A CARPENTER

Wolfgang Schwarzmann
Institute of Architecture and Planning,
University of Liechtenstein

Abstract

The ongoing transformation process driven by industry 4.0, will affect almost each and every thing in our environment. This change may take several decades; however, already today an impact on the daily work of a carpenter can be observed.

In Central Europe, new CNC robots are installed in many carpentry workshops. These machines provide quality and productivity using the current state-of-the-art technology. Emerging from this technological change, benefits to production according to speed, precision and reliability can be expected. Besides these advantages, a process of transformation with regard to knowledge and tradition will occur that can be understood as the beginning of a radical transformation. Embedded in the theoretical foundation of Actor-Network Theory (ANT), the profession of a carpenter has to be interpreted as being part of a constantly shifting network of relationships. Based on this social theory, it is possible to interpret the technological change as a new driving force, which changes the perspective of this profession. In this paper we compare two case studies from different centuries. By taking a closer look at the manufacturing process of a 'zig-zag' joint, old and new techniques are compared and evaluated, focusing on the integration of a CNC-joinery machine. Only by making use of these new technological solutions was an economic reintroduction of this 'zig-zag' joint possible. Furthermore, the successful adaption of this joint was only possible because the carpenter could provide specific knowledge, crucial for programming the robot and later assembling the material. Technology will make a carpenter faster and more cost-efficient, but without doubt, the core elements of his profession will be affected by the change. This research will promote further discussion for future developments in how digital technologies and physical production might act together.

Keywords: carpenter, Industry 4.0, digital transformation, tradition, handcraft, actor-network theory

1. Introduction

In Central Europe, the costs of erecting a building were constantly rising in recent decades. For example, in Germany, wooden components produced by a carpenter increased by 2.7% between August 2018 and August 2019 (Statistisches Bundesamt 2019, 8). Since the end of this development is not possible to predict, industry is forced to find new solutions for how to deal with these rising costs. One approach to lowering these increasing prices is a reduction of manual labour by shifting to automatic solutions. Nowadays, these technological solutions are already common in the car industry but might be surprisingly new in manual labour jobs like carpentry.

The profession of a carpenter can rely on a rich and long history. This job was always been in a close and direct relationship to the processed material. In recent years, more and more workshops have started to invest in CNC-joinery machines. By implementing these new technologies in existing structures, former processes start to shift. The presence of a CNC-joinery machine certainly changes the relationship between a carpenter and the processed material. In this paper, we are going to make a comparison that will examine how this shift in the structures can lead to new possibilities in the profession of a carpenter.

2. Background

2.1 The profession of a carpenter

The profession of a carpenter can be described as being an expert on structural wood constructions. In comparison to a joiner, whose daily work focuses more on interior elements like doors, windows and furniture, the carpenter is responsible for all kinds of loadbearing wooden parts of a building. These parts are mostly of a larger scale and weight, leading to the frequent use of machines like a crane, a forklift and other tools for reducing physical workload (Herres 2016, 38).

2.2 The profile of a CNC-joinery machine

A CNC-joinery machine is a computerised machine-centre with a variety of different manipulation tools. In comparison to a band saw or a circular saw, the machine itself can conduct all kinds of operations relating to the processing of materials. While most of 'traditional' electric tools need a skilled carpenter to guide the machine by hand, a CNC-joinery machine can conduct almost all tasks autonomically (Schindler 2009, 194). These processes are under the supervision of a machine operator. A huge advantage in comparison to manual work is the significant increase in terms of issues like processing time and accuracy of editing. Even though the job-specific programming of the CNC-joinery machine will claim some time, the process as a whole can show a number of economic benefits (mikado n.d.).

Since the early 1980s, machine-suppliers were able to deliver robots that could handle numerous manual tasks normally performed by a carpenter. With more than 5,000 globally shipped machines so far, the self-claimed world market leader for CNC-joinery machines Hans Hundegger AG can prove the high acceptance of their products (Hans Hundegger AG n.d.). These machines are constructed in close collaboration with the end users. The company can be seen as the general contractor in the case of engineering, constructing, installing and implementing a new machine in an existing workshop (Hans Hundegger AG n.d.). Furthermore, they offer a 24-hour hotline service to support local carpenters whenever hardware or software-based problems emerge. Therefore, industry not only targets the goals a carpenter might address, but already has already been meeting their needs for almost 30 years.

2.3 Industry 4.0, in the environment of a carpenter?

The previous description of what a carpenter might require and what a CNC-joinery machine might be capable of, leads to the question of how these two issues accompany topics like industry 4.0. On closer inspection of the solutions that might be available, investigations revealed that software companies already provide solutions to integrate a CNC-joinery machine in the world of the IoT (Internet of Things). Solutions like the platform 'tapio.one' provide services like real-time machine monitoring, material-flow-optimisation or machine-supporting cloud-backups. These applications can be implemented into an existing structure and are later accessed via a smartphone or tablet (Volm and Neumann, n.d.).

The ongoing transformation of processes relating to Industry 4.0 will not only affect single tasks but soon change the whole business process of a company (Vollmer et al. 2017, 44). Even though experts are unsure about when and how this transformation will substitute jobs, there is general agreement on the significant reduction of repetitive tasks (Vollmer et al. 2017, 61). This paper will take a closer look at what kinds of teamwork the new technologies and traditional knowledge might promote.

3. Methodology

In this research, our approach was to describe how technology can reintroduce knowledge, anchored in traditional ways of manufacturing. Two case studies, each from another period in history, are compared in terms of construction and fabrication techniques. This paper focuses on the application of one specific wooden joint, later described as the 'zig-zag' joint. Due to the infrequent occurrence of this joint over recent decades, its recent reappearance has to be seen as a remarkable phenomenon.

3.1 Actor-Network Theory applied to the profession of a carpenter

'The machine is not only a tool, it's more like a partner' (Belliger and Krieger 2006, 15). This quote already reveals fundamental points of 'Actor-Network Theory' (ANT). Following its line of argumentation, it is not possible to draw a strict separation between technology and society. According to Belliger and Krieger (2006), recent developments including *virtual reality, artificial intelligence* and *the process of digitisation*, further promote the blurring between humans and technology. They prefer to use the term 'Actants' (introduced by Bruno Latour) for human and non-human objects (Belliger and Krieger 2006, 15), in a constant process of alteration and movement.

In our research, the profession of a carpenter has to be seen as a node in a constantly changing network, the parameters of which might be culture, geography, nationality, or in our case, new technologies. In this study, we take a closer look at how the interwoven profession of the carpenter might have been influenced due to the new presence of the CNC-joinery machine.

3.2 Two case studies

To provide a better understanding of where this new emerging 'hybrid knowledge' might appear, an example shall be given. In the following sub-section, a comparison is made of two different wooden construction details. The first is a wooden composite beam from 1740 (Fig. 2). The 270-year-old beam was part of a research project and had to be replaced by a new fabricated one (Rug et al. 2012, 29). In 1740, solutions for spanning wide spaces were limited. Whenever possible, craftspeople made use of timber framing. In this case, even more structural strength was needed. As can be seen in the image (Fig. 1), two horizontal beams of wood were stacked directly on top of each other. To further raise their bearing capacity, the flanking planes were interlocked using a specific 'zig-zag' cut. This rare and challenging wooden connection had to be manufactured with the highest possible precision. Only if all the wooden teeth interlocked perfectly, could the static effect be achieved. To secure the pieces in their position, threaded bolts were installed. Their primary function was to keep the wooden parts in place (Fig. 1).

Over time, technologies like glue-laminated wood could evolve. These new wooden materials significantly cut the need for manual labour. New production techniques made it possible to deliver custom-made chunks of wood of the right size, quality and strength for each application. The labour-intensive and hard to manufacture interlocking 'zig-zag' shape became obsolete (Rug et al. 2012, 26).

This leads us to the second case study. For a number of years, industry has been able to mass-produce glulam from beech. Thin layers of veneer are peeled from beech wood and pressed into almost any shape needed (Pollmeier n.d.). Due to its high density as a hardwood, beech can handle a broad spectrum of challenging structural applications. When constructing with wood, one fundamental challenge is where columns and beams meet at one point.

In 2019, the Office 'Hermann Kaufmann + Partner' designed a production building for the SWG Produktion Schraubenwerk Gaisbach GmbH (Jacob-Freitag n.d.). SWG is a company well-known for manufacturing high quality screws. The roof is constructed as a wooden framework made from beech glulam (SWG 2019). The common approach to structures like these is to connect wooden sticks with custom-made steel knots. In this project, the client SWG demanded a reduction of structural steel parts. This requirement forced the carpenter to work out an alternative approach to the joints in the wooden framework.

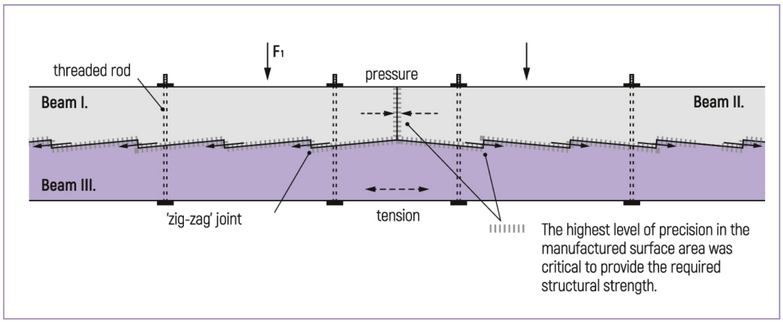


Fig. 1: Characteristics of the described traditional 'zig-zag' joint.

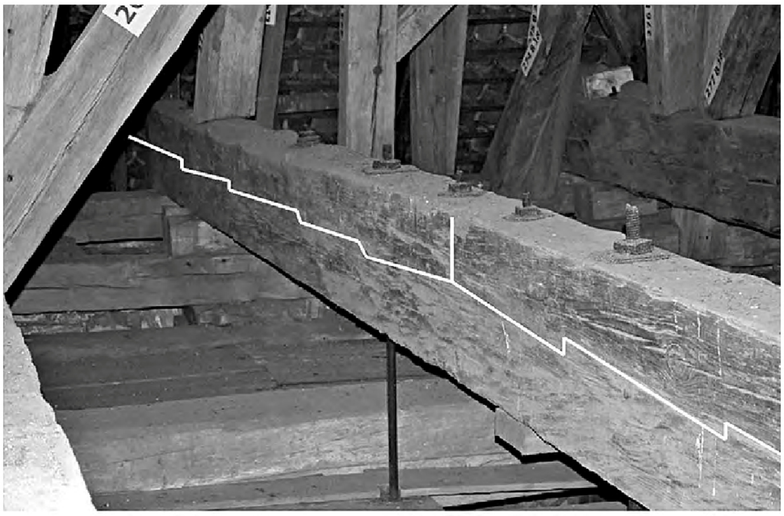


Fig. 2: Original composite beam from 1740
(Rug et al. 2012, 29).

Fig. 3: Timber frame knot with 'zig-zag' joint (Hermann Kaufmann + Partner ZT GmbH n.d.).

As can be seen in Fig. 3, their solution involved the integration of a 'zig-zag' shaped interlocking design. At some points, screws were needed to secure the wooden components in position. Only when unavoidable, additional steel parts were introduced. Structural and loadbearing functions are almost completely fulfilled by wooden parts.

In a personal interview, the carpenter confirmed that all the wooden processing operations in relation to the 'zig-zag' shape could be performed by their CNC-joinery machine. Furthermore, he mentioned that the milling tasks were carried out using a conventional milling head, normally used for cutting grooves.

3.3 Comparing the two case studies

Characteristics of the historic 'zig-zag' joint (1740):

(++) At that time one of the most suitable solutions for increasing the structural performance of wooden components (Rug et al. 2012, 26)
(+) all parts are easy demountable (reuse, recycling, replacing broken parts etc.)
(o) few metal pieces needed (nuts and bolts for securing the wood in position)
(-) very labour-intensive (multiple steps involving marking, cutting and chiselling)
(-) high precision needed (only skilled carpenter can perform this work)

Characteristics of contemporary 'zig-zag' joint (2019):

(++) CNC-joinery machine able to handle precision and speed in manageable amount of time
(+) overall reduction of steel parts in the framework
(o) knowledge of skilled carpenter for proper implementation of CNC-tool needed
(o) few metal-pieces needed (screws for securing the wood in position)
(-) only suitable for specific applications
(-) still more expensive (time, funds, manufacturing e.g.) than ordering a standard steel-piece

4. Results

When comparing these two case studies, it can be said that the motivation for manufacturing a 'composite beam' in 1740, is different than it might be for the recently erected SWG building. Over time, the manufacturing technique has changed dramatically when we compare the labour-intensive manual work and the machine-aided milling process. New technologies promote the frequent application of glue-laminated wood, and therefore eliminate the manual production of time-consuming operations, such as the 'zig-zag' joint. However, solutions for structural challenges are still an important issue to resolve. Although issues like wide spans can now be solved on a material basis; a robot might not substitute the creative new-combination of expert knowledge. Even though the motivation and background for these two applications emerge from different incentives, the implementation of this wooden joint did provide a suitable solution in both cases.

If we assume that in the first case study, the carpenter was using an axe or a saw as his most frequently used tool, it can be said that in the second case study, the contemporary carpenter mostly relied on the capabilities of his CNC-joinery machine. Following the argumentation of Schindler (2009, 223), the profession of a carpenter always evolved with the technological steps relevant in the surrounding society. These craftspeople are both making use of specific contemporary tools, common at the time they were working. In both cases, a skilled craftsperson made use of the 'zig-zag' shape. What really marks the unique achievement is the recombination of the knowledge to the tools offered, tailor made for a specific problem. Only the ability of an experienced carpenter can create a perfectly interlocking 'zig-zag' shape. Whether the professional makes use of an axe or a CNC-joinery machine need not be a determining factor in this comparison.

5. Summary and conclusion

In this work, we show how a rare wood joining technique can be re-introduced as a construction system in the 21st century. By comparing a traditional 'zig-zag' joint from 1740, and a contemporary 'zig-zag' joint from a recently erected building, similarities and differences in manufacturing can be illustrated. The first case study shows a traditional 'zig-zag' joint manufactured in 1740. It is the product of a labour-intensive process, where the production needed the knowledge and time of a skilled carpenter. The second case study shows a contemporary 'zig-zag' joint produced in 2019 by a carpenter in Germany. This solution was completely processed using a modern CNC-joinery machine. The labour-intensive processes of measuring, milling, and cutting were handed over to a computer-guided robot. The significant reduction in manufacturing time and cost could make this wooden connection compete with conventional solutions. Besides the fact that the carpenter made frequent use of the machine as the first key resource, his specific knowledge must be seen as the second crucial ingredient that finally led to a successful solution in the final product. As described by the carpenter, his specific knowledge caused him to propose this approach to joining wood with a 'zig-zag' shape, which is unconventional in today's industrial context. Furthermore, his particular programming skills and deep understanding of how to make use of a CNC-joinery machine gave him the ability to translate his expertise into a contemporary application of wood joinery. The cooperation of a skilled human and a programmable robot working together made it possible to find new solutions. Thanks to close cooperation, traditional methods of manufacturing might return to more contemporary applications. It can be argued that the establishment of a new application of 'hybrid knowledge' could be observed. Only if both 'Actants' have a deep understanding of their opponents' capabilities, might new applications emerge.

This paper focused on the comparison of how a special type of wood join can be interpreted in accordance with contemporary applied fabrication methods. Focus in this case could only be applied to a small part of this described network. Future work will be directed towards a deeper understanding of how the profession of a carpenter is currently influenced by new technologies to explore more recent applications.

Acknowledgements

I want to thank my Professor Urs Meister, along with Professors Dr Anne Brandl and Dr Christoph Michels, who provided expertise that greatly assisted this research.

Furthermore, I would like to thank Professor Dr Sascha Friesike for providing an open ear to the whole research project and in that improving my line of argumentation.

BIBLIOGRAPHY

Belliger, Andréa, and David J. Krieger, eds. 2006. *Anthology: Ein Einführendes Handbuch Zur Akteur-Netzwerk-Theorie*. Science Studies. Bielefeld: Transcript.

Hans Hundegger AG. 'Innovationen Für Den Holzbau: Image Brochure by Fa. Hundegger'. Accessed 9 October 2019. https://www.hundegger.de/fileadmin/Dateien/Web_pdf/Image-Broschures/Deutsch-Englisch/page.pdf.

Hermann Kaufmann + Partner ZT GmbH. 'SWG Schraubenwerk, Gaisbach | Hermann Kaufmann + Partner ZT GmbH'. Accessed 8 October 2019. https://www.hkarchitekten.at/projekt/swg-schraubenwerk-gaisbach/#lightbox-45.

Herres, Uli Matthias. 2016. *Spuren Des Handwerks: Der Einfluss Handwerklicher Herstellung Auf Die Architektur*. https://doi.org/10.3929/ethz-a-010738690.

Jacob-Freitag, Susanne. 'SWG Schraubenwerk, Gaisbach: SWG Baut Produktionshalle Aus Holz Und Eigenen Schrauben'. Accessed 8 October 2019. https://www.hkarchitekten.at/projekt/swg-schraubenwerk-gaisbach/.

mikado. 'Zimmerer Investieren in Die Zukunft: Maschineller Abbund'. Accessed 8 October 2019. https://www.hundegger.de/fileadmin/_migrated/content_uploads/2002-11_mikado_01.pdf.

Pollmeier, Ralf. 'Über BauBuche'. Accessed 8 October 2019. https://www.pollmeier.com/de/produkte/ueber-baubuche.

Rug, Wolfgang, Frank Thomas, Uwe Grimm, Guido Eichbaum, and Stephan Abel. 2012. 'Untersuchungen Zur Biegetragfähigkeit Von Verzahnten Balken'. Bautechnik, no. 89: 26–36. Accessed 8 October 2019. http://www.holzbau-statik.de/ibr/downloads/05_bestand/Biegetragfaehigkeit%20verzahnte%20Balken.pdf.

Schindler, Christoph. 2009. *Ein Architektonisches Periodisierungsmodell Anhand Fertigungstechnischer Kriterien, Dargestellt Am Beispiel Des Holzbaus*. ETH. Accessed 24 April 2019. https://doi.org/10.3929/ethz-a-005956976.

Statistisches Bundesamt. 2019. 'Preisindizes Für Die Bauwirtschaft: August 2019 (3. Vierteljahresausgabe)'. 17/4. Accessed 10 October 2019. https://www.destatis.de/DE/Themen/Wirtschaft/Preise/Baupreise-Immobilienpreisindex/Publikationen/Downloads-Bau-und-Immobilienpreisindex/bauwirtschaft-preise-2170400193234.pdf?__blob=publicationFile.

SWG Schraubenwerk Gaisbach GmbH Produktion. 2019. *Produktionshalle in Holzbauweise: Fertigung Der Haupt- Und Nebenträger*. Accessed 10 October 2019. https://youtu.be/oxfziZIUNcs.

Vollmer, Thomas, Steffen Jaschke, and Ulrich Schwenger, eds. 2017. *Digitale Vernetzung Der Facharbeit. Gewerblich-Technische Berufsbildung in Einer Arbeitswelt Des Internets Der Dinge*. Bielefeld: W. Bertelsmann Verlag.

Volm, Matthias, and Christian Neumann. 'What Is Tapio?' Accessed 8 October 2019. https://www.tapio.one/en/whatistapio.

Wolfgang Schwarzmann

is employed as researcher and enrolled as PhD student at the University of Liechtenstein. After he finished his Architecture studies in Austria, he worked as a carpenter-trainee at a workshop and thereby developed a deep understanding of this specific field. Further on he worked in the architecture office of Prof. Hermann Kaufmann, a well-known Austrian Wood-Construction Architect.

3 Paper II.; Traditional Knowledge on Modern Milling Robots

Title:	Traditional Knowledge on Modern Milling Robots; How CNC-joinery machines promote a renaissance to lost techniques in the profession of a carpenter.
Authors:	Wolfgang Schwarzmann
Contribution:	Based on a case study, it can be observed how a carpenter transfers his specific expertise to the joinery robot.
Status:	Published in the Proceedings of 'The 38th Conference on Education and Research in Computer Aided Architectural Design in Europe' Conference, eCAADe 38, Berlin

Traditional Knowledge on Modern Milling Robots

How CNC-joinery machines promote a renaissance to lost techniques in the profession of a carpenter.

Wolfgang Schwarzmann[1]
[1] University of Liechtenstein, Institute of Architecture and Planning; https://www.uni.li
[1] wolfgang.schwarzmann@uni.li

The profession of a carpenter is changing significantly. Over the last 20-30 years, CNC-joinery machines became ready to penetrate the market and lead to a significant optimization of daily processes in these firms. In this case study, we take a closer look at the working techniques of a carpenter in the Bregenzerwald. This skilled craftsman found a way, of how to translate his expert knowledge on to a CNC-joinery machine. Instead of only following modern, simplified construction methods, he tried to revive historic methods and developed a way to translate his expertise. By scaling up on a technological basis, he was able to reintroduce the so-called `Dovetail joint' and by that managed to erect the first proof of concept, a single-family house. This research shows, how a new integrated robot enables a way of manufacturing, that otherwise might not be affordable anymore. Benefits of this approach can be seen on a variety of economic and ecologic aspects. As mentioned by the carpenter, these results are encouraging, but for him, the real advantage is the increased empowerment to skill, craft and knowledge typical for his profession.

Keywords: *robotic fabrication, carpenter, renaissance, knowledge, tradition, wood construction*

INTRODUCTION - CRAFT AT A CHANGE

In central Europe, the profession of a carpenter can rely on a rich and long-lasting history of at least 4000 years (Gerner, 2002). Even though the overall description of these experts on wood almost remained to be the same, the field of activity covered by a carpenter has changed. A continuous stream of technological innovation could be observed. Gradually a change of the former labour-intensive manual work progressed towards a 'machine supported wood craftsman'.

In this paper, we are going to take a closer look at one specific way of joining wood and by that illustrate a process of translation between men and machine in the environment of a carpenter. The so-called 'Dovetail-joint' was a typical and frequent way of joining wood, already used in ancient times. While this seemingly simple connection only consists of a pin and a tail, a high level of precision is crucial when translated the intelligence of knitting instead of just repeating shape and form. Recording the human movement when carving a piece of wood and afterwards translating these actions on to a robot were investigated by Brugnaro and Hanna (2018). Their research showed a way of applied 'machine learning' based on human craft, that leads to a variety of craft-inspired design solutions. As finally pointed out by Brugnaro and Hanna, further research needs to be done towards new developments considering the knowledge transfer between 'human' and machine'.

Figure 2
C-Hocker by the 'NEWCRAFT' cooperation (Gros, 1993); This stool can be seen as a modern, technological reinterpretation of the 'Ulmer Hocker' designed by Max Bill. Even though the size, geometry and function remained the same, the final delivered product does represent a different appearance than the original design.

METHODS

In this ongoing research project, data was collected by conducting an interview with Berchtold (2020). This interview frames the first position in the ongoing research project. As next steps, it will be supported by further expert-interviews, participatory observations and qualitative data sources. Being an experienced carpenter, Berchtold is running a carpentry in the region of Schwarzenberg, Vorarlberg. He and his company (including his employees, machines, etc.) will be treated as being one case. As described by Kumar (2019) a case study can be conducted as 'in-depth explorations' that will provide deeper insights into a topic. Information was gathered through observations in the workshop, an analysis of their webpages and by conducting an interview with Berchtold. Due to his unique background, his valuable knowledge and his years of experience as a carpenter, Berchtold can be seen as an expert on the topic of wooden constructions, especially on the manufacturing processes of wooden structures typical for his region.

In this paper, the results will be interpreted in accordance with Actor-network theory (ANT). This theoretical and methodological approach shall help to develop a deeper understanding of the constantly changing relationship between human and technology (Belliger & Krieger, 2006). Arguing in the way of Latour (2006), the presence of technology transforms/translates its surrounding fundamental. Considering these thoughts, it can be said that a carpenter who now owns a CNC-joinery machine, is a different Carpenter than he was before (not only just because of scaling up on a technological basis). The new technological opportunities extend the range of possible solutions, but on the other side cause an unavoidable transformation of the characteristics that were formerly implied by this craftsperson like craft, skill, perception and so on. Following the argumentation of Latour, borders between 'men' and 'machine' start to blur gradually. A strict separation between 'human' and 'technology' can/could never be drawn. Equipped with these new, physical and digital extensions, the craftsperson now ought to be described as a 'CNC-joinery-carpenter' illustrating a more up-to-date image of this craftsperson. At some point, the machines we operate, the technology we make use of, defines what solutions we are able to offer and implies how we work, inferring what the final product will look like. On the other hand, the machines themselves represent a structure, an accumulation of sensors, actuators and programs that were designed by engineers and designers with the intention to support craftspeople in the very best possible opportunity. The final developed product, in this case, a CNC-joinery machine, will only offer as many solutions, as the construction-team was convinced to imply. Wooden connections that were used infrequently on a manual basis are very unlikely to be translated into the machine program. Therefore, these options will not reappear on the CNC-joinery machine. Possible manufactured. Craftsmen have to gain a significant skill and develop a material-specific knowledge to develop appropriate solutions.

At the beginning of the 19th century, the industrial revolution gave these needs a turn. The industrial rise of nails, steel brackets and other metal fasteners made this labour-intensive way of joining wood expire (Schindler, 2009a). Besides these developments on a material basis, the upcoming science of engineering promoted structural calculations towards a more frequent use of steel parts (Polónyi, 2014). These economic and structural developments fostered a slow but steady vanishing of the 'Dovetail'.

PROGRESSION OF CNC-JOINERY MACHINES

Since the early 1980s, a turn in wooden manufacturing can be seen. Digital tools promote a faster and more accurate production of wooden constructions. While the very first joinery-machines gave an increase on manufacturing time and precision, a raise in construction complexity could be observed since 1990 (Jeska, Saleh Pascha, & Hascher, 2015).

Even though the industry might already work with robotic manufacturing since the late 1950s (Heßler, 2014), a real starting point of CNC-robots in wooden workshops could be observed from 1989 on. According to the self-claimed world market leader in 'CNC-joinery machines for wooden workshops' (Figure 1), it was the first time that CAD-files were directly sent from a computer to a joinery machine (Hans Hundegger AG). As a direct response to a personal request, the Senior Sales Manager, Wolfgang Piatke of Hans Hundegger AG could provide a deeper glimpse. Until 2020, the Hans Hundegger AG shipped approximately 3000 CNC-joinery machines (P8/P10/K1/K2 and ROBOT Drive). Their core business can be seen in the European Union with only a few deliveries to North Amerika. For Piatke the diverse business area of CNC-joinery machines can be explained due to a wide variety of different workshop structures. These structures range from a small family-business (primarily in GER, CH and AUT) to large production plants (North Amerika) (Piatke, 2020). The company is able to cover a broad spectrum of different technological needs, aligned to the individual requirements. However, further research in the ongoing research project shall be invested to collect more data on these application characteristics.

Figure 1
Hundegger K2i working on a Dovetail (Hans Hundegger AG, p. 21); These robots represent affordable and ready-to-use solutions for a carpenter workshop. Even though they optimize issues like precision, speed and complexity of the manufacturing process, they definitely change the workflow and skill of a carpenter.

These technological advantages establish a new basis for the reintegration of wooden connections. While these wood-wood joints were to labour intensive a few decades ago, CNC-joinery machines now operate fast, precise and at a fraction of cost compared to manual work. As described by Jeska et al. (2015) this new application of 'old' wooden connections does not only replace steel connections and increase aesthetics in architecture; it furthermore has to be understood as a renaissance of traditional manufacturing techniques with a sense of novelty.

Similar approaches to translating historic knowledge into a modern way of manufacturing were already conducted by Gros (1993), Brugnaro and Hanna (2018) and Klein (2015). By developing a new interpretation of the 'Ulmer Hocker' (originally designed by Max Bill, in 1954) Gros (1993) showed, how a design classic can be interpreted in a modern production language (Figure 2). As part of his research, Klein (2015) showed how the craft of Irish crochet could be adopted to a 3d printer which leads towards a new, more contemporary interpretation of textile craft. The final presented 'Incunabula Dress' does not aim to imitate historic designs but progresses towards a new aesthetic of crochet. Klein (2015) solutions a craftsperson might have been able to offer, are then out of reach.

This permanent moment of translation, affects both, object and subject, leading to a continuous process of transformation in the perception/profession of a carpenter and the supporting technologies. This research shall provide another position in the continuous discussion concerning the evolution of human-machine interface, or more precisely state an additional perspective to current research trends (Figure 3).

Figure 3
Men and machine - working together (Schwarzmann, 2019); This image illustrates the current situation of a carpenter and a robot, working together on one piece of wood. The historically rooted profession of a carpenter therefor does undergo a significant change, concerning its way of manual work

RESULTS

'Well, the times changed, the demands changed [...] once, there came a time when craftsmen didn't find the time to make a wooden connection anymore. Everything that was left was a straight cut, a steel bracket and some screws' (Berchtold, 2020).

Following this quotation of Berchtold, a little frustration concerning the profession of a carpenter in the 21sth century can be heard. Similar observations were noticed by Schindler (2009b) who named the steel nail as the end of any manual skill by craftspeople. Induced by his perceptions, Berchtold decided to establish a different approach towards his moral concept of a modern carpenter. For Berchtold, three core values had to be fulfilled to meet his demands of craft:

1. **Cost: The result has to be affordable.** As described by Berchtold, a wooden construction has to be affordable for an average client, with an average project and budget. His new approach shall be an option for all kind of future projects.
2. **Regional resources: Construction material has to be regionally available.**The primarily used building material has to be available in a radius of about 20-40 km. Due to the fact that the workshop of Berchtold is located in a rural area with nearby forests and sawmills, the utilization of industrial engineered wood (CLT, glulam timber etc.) was rejected. To meet the guidelines for insulation, statics etc. large pieces of solid timber (single pieces of solid wood, 30x30cm in cross-section) were chosen. Manipulating these huge logs does require specific skills and knowledge when being dried and processed.
3. **Craft: Construction has to meet his definition as being authentic to the profession of a carpenter.**As defined in the short quote above, the craft inherited by a carpenter did change over the last decades. The concept of Berchtold is characterised by his unique regional surrounding, his cultural network and his own definition of craft. For him, the profession of a carpenter has to be more than just erecting wooden constructions, in the most efficient way. Economical decisions and a constant longing for optimisation transformed the job of a carpenter. Furthermore, in Austria, every company has to educate young craftspeople. Therefore, Berchtold felt responsible to teach these 'craftspeople of the future' on a broad variety of construction methods.

Following these three core values, Berchtold found traditional log construction to fit best for his demands. This way of erecting a building can rely on a rich history and therefor provide numerous examples. Especially the corner styles of a log building (dovetail, tooth-edged joint, saddle notch etc.)

seemed to rise a challenge, worthwhile conducting for him.

'Why can't we just take a way of constructing a building that did proof for the last 300, 400, 500 years. Something ... where we know what we are talking about ... and just translate it to meet today's needs!' (Berchtold, 2020)

Since a few years, the workshop of this carpenter owns a 'Hundegger' CNC-Joining Machine. Even though the machine comes with a bunch of pre-programmed dovetail-solutions that might fit for a simple log building, these solutions miss some crucial details concerning structural and functional needs. As described by Berchtold, these pre-programmed dovetails did miss, for example, a so-called 'wind comb' (in German, transl. 'Windkamm').

At first glance, these details might not look important, but as described by the carpenter, especially these small details did prove to be essential additions when dealing with massive pieces of wood. Figuring out this lack of knowledge in a pre-programmed solution, he got into contact with the machine supplier 'Hans Hundegger AG' and started to elaborate on an improved version of their 'corner-dovetail'. With his carpenter knowledge, Berchtold convinced the 'Hans Hundegger AG' towards an optimised solution while the company took charge of all technical issues concerning the CNC-machine. As a result of this joint venture, a traditional dovetail, translated into the language of a modern CNC-joinery machine was developed. Even though the modern solution did look slightly different (due to the milling tools characteristics like round corners on the inside, instead of sharp ones etc.), the 'intelligence', the structural behaviour and the material optimization of a traditional connection could be reintegrated (Figure 4). Later on, the exterior corners will be covered with wooden cladding.

Figure 4
Close-up of final erected Corner 'Wertvollhaus' (Berchtold, 2004); Even though it was manufactured on a 'CNC-joinery machine', the final presented corner does look like a historic solution. Only on the inside, changes concerning the fabrication with a round milling tool would be observable. Later on, a wooden cladding will protect the corner from environmental impacts.

Equipped with this new Dovetail-solution, Berchtold could fulfil all three predefined core values. To give the first proof of concept, the carpenter could erect a single-family house (Figure 5). As concluded by him, the success of this project was only possible due to the extensive implementation of his CNC-joinery machine in combination with their expertise.

'[...] starting a new project right from the absolute beginning, that's what filled us with pride and confidence. Well ... these days [when erecting a building by hand] were exhausting, but they [the craftsmen] could see the whole work from another perspective, in some kind of... as we did it a hundred years ago. [...] these challenges, that is where you really can develop your personal skills. (Berchtold, 2020)

Even though a CNC-joinery machine did most of the processing steps, the final project does meet his definition of wooden construction, built by a carpenter. As described by Berchtold, this way of erecting a building is only slightly more expensive than compared to a cross-laminated wood construction (CLT). When comparing the overall building cost to a CLT-construction, the increased cost tend to rise for about 1-2% of the whole budget. In this case, the client was willing to get a building made from regional wood and therefore had to spend an additional 7.000€.

Figure 5
Carpenter building a log house from solid wood beams in 2019 (Berchtold, 2019); The wooden construction of this single-family house was erected in less than one week. Berchtold mentions that the same building would have taken them at least four weeks to produce if they would have worked without a CNC-joinery machine.

DISCUSSION

Why not imagine a unified design and fabrication process based on a series of conversations between men, designers and workers, and machines, computers and robots? (Picon, 2014)

Following the argumentation of Picon, the ongoing debate on digital transformation in craft has to be seen as a broader discussion between all involved 'Actants'. When asking the question whether a carpenter/human or a machine/robot built this house, an answer might sound like 'none of both, but only both of them'. Arguing in the line of Belliger and Krieger (2006), a machine has to be interpreted as a partner, not as simple 'tool'.

Currently, a lot of research is being done towards new implementations of robots in construction processes. These projects, mainly fostered by architects, designers, engineers etc. could benefit from the experiences possessed of craftspeople and the people who operate these machines on a daily basis. These people own deep and rich knowledge, acquired in uncountable spent hours of working and reflecting on the material/result and therefore might be able to deliver valuable insights.

In this case-study, the carpenter did make use of knowledge, unique for his profession and was able to translate it to a contemporary technological solution. With his insights, he managed to innovate a poor pre-programmed dovetail that is regularly shipped with a CNC-joinery machine. His desire for improving an unsatisfying solution motivated him to translate his expertise and hand it over to a machine supplier who then rearranged the technological circumstances (Figure 6).

The carpenter (together with the machine supplier) managed to translate his knowledge into a language that can be understood by the CNC-joinery machine. On the other hand, the machine enabled new opportunities that the carpenter otherwise could not offer anymore. Only if the carpenter understands, how to translate his knowledge into a form that the machine can handle, an appropriate solution will result. Therefore both involved 'Actants' (the carpenter and the CNC-joinery machine) had to find a way to communicate, a mode of translation, to interact with each other. As a result, this mutual approximation does unavoidable influence the 'craft' of a carpenter but also the 'processing' of the machine and in conclusion, the final revealed product. We, therefore, have to confess that a carpenter with a machine, is a different carpenter than on without.

CONCLUSION

This paper has to be seen as a further contribution to the ongoing discussion of human-machine collaboration. The carpenter in this case made use of modern CNC technology and furthermore found a way to reintegrate his singular expertise when constructing with wood. Knowledge that was crucial for the last few hundred years, but then pushed back over the last decade, now reappeared as contemporary interpretation. In this case, another approach of a human-machine collaboration could be observed. Therefore the 'machine' did not only optimize speed and precision of production but furthermore enabled the application of wooden connections that otherwise would not be affordable anymore.

The solution, developed by Berchtold suggests a reintegration of human knowledge into modern production technologies while acting in awareness to his craft specific historic roots.

By developing a solution that follows a line of historic instruments (axe, saw, etc.) but acts with the current state of technology, he could develop an ap-

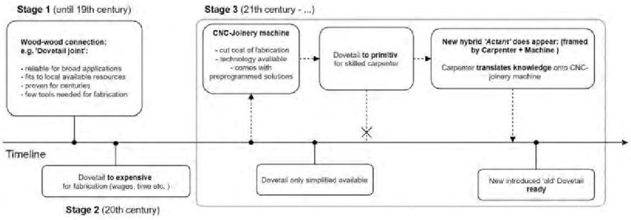


Figure 6
(Re-)Evolution of the Dovetail in this Casestudy; When illustrating this process of 'reintegration of traditional knowledge', three characteristic stages have to be considered: 1) the 'historic craft', when building material was costly and in comparison, wages were low (until 19th century). 2) The 'industrial solution': when wages rose in comparison to material cost and therefor cheaper solutions than the 'wooden dovetail' were available (20th century). 3) The now available technological solution (CNC-joinery-machine) offers the possibility to fabricate historic solutions at a fraction of cost. The provided case study shall illustrate this process of 'reintegration of traditional knowledge'.

proach to meet his definition of modern craft. This moment of translating knowledge between human expertise and upcoming robotic solutions frames the core of this research and therefore will be further explored in the next steps of this ongoing research project.

REFERENCES

Hundegger AG, H n.a., 'Innovationen für den Holzbau', in Hundegger, H (eds) n.a., *Brochure by Fa. Hundegger*, Hundegger AG

Belliger, A and Krieger, DJ (eds) 2006, *Anthology: Ein einführendes Handbuch zur Akteur-Netzwerk-Theorie*, Transcript, Bielefeld

Berchtold, G 2004, *Wertvollhaus: Von alten Traditionen, neu Gedacht*, no thesis type given, https://www.wertvollholzhaus.at/details.php

Berchtold, G 2019, *Ein Holzhaus entsteht - Zeitraffer*, no thesis type given, https://www.facebook.com/berchtoldholz/videos/ 2182427378694640/

Berchtold, G 2020, *Insights of a Carpenter in the 21th century in the region of the Bregenzerwald*, no thesis type given, Interview conducted by Schwarzmann, W

Brugnaro, G and Hanna, S 2018 'Adaptive Robotic Carving: Training Methods for the Integration of Material Performances in Timber Manufacturing', *Robotic Fabrication in Architecture, Art and Design*

Gerner, M 2002, *Die Kunst der Zimmerer: Meisterwerke aus Europa, Amerika und Asien*, DVA, Stuttgart

Gros, J 1993, *C-Hocker*, no thesis type given, https://jochen-gros.de/A/C-Lab.html

Heßller, M 2014, 'Die Halle 54 bei Volkswagen und die Grenzen der Automatisierung. Überlegungen zum Mensch-Maschine-Verhältnis in der industriellen Produktion der 1980er-Jahre', *https://doi.org/10.14765/zzf.dok-1495*, -, p. -

Jeska, S, Saleh Pascha, K and Hascher, R (eds) 2015, *Neue Holzbautechnologien: Materialien, Konstruktionen, Bautechnik, Projekte*, Birkhäuser, Basel

Klein, T 2015 'Digital Craftsmanship: The Making of Incunabula, a Fully 3D Printed Wearable Dress', *Design, User Experience, and Usability: Users and Interactions*, Cham, pp. https://link.springer.com/chapter/10.1007/978-3-319-20898-5_61

Kumar, R 2019, *Research methodology: A step-by-step guide for beginners*, SAGE, London and Thousand Oaks, California

Latour, B 2006, 'Über technische Vermittlung: Philosophie, Soziologie und Genealogie', in Belliger, A and Krieger, DJ (eds) 2006, *Anthology*, Transcript, Bielefeld, pp. 483-528

Marcus, A (eds) 2015, *Design, User Experience, and Usability: Users and Interactions*, Springer International Publishing, Cham

Pallasmaa, J 2015, *The thinking hand: Existential and embodied wisdom in architecture*, Wiley, Chichester

Piatke, W 2020, *Direct Email correspondence*, no thesis type given, CSO - Hans Hundegger AG

Picon, A 2014, 'Robots and Architecture: Experiments, Fiction, Epistemology', *Architectural Design*, 84(3), pp. 54-59

Polonyi, S 2014, 'Bauartgerechte Holzkonstruktionen', in Rinke, M and Schwartz, J (eds) 2014, *Holz: Stoff oder Form*, Niggli, Sulgen, pp. 163-167

Schindler, C 2009a, 'Genagelt und geschraubt', *Arch plus,*, 193, p. 35
Schindler, C 2009b, *Ein architektonisches Periodisierungsmodell anhand fertigungstechnischer Kriterien, dargestellt am Beispiel des Holzbaus*, Ph.D. Thesis, ETH Zurich
Schwarzmann, W 2019 'How Does the Process of Industry 4.0 Change the Job of a Carpenter?', *Börekci, Kocyildirim et al. (Hg.) 2019 - Proceedings of DRS Learn X*, pp. 949-952

4 Paper III.; The Renaissance of Structural Ornamentation

Title:	The Renaissance of Structural Ornamentation: How CNC-Joinery Machines are Helping to Re-Discover Lost Construction Techniques in Carpentry
Authors:	Wolfgang Schwarzmann, Sascha Friesike
Contribution:	Elaborate a comparison of historical and modern manufacturing techniques, incorporating the debate on ornamentation.
Status:	In review at *Architectural Intelligence;* Editor-in-Chief: Philip F. Yuan

The Renaissance of Structural Ornamentation:

How CNC-Joinery Machines are Helping to Re-Discover Lost Construction Techniques in Carpentry

Wolfgang Schwarzmann, (Corresponding author)
Institute of Architecture and Planning, University of Liechtenstein, Vaduz, Liechtenstein
https://orcid.org/0000-0003-1730-0299
wolfgang.schwarzmann@uni.li
&
Prof. Dr. Sascha Friesike,
Professor for »Designing Digital Innovations«, Berlin University of the Arts, Berlin, Germany
https://orcid.org/0000-0002-9314-5633

Abstract

What aspects are needed to generate regional, social and environmental added value through modern technology? More than a hundred years ago, Adolf Loos criminalized ornament in architecture. The consequence has been the disappearance of many building practices. At the same time, the last century has brought significant advances in technical developments. The profession of carpenters in particular has changed significantly due to CNC joinery robots. In this paper, we present a case study to examine how a historical construction principle, the "Rautenfachwerk", has been rediscovered and manufactured with modern technologies. We provide three perspectives, which jointly illustrate to what extent humans and machines have needed to work together to make this renaissance of structural ornamentation possible. Through a process of collective thinking, an old construction principle was translated into the modern day. This case study illustrates how new robot technology can generate regional, social and environmental added value.

Keywords

Traditional knowledge, robotic fabrication, ornament, historic construction, manufacturing, Interdisciplinary co-design

1 Is "Ornament and Crime" Still Relevant in 2020?

At the beginning of the 20th century, architects like Louis Sullivan, Mies van der Rohe and Adolf Loos proclaimed a new, modern and functional era in architecture (Caspary 2013). Today, more than a hundred years later, what Loos called "decorative ornamentation" is usually found only on old buildings or listed historic landmarks. Modern architecture and construction techniques aim towards fast and functional building processes. Elements that are not directly linked to substantial functions are therefore typically omitted. There are of course exceptions, buildings with an important representative function, for instance, are often decorated with ornaments. The Olympic stadium in Beijing by Herzog and De Meuron (Picon 2010, 141) the Swatch Headquarters in Biel by Shigeru Bahn (Kurz 2020) are popular examples that also rekindled debates concerning ornamentation in general (Caspary 2013, Gleiter 2008, Picon 2012). The question of the role of humans in robotic manufacturing is currently intensively discussed by Picon (2022), while Snooks (2022)is providing valuable examples of the possibilities with his applied research.

Adolf Loos called ornaments outdated and obsolete and laid the foundation for his radical view on architecture in his often-quoted essay "Ornament and Crime". In his view, the fact that ornamentation no longer seemed appropriate was supported by three observations:

- **Waste of resources:** For Loos, the production of ornamentation was a waste of resources. Workers spend time producing unnecessary objects and clients have to pay for them. To illustrate his point, he used the example of a shoe. All decorative elements on a shoe would cost time during which a cobbler is kept busy. Loos argues that he would much rather invest the same money in a decor-free pair of shoes that could then be made of better materials, because all the money that traditionally went into decoration could be saved. Applied to architecture, Loos argues that functionally better buildings could be constructed from more valuable materials if one simply refrained from adding ornamentation to them (Loos 1962, 282).
- **Lack of cultural relevance:** To him, decorative elements seemed disconnected from a deeper cultural context and were consequently without relevance (Loos 1962, 283). He argued that design

and decoration had become interchangeable and only followed fashions. Superficially applied decorations were copied from one object to another, were exchanged, replaced and remixed without any cultural reasoning. Loos argued that the relevance for society was quickly lost and that what was popular one day was often discarded as unfashionable a few years later.

- **No awareness for the past:** Loos attributed this fast-moving nature of fashionable ornamentation to a lack of awareness for the past (Loos 1962, 26). To him, objects could be copied as long as they remained in their original context. Otherwise, their form and function needed to be fundamentally re-explored and explained (Gleiter 2008).

These observations are more than a century old. A century that has seen considerable innovations in construction technologies. Particularly the crafts like carpentry have undergone numerous developments like automation or computer-aided design. There are constant debates around these developments. What *is* the profession of carpentry in light of automation? Which tasks will be performed by machines and which remain with humans? Can we speak of a new, collective work process? What roles do expert knowledge and creative thinking play?

In this essay we would like to address a very specific aspect of technological development. We would like to discuss how the increase of automation in the construction of buildings affects the approach to ornaments. We intend to ask whether the basic assumption of modern architecture, that better buildings can be built if we refrain from using ornaments, is still applicable in a world where the construction of buildings is increasingly automated. And we aim to discuss this topic on the basis of wood construction, since the effects of increasing automation and robotization can be observed particularly well here (Fig. 1).

Fig 1

Wood construction, ornamentation and architecture. Building complicated wooden constructions by hand is not affordable any more. Modern CNC robots, however, open up new possibilities here, such as at the "Halle Rauch" ©: Erden Lehmbau GmbH and Hanno Mackowitz

1.1 The Craft of Carpentry as a Constant Process of Change

Tools that carpenters use have always evolved. Countless developments have been influenced by technology advancements, local culture, and other soft factors, resulting in today's global variety of carpenter tools (Aigner and Müller 2017, 33). Especially the last century has seen considerable changes in carpentry. From the 1950s onwards, complex wooden connections like dovetails, which once needed a skilled and patient carpenter, have been replaced by industrially produced steel parts and nails (Graubner and Grunder 2016, 19)[1]. An unskilled worker was then able to assemble a wooden structure without the need for labor-intensive details. Schindler (2009, 35) describes the invention of the steel nail as marking the end of every handcrafted joint.

Since the 1980s, another trend can be observed, as the cost for wooden connections then fabricated by CNC-joinery machines dropped significantly. CNC-joinery machines have increased both manufacturing speed and precision. Complex tasks like sawing, drilling and labeling are now handed over to a "robot" (Jeska, Saleh Pascha, and Hascher 2015, 60). Even though the first simple robots were basically new combinations of existing machines (Brynjolfsson and McAfee 2016, 57–96), they laid the groundwork for today's carpentry industry. Traditional manufacturing methods and hand held tools would not have been able to make the timber construction industry what it is today (Aigner and Müller 2017, 33). To give an example, the dovetail made a comeback in wood connections as CNC-joinery machines made it possible to bypass the previously needed intricate handiwork. In its modern interpretation, the dovetail joint is fast to produce and easy to assemble (Jeska, Saleh Pascha, and Hascher 2015, 67; Kolb 2010, 165). The following figure provides a brief comparison of the various solutions using the dovetail connection. At first glance, the CNC-fabricated dovetail has tectonic and geometric overlaps with the classic dovetail. However, the production process and the work of the carpenter involved are fundamentally different (Fig. 2).

[1] Extensive reviews of the large variety of wood joints can be found in Gerner (2002), Graubner and Grunder (2016), and Zwerger and Olgiati (2012).

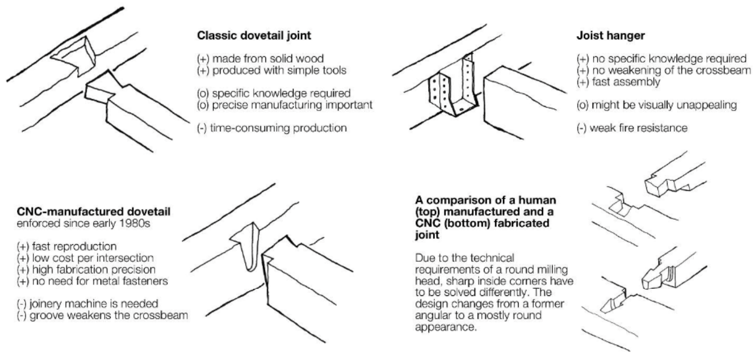


Fig. 2

Comparison of the same connection point with different solutions: While both the classic dovetail and the CNC-manufactured dovetail are made only of wood, the joist hanger is made with steel and nails. Due to the manufacturing methods, the appearance of the wooden dovetail has changed from an angular (hand-made with chisel and saw) to a round (CNC milling head) design.

1.2 CNC Technologies Open Up New Possibilities in Carpentry

Architecture is always pushing the boundaries of what can be built. This is arguably true for no other building material as much as for wood, since wood is the material that people have been using since they started building in the first place and one that still plays an essential role today. The abovementioned Swatch Headquarters in Biel is a contemporary example of a construction that showcases what is technically possible with wood.

Finished in 2019, the building is an impressive manifestation of today's possibilities in fabrication complexity, structural options and aesthetics in wood constructions. The building's structure consists of more than 4,600 uniquely worked pieces of timber (Fig. 3). Manufactured on a CNC-robot and clearly visible, the building openly presents its complex wooden structure (Strehlke 2020a). In a recent lecture, Strehlke (2020b) shows the incredible complexity involved in such timber construction projects. The entire presentation is available online and shows the scope of the project in detail.

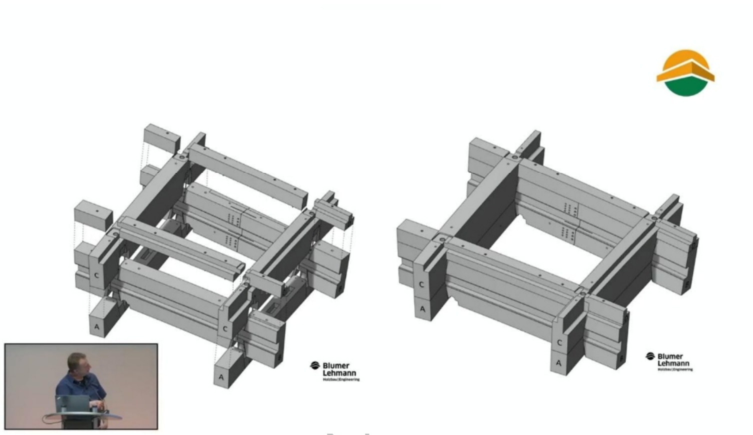


Fig. 3

The sheer complexity of a single connecting node at SWATCH headquarters built by Blumer Lehmann is revealed in Strehkle's presentation. © Blumer Lehmann

But the striking building is not free from criticism. Kurz (2020) argues that the building might be impressive on a structural and technological basis, but challenges its connection to the surrounding city (Fig. 3). Kurz explains that the architecture does not correspond to regional values, but is simply designed for the "global visibility" of the world wide web. A related and more general argument comes from Picon (2013, 143), who calls for an architecture that must consist of more than a designer whose detached idea is then reproduced by a CNC machine. For him, here the elementary tasks of craftsmen, artists and clients have been replaced by the architect, whose design is produced on a CNC joinery machine resulting in a random and incoherent formalism.

While the Swatch Headquarters in Biel is an impressive architectural achievement, it is an extreme example in size, complexity and budget. To study the changing relationship between architecture and ornamentation in light of modern construction technologies we therefore turn to a more common example: the case of the cereal drying rack.

Fig. 4

The Swatch Headquarter in Biel, Switzerland after completion in 2019 © Swatch Group

2 The Case of the Cereal Drying Rack

Constructed as simple agricultural buildings, cereal drying racks have developed their own unique aesthetics. These wooden buildings were once erected to protect grain and hay in the changeable and rainy weather of the central European Alps. While they offer a broad range of different wooden connections, we will focus our attention on the wooden cross bracings, the so-called "Rauten-Fachwerk". This wooden grid addresses a variety of needs:

- **Support structure:** The beams were typically interlocked using multiple half-lap joints, resulting in a cross bracing for the whole building
- **Air circulation:** The wind- and air-permeable geometry enables air to circulate, which favors the storage conditions for hay and grain
- **Controlled enclosure:** The structure keeps light and loose materials such as hay in place during strong wind and poor weather conditions
- **Natural light:** The numerous small openings are a simple but efficient solution to get light into the building

While cereal drying racks were originally meant to dry and protect grain from environmental influences, over time craftspeople came to appreciate the aesthetics of the construction. Even though this kind of connection typology required time and skill, the manufacturing of such half-lap joints could be done quite fast, due to their right angles and simple geometry (Zwerger and Kaufmann 2020, 109-10). To express the status and wealth of a farmer, sometimes more wooden logs were used than structurally necessary. A construction once purely functional increasingly became a symbol of wealth. With the growing skills and expertise of the craftspeople, the wooden grid progressed towards an expressive two-dimensional pattern (Fig. 4).

Fig. 5

The "Rauten Fachwerk" as it was historically used on a cereal drying rack in the central European Alps, Slovenia © Klaus Zwerger

In recent history these buildings have gradually disappeared. This trend can be attributed to changes in modern agriculture, which have made the building unsuitable for its original purpose (Zwerger and Kaufmann 2020, 339). Inspired by cereal drying racks, we started to investigate and discovered the construction of a contemporary interpretation: the "Halle Rauch", a large workshop for clay construction.

3. Methodology

To gain insights into the relationship between modern wood construction technologies and the use of ornaments in architecture, we conducted a case study research on the construction process of the "Halle Rauch" in Schlins, Austria. The "Halle Rauch" contains a modern interpretation of a "Bundwerk", a specific kind of wooden construction, which allowed us to study the use of ornaments in a contemporary building process.

3.1 Case Description

In 2020, "Erden Lehmbau Gmbh" built a new workshop in Schlins, Austria. Some structural parts of their new workshop were made of rammed earth, while others were constructed from wooden elements (Fig. 5). The rammed earth was manufactured by "Erden Lehmbau GmbH" on site, the wooden elements had been pre-assembled by a carpenter in his workshop.

The fact that the wooden grid fulfills structural needs, as well as the fact that the carpenter manufactured this structure on a CNC-joinery machine, offered an ideal basis for our case study research.

Fig. 6

While the left wall of the "Halle Rauch" was manufactured with rammed earth, the right wall was erected as a wooden construction. The image shows the three finally installed "Rauten Fachwerk"-Frames. © Erden Lehmbau GmbH, Schlins and Hanno Mackowitz)

3.2 Data Collection

At the beginning of this research project, the building site was documented photographically. The geographical proximity of the building to the first author's university allowed ongoing interactions with all the project participants and in-depth direct exchanges. The qualitative data of this research was collected through open structured interviews, photographs, notes, technical descriptions and observations. The different data points were collected in a digital case database, which laid the groundwork for discussions between the two authors.

Martin Rauch was interviewed in his dual position as both client and architect. He was interviewed with regard to the design, tradition, motivation and geographical background of the construction. As an experienced clay artist, he expressed his interest in interacting with material, form and context.

Further interviews were conducted with the carpenter in charge of the project and the CEO of the carpentry company. Their knowledge as wood construction experts, but also as owners of a CNC-joinery machine provided valuable insights. The working craftsmen were questioned about the construction process, production and assembly. They provided valuable insights like their relationship towards their own craft, their identification process, and the way they act within the tradition of their field. Further questions regarding their profession, the role of the CNC- joinery machines and the role of the collaborative work process between humans and machines were discussed.

These conversations were supported by a selection of research-specific images showing traditional and contemporary wood joints, an old hay barn from nearby, and pictures of the building site of the "Halle Rauch". The interviews were transcribed and added to the case database.

3.3 Data Analysis

The case database laid the foundation for the data analysis. The two authors annotated the collected data and discussed them in joint meetings or telephone calls. Over time we, the authors, developed a structure to make sense of the case. We converged on three perspectives that together explain how the case of the "Halle Rauch" involved the construction of ornamentation that is rooted in history, reflects local culture, and was produced for the same cost as a simple alternative:

1. **Contextualize:** Contextualizing is defined by us as the ability to view an object or an action in relation to other subjects and to place it in an appropriate correlation. According to our understanding, the environment must first be analyzed and understood. When consciously taken into account, a context-related design can be seen as a quality criterion in which aspects like cultural, regional and historical conditions will be reflected.

2. **Cooperate:** The process of cooperation can be seen as the interaction of multiple people/entities as one system. In most cases there is a corresponding benefit/added value for all participants in the process. A temporary symbiosis is formed. This joint work can achieve something that each individual would not have been able to achieve alone. Ideally, the skills of all are taken into account and merge into one strength.
3. **Expertise:** Within the scope of this work, we define expertise as possessing subject-specific knowledge and experience. This knowledge can be applied to a specific and challenging problem. According to our definition, the process of acquiring this expertise might have happened through a specific education or a time-consuming process of confrontation with the subject area. Through expertise, a specific problem can be solved by drawing on existing competencies.

These three perspectives help to relate our case-specific observations of the Rauch building to the historical construction of cereal drying racks and the computer-aided manufacturing process. The following sections will provide detailed examples from each of the three perspectives.

4 Contextualize: Reinterpreting a Regionally Embedded Construction

To Rauch, the ornamental appearance of the "Bundwerk" has a direct connection to his hometown Schlins in Austria. After closely observing his environment for many years, Rauch described the "Rauten Fachwerk" as identity building for the region (Fig. 6). For many years, he has lived and worked in this area that was once characterized by its agricultural infrastructure. Recently, yet another barn with these structural elements was taken down to make room for a new building. While the wooden grid works as a structural part on the one hand, this element functions as an object for regional identification and ornamentation on the other.

Fig. 7

A still existing hay-barn in Gatschief, Vorarlberg, in proximity to the new "Halle Rauch" showing the characteristic "Rauten Fachwerk" ornamentation © Johann Peer

It was once frequently used in agricultural buildings, and Rauch decided to take up this way of joining wood and reinterpret it as part of his new workshop. Rauch is aware that his workshop serves a different function than hay barns, yet the building is also a "commercial building" (Fig. 7). As noted by Rauch, the translation of the wooden framework has been a success. Every now and then, local people visit his new workshop. The similarity to the cereal drying racks can be heard in what they tell him.

Fig. 8

The already partially furnished wooden hall. In the background, air and light is transmitted through the wooden lattice.

5 Cooperate: Collective Thinking and Problem Solving as a Source of Novel Solutions

Without a joint thinking process, the wooden lattice (Fig. 8) would not have been possible. As mentioned by Rauch, the very first solution proposed by the carpenter was an industrially manufactured CLT panel with an approximate thickness of 4.7 in. (12 cm). At first glance, this contemporary and obvious solution might be the most straightforward approach to meet the requirements of statics, building physics and functional necessity. However, this obvious solution was not what Rauch had in mind. Although all the project participants had already rejected the initially proposed wooden lattice, Rauch wanted to debate it one more time. Concerns among project partners about this solution were numerous:

- **Cost:** the complex production might become too expensive
- **Assembly:** compared to a solid wooden panel, the grid is much more challenging to assemble
- **Precision:** The precise production of such a complex structure might be very challenging and difficult to master by hand

Only after intensive discussions and joint reflections could a solution be outlined that made a reliable basis for a cost estimation. As a result of this joint discussion process, the carpenter came up with the idea of using the CNC-joinery robot for the task. Although the carpentry shop had already owned this robot for more than two years, so far it had only been used for simple tasks. To everyone's surprise, the cost estimate showed that the wood-grid, manufactured on the CNC-joinery machine and assembled by the carpenter, would be almost the same cost as the wooden panel initially suggested. However, the change in the wage-to-material ratio resulted in a more profitable commission for the carpenter. Although both solutions result in roughly the same costs, the wood lattice almost triples the carpenter's wages.

	CLT-Slab	**Wood-grid "Rauten Fachwerk"**
Dimension (l/d/w)	412.9 in. x 186.2 in x 4.7 in	412.9 in. x 186.2 in x 7.0 in.
	(1049 cm x 473 cm x 12 cm)	(1049 cm x 473 cm x 18 cm)
Manufacturing h per Unit (carpenter workshop, inhouse)	8.6h	30h
Cost per Unit (net)	4,820 €	5,290 €

Wages per Unit (net)	500 €	1,760 €
Material per Unit (net)	4,290 €	3,080 €
Ratio of wages to material (net)	1 : 8.5	1 : 1.75

Table 1: A comparison of the CLT-Slab and the "Rautenfachwerk" reveals fundamental differences in cost, manufacturing time and wages.

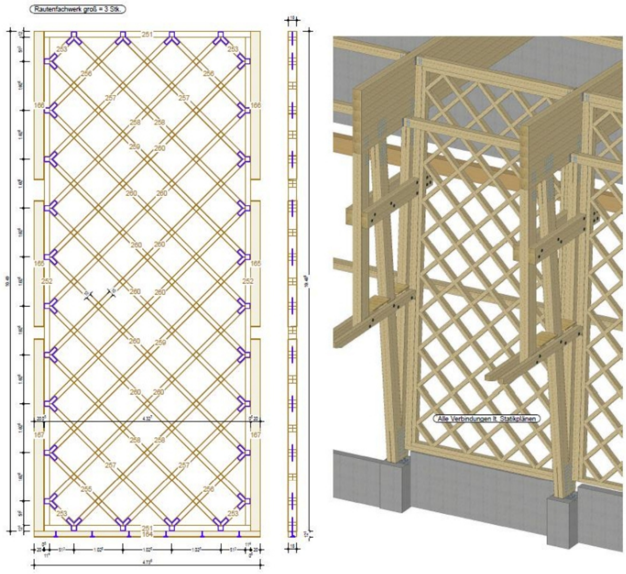


Fig. 9

The manufacturing drawings by the carpentry workshop showing one single "Rauten Fachwerk" and its elements. © Dobler Holzbau, Röthis

This comparison of the costs illustrates what can arise from a joint thinking process. As a result of the repeated discussions, all the participants were able to adapt their contributions to the process. By combining individual competencies (human and machine) a previously unthinkable solution became doable. As a result, an object was developed that none of the entities involved would have been able to accomplish on their own.

6 Expertise: When Traditional Tectonics and Modern Craftsmanship engage

The overall building process of the reinterpreted "Bundwerk" turned out to be a challenge. Although this type of construction has been used for hundreds of years, the contemporary implementation with the required size turned out to be complicated. Each of the three lattice grid structures measures 34 ft. 5 in. (10.48m) H x 15 ft. 6 in. (4.73m) W x 7 in. (18cm) D and was constructed from 32 wooden beams.

All the wooden pieces were manufactured on the CNC-joinery machine owned by the carpenter's workshop. Originally, it was planned to build the entire framework from regionally available wood beams. However, as it has turned out, industrially manufactured beams were necessary to meet the technical needs for smooth production on the CNC- joinery machine. So called "Duo-balken" consist of two planks, laminated together with parallel wood grain, resulting in one large beam. This technique compensates for the natural deformation and structural inequalities of wood. Furthermore, a short handling time between delivery and assembly of the wooden grid proved to be crucial for a smooth process. As an expert on wooden constructions, the carpenter explained that wasted time between these steps would affect the humidity of the wooden pieces and consequently the geometry of the manufactured parts. This distortion would have substantially complicated the later assembly process. The pieces were put together on a horizontal plane (Fig. 9). After rectifying all vital measures, all the pieces were screwed together (Fig. 10). To make each frame rigid, the right angle joints were fabricated as cross-lap joints and secured in position with 4 screws. Compared to the historic example of wooden lattice, it can be seen that traditionally, these junctions were secured with oak dowels (Fig. 9). As explained by the carpenter, the holes for the dowels need to be predrilled, resulting in a significant weakening of the wooden grid.

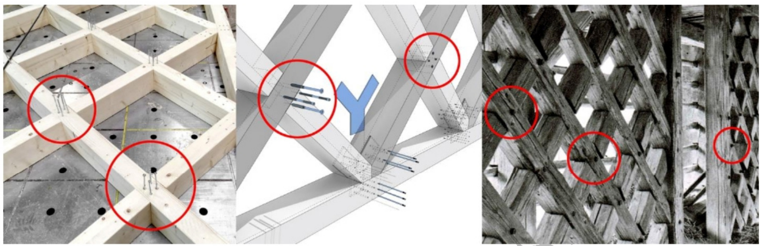


Fig. 10

The framework was put together horizontally, then screwed four times per joint and raised as one big panel. A comparison of the modern and the historic lap-joint. While the historic solution worked with just one solid oak dowel every now and then, the modern translation required 4 screws per intersection. © right image: Klaus Zwerger

At the side points, where the interwoven wood grid connects with the surrounding frame, a 0.15 inch (0.4 cm) steel-Y was inserted and screwed in position. Although this solution would have been possible with a pure wood-wood connection, it was decided to implement a steel part for a better structural performance.

Fig. 11

Prefabrication at the workshop: Each of the three "Rauten Fachwerk" -frames was assembled on a horizontal plane and later lifted as one big piece. © Dobler Holzbau, Röthis

Although the historical example of the cereal drying rack was already known, the carpenter's specialist knowledge and expertise proved to be essential. As an experienced craftsman, he was able to bring his knowledge from numerous years of work into the process and combined it with his technical skills on the CNC-joinery machine.

Fig. 12

Finally assembled and stored, ready for transportation: A “Rauten Fachwerk” frame at the carpenter’s workshop © Dobler Holzbau, Röthis

7 Discussion

Despite the fact that Adolf Loos wrote “Ornament and Crime” more than a century ago, the debate about the relevance of ornamentation is still omnipresent in architecture (Balik and Allmer 2016, Ghada 2018, Riisberg and Munch 2014). His initially raised questions regarding the waste of resources, a lack of cultural relevance, and an uncertain use of historical artifacts remains relevant in today's building culture. Loos not only challenged decorations in general but also believed a deeper connection with the surroundings was missing.

Since the beginning of the early 1980s, CNC technologies have substantially changed the manufacturing process in wooden craftsmanship. Even though a CNC-joinery machine is able to handle large parts of the time-consuming manual work, the fundamental question of an appropriate application of these opportunities is still open.

In our case study, we took a closer look at the reinterpretation of an historic construction technique, fabricated on a CNC robot. Certain tasks were outsourced to the machine, while other, cognitively demanding tasks had to be performed by humans. A regionally specific construction element, the "Rautenfachwerk", was rediscovered. This paper is intended to engage in a discussion about the extent to which modern production possibilities can contribute to rediscovering historical practices. By following our three proposed perspectives, this discourse between man and machine can be illustrated:

7.1 Interpreting Regional Building Culture

As described by Kurz (2020), the Swatch Headquarters in Biel is an impressive building in terms of its complexity. However, Kurz believes it lacks a reference to the local context, to the site's history, to its culture. Loos argued in a similar manner when he deemed fundamental the human ability to respond to regional characteristics and to act in a context-related manner. As Loos saw it, ornamentation that is merely taken decoratively from one object and applied to another is torn out of context.

In our case study, we observed how an architectural design was established on the basis of historical memories and physically built references. Inspired by his own experiences and observations, Rauch challenged contemporary construction methods with an alternative solution. The re-discovery of the "Rautenfachwerk" inspired him to push the carpenters and the construction engineers towards a "lost" solution. Rauch's life and history as a local artist made him sensitive to regionally specific elements.

This ability to absorb, understand and interpret regional characteristics laid the foundation for a contextually sensitive design. While our first dimension "Contextualize" addresses essential aspects of regionally specific building culture, the question arises of how a collaborative working and thinking process might take place, leading us to the second observation:

7.2 Dialog as a Basis for New Solutions

Looking at the architecture of Adolf Loos, his typical solution was the reduction of unnecessary elements and the use of high quality materials. As a counterpart to the cluttered architecture of his era, he established a radical simplicity in his designs.

The first solution for the Rauch building was presented with a similar, minimalistic logic. This first idea for closing the side walls was an industrially produced CLT panel. For the structural engineer and the craftsmen involved, this seemed to be the simplest and most efficient approach. Referring to "Ornament and Crime", this solution would also probably be the most straightforward interpretation, as it omits every unnecessary element.

However, as it turned out in further discussions, due to CNC-joinery machines the production of the wooden grid would be conceivable at approximately the same cost. As a result, a much more complicated (and ornamented) solution suddenly became competitive because the required work was assisted by a robot. However, it took intensive discussions with all parties involved to figure this out. Only after ongoing inquiries from Rauch to search for an alternative solution did the carpenter consider his CNC-joinery machine. The expertise of the carpenter, who has internalized both the technical possibilities of the CNC-joinery machine and the necessities of the assembly on site, was able to fundamentally enrich this dialog. Through his person, the technical potential of the CNC-joinery system was unlocked for the evaluation process. Hence, the waste of human labor initially criticized by Adolf Loos is no longer necessarily valid in the face of modern production possibilities.

However, in our case this solution could only be established after an intensive evaluation of all available competencies (be they human or machine). Picon (2014, 57) described this challenging process as a utopian scenario, as follows: "*Why not imagine a unified design and fabrication process based on a series of conversations between men, designers and workers, and machines, computers and robots?*"

7.3 How Man and Machine develop New Potentials from Old Insights

When it comes to handling the old and the existing, Loos offered two options. Either keep the existing in an identical form and copy it, or completely disassemble a component into its single pieces and rethink it from the ground up (Loos 1962, 28). He believed that if something new was envisioned, any formalism had to be avoided. Objects that were newly created had to stand within the time, the culture and the society from which they originated.

In our case study, a construction principle that had been established for hundreds of years in the craft of carpentry was reinterpreted. Until recently, this very specific way of joining wood had not been able to stand up to newer solutions emerging in the 20th century. Now opportunities offered by a modern CNC-joinery system made it possible to rediscover this design principle. The manual work that was initially required to build this structure could now be handed over to a robot. The milling grooves of the CNC-joinery machine were left as they came out of the machine. Likewise, the chosen fasteners, the steel screws, were not hidden by wooden plugs.

The role of the carpenter, as a wood expert, remained essential throughout the entire case. Only due to his profound knowledge of both the building material wood and the required processing steps on the CNC-joinery machine made the renaissance of the lost "Bundwerk" structure possible. As a wood construction expert, he was able to analyze, interpret and re-engineer the traditional joining method of the wood grid. Although former manual work was carried out here by a joinery robot, the cognitive performance as an expert in his field was fully preserved.

The summarizing question could therefore be posed as follows:

> Is an ornament justified in modern architecture if it can be manufactured without extensive use of manual labor?

It can be said that "Ornament and Crime" fundamentally criticizes an unreflective application of decorative ornamentation. In today's world, complex structures can be produced quickly and efficiently by using modern manufacturing technologies. However, the cognitive performance of a human being, which establishes the regional, cultural and social connection of the ornamentation, cannot (yet) be outsourced to a robot. In our case we have been able to showcase an example of ornamentation that is rooted in history, reflects local culture, and was produced for the same cost as a simple alternative.

Declarations:

Availability of data and materials:

The mainly qualitative data generated from the interviews and observations during this study are not openly available due to protection of subjects' personal information as well as their privacy. The data are available from the corresponding author upon reasonable request.

Competing interests:

The authors declare no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding:

No funding was received to assist with the preparation of this manuscript.

Authors' contributions:

Both authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Wolfgang Schwarzmann. The first draft of the manuscript was written by Wolfgang Schwarzmann and later on commented and further developed together with Sascha Friesike. Both authors read and approved the final manuscript.

Acknowledgments:

The author wants to thank Martin Rauch, Johannes Welte and Christoph Greußing for supporting this research and for sharing their profound insights concerning the building process of the 'Halle Rauch'.

References

Aigner, N., and Müller., P. (2017). "The Industrialization of Timber - a Case Study." In *Cultivated Building Materials: Industrialized Natural Resources for Architecture and Construction*, edited by Dirk E. Hebel and Felix Heisel, 32–39. Basel/Berlin/Boston: Walter de Gruyter GmbH.

Balık, D., and Allmer, A., (2016). "A Critical Review of Ornament in Contemporary Architectural Theory and Practice." *AZ* 13 (1): 157–69. https://doi.org/10.5505/itujfa.2016.73745.

Brynjolfsson, E., and McAfee, A. (2016). *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. New York, London: W.W. Norton & Company.

Caspary, U. (2013). *Ornamente der Fassade in der europäischen Architektur seit den 1990er Jahren.* Berlin: Jovis. Zugl. Berlin, Humboldt-Univ., Diss., 2011.

Gerner, M. (2002). *Die Kunst der Zimmerer: Meisterwerke aus Europa, Amerika und Asien.* Stuttgart: DVA.

Ghada, M. El. (2018). "Architectural Ornaments in the Twenty-First Century: An Analytical Study." In *Cities' Identity Through Architecture and Arts: Proceedings of the 1st International Conference on Cities' Identity Through Architecture & Arts, Cairo, Egypt, 11-13 May 2017*, edited by Anna Catalani, 9–25. Leiden, The Netherlands: CRC Press/Balkema.

Gleiter, J. H. (2008). "Zur Genealogie des neuen Ornaments im digitalen Zeitalter: Eine Annäherung." In Entwurfsmuster: Raster, Typus, Pattern, Script, Algorithmus, Ornament, edited by Nikolaus Kuhnert, 78 83. *Arch+* 41.2008/09,II. 189. Aachen: Arch+.

Graubner, W., and Grunder, W. (2016). *Holzverbindungen: Gegenüberstellungen japanischer und europäischer Lösungen.* With the assistance of L. Oldenbourg. 2nd edition. Munich: Deutsche Verlags-Anstalt.

Jeska, S., Pascha, K., S., and Hascher, R., (2015). *Neue Holzbautechnologien: Materialien, Konstruktionen, Bautechnik, Projekte.* Basel: Birkhäuser.

Kolb, J. (2010). *Holzbau mit System: Tragkonstruktion und Schichtaufbau der Bauteile.* 3rd edition Basel: De Gruyter. http://www.degruyter.com/search?f_0=isbnissn&q_0=9783034611800&searchTitles=true.

Kurz, D. (2020). "Kathedrale Ohne Form: Seine Konstruktion Ist Spektakulär, doch der Swatch-Hauptsitz entzieht sich der Beschreibung." *werk, bauen + wohnen* 74 (107): 32–33.

Loos, A. (1962). *Sämtliche Schriften: In Zwei Bänden.* Edited by Franz Glück. 2 vols. Vienna, Munich: Herold.

Picon, A. (2010). *Digital Culture in Architecture: An Introduction for the Design Professions.* Basel: Birkhäuser.

Picon, A. (2012). "Ornament: Architecture, Subjectivity, Politics." New York, April 4. Accessed November 27, 2020. https://www.youtube.com/watch?v=KnwSoRUZEto.

Picon, A. (2013). *Ornament: The Politics of Architecture and Subjectivity.* AD primers. Chichester, West Sussex, United Kingdom: Wiley A John Wiley and Sons Ltd Publication. http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=787230.

Picon, A. (2014). "Robots and Architecture: Experiments, Fiction, Epistemology." *Archit. Design* 84 (3): 54 59. https://doi.org/10.1002/ad.1754.

Picon, A. (2022). Digital Technology and Architecture: Towards a Symmetrical Approach. *Technology|Architecture + Design, 6(1),* 10–14. https://doi.org/10.1080/24751448.2022.2040297

Riisberg, V., Munch, A., (2014). "Decoration and Durability: Ornaments and Their 'Appropriateness' from Fashion and Design to Architecture." *Artifact* 3 (3): 5. https://doi.org/10.14434/artifact.v3i3.3918.

Schindler, C. (2009). "Genagelt Und Geschraubt." *Arch plus,* (193): 35.

Snooks, R. (2022). Behavioral tectonics: agentBody prototypes and the compression of tectonics. *Architectural Intelligence*, 1(1). https://doi.org/10.1007/s44223-022-00007-8

Strehlke, K. (2020a). "Schönheit Der Tragstruktur." *werk, bauen + wohnen* 74 (107): 34–38.

Strehlke, K (2020b): *EXPERTiNNENTALK mit KAI STREHLKE, BLUMER LEHMANN.* Zentralvereinigung der ArchitektInnen Österreich. OFROOM Innovations Agentur, 2020.

https://www.facebook.com/zv.steiermark/videos/expertinnentalk-mit-kai-strehlke-blumer-lehmann/809229339608349/.

Weigel, A. (2008). *"Pyjama Und Verbrechen: Wien 1928: Warum Adolf Loos Wegen Kindesmissbrauch Angeklagt Wurde Und Mit Einer Bedingten Haftstrafe Davonkam."* Die Presse, https://www.diepresse.com/406436/pyjama-und-verbrechen.

Zwerger, K., Kaufmann, H. (2020). *Cereal Drying Racks: Culture and Typology of Wood Buildings in Europe and East Asian.*

Zwerger, K., Olgiati, V. (2012). *Das Holz und seine Verbindungen: Traditionelle Bautechniken in Europa, Japan und China.* 2. Ed. Basel: Birkhäuser.

5 Paper IV.; What a carpenter can learn from 'Thingiverse'

Title:	What a carpenter can learn from 'Thingiverse'; how robots are already changing the craft of carpentry
Authors:	Wolfgang Schwarzmann
Contribution:	Identifying 3 overlaps and 3 contrasts between the Maker movement with 3D printers and carpenters with joinery robots.
Status:	Published in the Proceedings 'Structures and Architecture. A Viable Urban Perspective?' of the Fifth International Conference on Structures and Architecture (ICSA 2022), Aalborg, Denmark

Structures and Architecture (ICSA 2022) – Hvejsel & Cruz (eds)

What a carpenter can learn from 'Thingiverse'; how robots are already changing the craft of carpentry

W. Schwarzmann
Institute of Architecture and Planning, University of Liechtenstein, Vaduz, Liechtenstein

ABSTRACT: CNC-supported manufacturing makes common construction processes more efficient and predictable. However, this change in manufacturing processes also enables a re-think of current process workflows. This paper explores what carpenters with joinery robots can learn from the maker movement with 3D printers. In contrast to this long-established craft, the maker movement can be seen as a young phenomenon that works dynamically with modern technology like the Web and CNC machines. For some years now, carpenters have been investing more and more in CNC robots. By conducting a comparison, three overlaps and three differences between these two disciplines are discussed. As the results indicate, craftsmen will continue to face geographical, legal and static challenges in the future. However, there is still great potential in dealing with the digital model among craft people. Not only automated production of components but also the digital model would open up new possibilities in their profession.

1 INTRODUCTION

As architects and engineers, it is our task to observe and question common building processes. Robots and smart production processes can contribute to the further development of our current building culture. New timber construction principles such as the 'Recycleshell' by Robeller & Haaren (2020) or the robotic assembly of reversible timber structures by Naboni et al. (2021) already extend the limits of what new manufacturing processes using robotics can do. Looking beyond one's own backyard, other disciplines can reveal new approaches to solutions. In the context of this publication, the question is what differences and similarities can be observed between CNC joinery systems used by carpenters and 3D printers used by makers.

At first glance, these two disciplines seem to have little overlap. However, considering how current manufacturing processes in carpentry companies could be developed further using state-of-the-art CNC technology, a comparison to the maker movement appears promising. By comparing the manufacturing processes of the automotive industry to the home construction industry, Aitchison (2017) provided a similar approach. The first section of this publication provides a background to the two different cultures and histories of carpenters with their joinery robots and the maker movement with its corresponding 3D printers. In the methods section, a comparison between the manufacturing processes of these two observed groups is illustrated. Our observations show that the different project sizes significantly influence the manufacturing processes, but also that the working methods of the communities (makers and carpenters) follow a different solution-oriented approach. Finally, on the basis of three overlaps as well as three differences, we show where the craftsmen are similar to or different from the makers. In the context of the discussion, further innovation potentials for robotic manufacturing in the craft of carpentry are identified and opened up for this ongoing research process.

DOI 10.1201/9781003023555-69

2 BACKGROUND

2.1 *The profession of carpenters and the joinery robot*

Looking back on a history of more than 5000 years, the profession of carpentry is one of the oldest professions in our society (Gerner 2002). As experts in the construction of roof trusses, wooden bridges and other demanding wooden structures, this profession is strongly characterised by manual work with special tools. In the last 20–30 years, modern CNC joinery systems have been able to establish themselves in numerous timber construction companies in Central Europe (Schindler 2009). A CNC joinery machine is a computer-controlled robot that is able to take over many steps in the carpenter's craft (Verband HIGH-TECH-ABBUND e.V., 2019). These machines automatically draw in the raw material, cut it to size, drill holes, mill joints or create other complex connections such as a stud or dovetail (Figure 1). Work that was previously done by the craftsmen in laborious manual work is now done quickly, efficiently and precisely by this robot. The final assembly, the joining of the individual components, is completed in turn by the carpenters. Nevertheless, the joinery robot has automated many of the former physically demanding tasks.

Figure 1. A joinery robot (left) is able to produce round wooden studs (right) or dovetail joints quickly and accurately.

Generally, a joinery robot is programmed by a carpenter, trained as a CAD draughtsperson in the office. The timber components are drafted on the basis of a three-dimensional model, the digital model. After the construction has been drawn as a digital model, the manufacturing steps are sent digitally to the joinery robot via the software interface. In the cases observed, the joinery robot is operated by a specially trained carpenter, the machinist. This person is a timber construction expert with an additional understanding of the joinery robot. As a machinist one loads the wood onto the machine, monitors the production process and afterwards stores the finished components, mostly wooden pieces. Other craftsmen are then involved in the further assembly. The different areas of responsibility (3D development, production on the robot, assembly) are usually in direct and personal communication with each other.

2.2 *The maker movement phenomenon and 3D printers*

The beginning of the maker movement phenomenon can be dated back to 2005 (Anderson 2013). The first issue of the magazine 'Make' as well as the first maker fairs in Silicon Valley gave a visible context to the movement, which had been quite unobtrusive until then. A further milestone occurred in 2007 following the arrival of the 'RepRap', one of the first open-source 3D printers. The independent research and development of new technologies as a hobby already had a community in the 1970s as the 'DIY-movement' (Design-It-Yourself). Starting from this basis, the maker movement, as it is known today, made use of the communication opportunities of the world-wide-web

(Dougherty 2012). According to Anderson (2013), the profile of a maker can be summarized by three main characteristics:

1. People using digital desktop tools to create designs for new products and prototype them ("digital DIY")
2. A cultural norm to share those designs and collaborate with others in online communities.
3. The use of common design file standards that allow anyone, if they desire, to send their designs to commercial manufacturing services to be produced in any number, just as easily as they can fabricate them on their desktop. This radically foreshortens the path from idea to entrepreneurship, just as the Web did in software, information, and content.

The 'norm' of sharing a design with the community, which is more or less taken for granted in point 2, is remarkable in this context. As a result of this 'digital DIY' scene, a wide variety of online platforms has emerged over the past years. Besides numerous sites such as 'pinshape.com' and 'grabcad.com', 'Thingiverse.com' is currently the largest platform that makes user-generated data available under an open license. The name was formed from a combination of the words 'Things' (as in 'IoT' Internet of Things) and 'Universe' and is intended to represent the vast range of possibilities. On the website 'Thingiverse', 3D print files can be uploaded and made available in digital form to other users free of charge (West & Kuk 2016). Via the remix function, modified files can be kept in chronological order along with previous versions. Thus, it is possible to trace the evolution process of a design. This means that a single design can be the starting point for a discussion with hundreds of comments, variations and produced objects. Considering that these developments only started 14 years ago, and a site like 'Thingiverse' was created 13 years previously but already makes more than 2,117,000 3D models available online, it is remarkable how much data has been contributed, commented, on and further developed by the community.

3 METHOD

As part of this research, qualitative data was collected through interviews and supported by a corresponding case study. After a pre-selection of 12 carpentry companies (regarding their technical setting, working methods and interest in the topic), two companies qualified for a deeper analysis. In these companies, the craftsmen in the assembly hall, the technicians at the CNC joinery machine and the CAD-technicians in the office were interviewed. A total of 6 expert interviews were conducted in two companies. The broad, openly held interviews provided deep insights into the work of these craftsmen. Several images of 3D printers and joinery robots were used to support the conversation visually. In addition to these individual insights, the workplaces, the technical setting of the machines and the factories were documented in sketches, photos and videos. Furthermore, the work process of the craftsmen was observed by conducting a case study of the 'Halle Rauch' presented in the following section.

Aspects concerning the topic of the maker movement were gathered in a preceding literature research (Buehler et al. 2015; Friesike et al. 2021; West & Kuk 2016; as well as an underlying analysis of the homepage 'Thingiverse'. The author is able to include his own personal experiences as still being an active member of the maker movement which made it possible to illustrate the work processes. To triangulate these data, workshops and discussions were held with other researchers. The term 3D printer covers a wide range of additive processes (Berman 2012), therefore in this research, the focus is placed on fused deposition modelling 3D printers (FFF). The following comparison of the two case studies 'Halle Rauch' and 'The Hive' help illustrate the qualitatively collected data from the interviews.

3.1 *Case No. 1: the newly built wooden structure 'Halle Rauch' in Schlins, Austria*

A newly built wooden workshop was selected as the first case study. Built in 2020, this structure was mostly made of wood and manufactured by a regional carpentry company. The project managers (client, architect, engineer and carpenter) made use of a historically proven construction principle, the so-called 'rhombus truss'. This construction method, which is assembled from individual beams, can be stressed subsequently like a solid wooden slab when fully installed (Figure 2).

Figure 2. A finished and installed rhombus truss at the 'Rauch' hall. (Photo by Hanno Mackowitz).

The building was first modelled in 3D on a computer as a digital model and then milled on a CNC joinery machine. The single beams were then assembled and screwed by the craftsmen. As final step, the elements were transported to the construction site. In total, three large rhombus truss frames (each measuring 10.49 m × 4.73 m × 0.18 m) were produced for this building. Here, the precision of the CNC machine greatly benefited both the assembly process and the stability of the individual elements. As explained by the carpenter in charge of the project, the digital model is always drawn project-specifically, which means that the data is only used on one project.

Figure 3. The digital model (left) and the physical object (right) in production.

3.2 *Case No. 2: 'The Hive', a 3D-printed shelf on the platform 'Thingiverse.com'*

'The Hive' is a 3D model made available on the platform Thingiverse.com by a user called 'O3D'. Designed as a modular shelf and assembled from individual hexagons, it can be used open or with drawers. Currently, the design has 568 comments, 166 replicas and 52 remixes. Since a file can also be downloaded without registration and these downloads are not displayed on 'Thingiverse', the actual distribution is unknown. Considering the numerous comments and replicas, however, it can be assumed that the downloads are correspondingly high.

In the case of 'The Hive', the 3D printer produces a component that only fulfils its purpose after assembly. Drawers have to be pushed in, or further 6-corner modules can be added. This secondary, manual activity has two relevant aspects:

1) The finished object can be larger than the maximum printable area of the 3D printer. Therefore, a design is only limited in the individual part size, but not in the overall size.

2) Human post-production is required to complete the object. Thus, although the 3D printer can produce the components correctly and ready for processing, a human post production step is required to complete and finish the object.

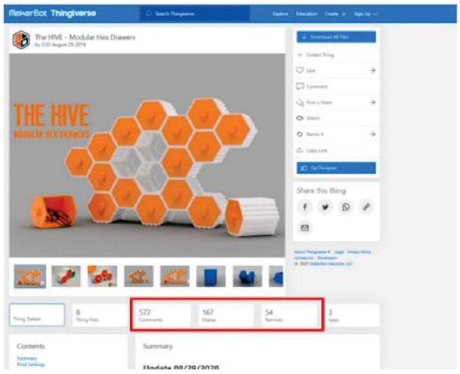


Figure 4. The appearance of ‘The HIVE’ with more than 500 comments and 50 remixes on Thingiverse.com.

4 RESULTS

While in everyday life the fields of a carpenter with a joinery robot and a maker with a 3D printer have little intersection, in the context of this research several parallels could be observed:

4.1 *Parallel No. 1: Physical problem tackled with a digital model*

In both disciplines, any work starts out from a problem, from a task. While in the case of carpenters, the craftsmen are usually given a task by architects or clients, in the case of makers it is usually a self-chosen task or a curiosity trigger that provides the initial impulse (Friesike et al. 2021). In a subsequent step, details are sketched and a digital model is created in CAD. This builds on existing knowledge, experience and inspiration until an adequate solution can be found. Both, the craftsmen and the makers, then send this file to their robot.

4.2 *Parallel No. 2: Digital extension of human capabilities*

In principle the carpenters as well as the makers could physically manufacture the digital model even without robots. What was daily work for carpenters until 20 years ago was mainly summarised for makers under the title of the ‘DIY’ movement in the early 1970s (Anderson 2013). If you compare today’s working methods with processes as they were 30 years ago, both disciplines can now produce much more complex projects in a shorter time. Yet, for both groups, the ability to manufacture a complex object was also possible without CNC technology. Therefore, the robot can be seen as a digital enhancement of existing analogue skills.

4.3 *Parallel No. 3: Necessity of expertise*

As stated in these observations, both groups have a specific expertise that lies on both the material and the software levels. For example, a modern carpenter is familiar with CAD software and joinery machines, but also with wood as a construction material and the necessary processing steps. As mentioned repeatedly by the craftsmen, joinery robots work with great efficiency and speed. However, there are always unforeseen incidents that have to be solved fast and in a targeted manner. Likewise, the production of a digital object using a 3D printer is only possible with the corresponding knowledge of the software (CAD + CAM) and hardware of the 3D printer. Both groups need particular knowledge of the material, the process and the equipment.

Besides these overlaps, three major differences could be observed:

4.4 *Difference No. 1: Project size as a multiplier for complexity and risk*

The sheer size difference between a carpentry project and a maker project has to be seen as a basis for numerous challenges. While a maker can order and store printing filament in 1–2 kg plastic spools, the raw material for a carpenter's project is transported by several trucks. Due to the large dimensions of craft objects, time, logistical and financial flows have to be coordinated very precisely. While a more complex 3D print object requires about 5–10€ worth of raw material, a carpenter's project can easily cost several hundred thousand euros. The same goes for the working hours of the robots and the later assembly of the object.

While failed attempts are considered to be part of the creative process in the maker community, such mistakes are medium to large disasters in the craft of carpentry. Large quantities of materials, correspondingly high investment costs and the resulting hourly rates for human and machine labour increase pressure on the craftspeople. Accordingly, wherever possible, familiar, standardized and solution-optimized process sequences are pursued, while keeping the risk of failure as low as possible.

4.5 *Difference No. 2: Geographical and legal dependencies*

In contrast to a 3D-printed object, a building erected by craftsmen (in most cases) cannot be moved afterwards. This region-specific placement makes it necessary to deal with the local legal and geographical framework conditions. As explained by the craftsmen, different building materials or static dimensions have to be applied, depending on the altitude and climatic conditions. Over the course of a year, external influences such as high temperatures, strong wind or snow can occur, depending on the building site. A building must be able to withstand all these geographically specific influences (Aitchison 2017). In contrast, for a maker it is irrelevant whether his or her working place is in America, Europe or Asia, as an object will usually be produced in a controlled environment. Apart from these natural influences, a building must comply with building laws and standards that vary from country to country. Two buildings may be located only a few kilometers apart, but a national border in between may provide fundamentally different conditions. These regional and geographical differences do not have to be taken into account by makers in their work.

4.6 *Difference No. 3: Reuse of the digital data*

A further difference was found in relation to the subsequent use of the digital model. As Anderson (2013) notes, the sharing of digital data is a fundamental characteristic of the maker movement. In doing so, its members actively engage in discourse, exchange ideas and improve their design. The focus of the work is thus only partly on the physical object and can also be placed on subsequent innovation and development steps. We can therefore speak of a process-oriented approach (Friesike et al. 2021). Figure 5 illustrates how the CAD and CAM work process of makers and craftsmen is comparable in most parts. However, the later use of the digital data is not. While the makers are able to put their designs up for discussion on the web via a platform, the use of the digital model in the carpenter's approach is finished as soon as the craftsman hands it over to the robot.

As the craftsmen reported, none of them reworked the digital model at a later stage, used it as a basis for another project, or handed it over to other workshops. In some cases, the data set was re-accessed later on, but only for documentation purposes. Therefore, an evolution of a design,

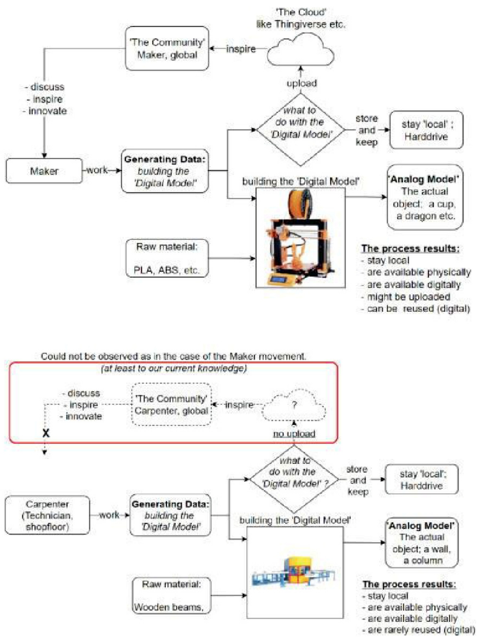


Figure 5. A comparison between the project-flow of a maker (top) and a carpenter (bottom).

based on the digital data set, could not be observed. Yet it is precisely this phenomenon of being inspired by other projects and different sources that has fostered the success of the maker scene (Flath et al. 2017).

5 DISCUSSION AND CONCLUSION

Although the initial motivation of a carpenter (extrinsic motivation / client) differs from that of a maker (intrinsic motivation / community), the focus of this paper is being laid on a comparison of the subsequent manufacturing process. Therefor 3 similarities and 3 differences shall be discussed. The conducted observations revealed some common ground concerning the physical problem tackled with a digital model, the digital extension of human capabilities, and the necessity of expertise.

With regard to future development potential, the three differences have the potential to stimulate further discussion. Considering the point 'Project size as a multiplier for complexity and risk' in more detail, little relief can be expected, as construction projects are tending to become even larger and more complex. Likewise, country-specific building standards and legal bases, as summarized under 'Geographical and legal dependencies', will remain an integral part of the process in the future. There will always be framework conditions for a building site. However, after intensive reflection and discussion, a gap can be identified under the third point 'Reuse of the digital data', which can be used for future research and development work. The maker movement demonstrates how a global discussion with digital data may take place. However, the results revealed that this digital exchange cannot be observed among craftspeople. Although a carpenter, just like a 'maker', first creates a digital 3D file, after the manufacturing process this data is only stored as an archive for documentation purposes.

As mentioned in the introduction to this article, the two communities compared here are based on different cultural and historical backgrounds. The relatively young and dynamic maker movement seems to manage the collective design process excellently in the community. In contrast, craftspeople used to gather, protect and pass on their expertise in guilds and associations. Although the craft of carpentry has opened up and developed considerably in recent times (Zwerger & Olgiati 2012), these historically founded roots might still influence a profession to a certain extent. In order to be able to meet future challenges in an adequate way, it would be worth exploring what new symbioses can arise in the craft of carpentry. New robotic manufacturing possibilities open up unimagined potentials and thereby enrich the processes in such a strong profession. As observed in the maker movement, these global discussions, the constant dialogues and joint working and thinking processes are precisely what develop a community step by step. Especially in modern timber construction, such globally led, collective thought processes could lead to new solutions in robotic manufacturing.

REFERENCES

Aitchison, M. (2017). A House Is Not a Car (Yet). *Journal of Architectural Education, 71(1)*, 10–21. https://doi.org/10.1080/10464883.2017.1260915

Anderson, C. (2013). *Makers: The new industrial revolution.* London: Random House Business.

Berman, B. (2012). 3-D Printing. The New Industrial Revolution, *Business Horizons* 55(2): 155–162.

Buehler, Erin; Branham, Stacy; Ali, Abdullah; Chang, Jeremy J.; Hofmann, Megan Kelly; Hurst, Amy; Kane, Shaun K. (2015): Sharing is Caring. *In: Bo Begole, Jinwoo Kim, Kori Inkpen und Woontack Woo (Hg.): Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems. CHI '15: CHI Conference on Human Factors in Computing Systems.* Seoul Republic of Korea, 18 04 2015 23 04 2015. New York, NY, USA: ACM, S. 525–534.

Dougherty, D. (2012). The Maker Movement, *Innovations: Technology, Governance, Globalization* 7(3): 11–14.

Friesike, S., Thiesse, F., & Kuk, G. (2021). What can the maker movement teach us about the digitization of creativity? *Communications of the ACM, 64(3)*, 42–45. https://doi.org/10.1145/3447524

Flath, C. M., Friesike, S., Wirth, M., & Thiesse, F. (2017). Copy, Transform, Combine: Exploring the Remix as a Form of Innovation. *Journal of Information Technology, 32(4), 306–325.* https://doi.org/10.1057/s41265-017-0043-9

Gerner, M. 2002. *Die Kunst der Zimmerer: Meisterwerke aus Europa, Amerika und Asien.* Stuttgart: DVA.

Naboni, R., Kunic, A., Kramberger, A., & Schlette, C. (2021). Design, simulation and robotic assembly of reversible timber structures. *Construction Robotics, 5(1)*, 13–22. https://doi.org/10.1007/s41693-020-00052-7

Robeller, C., & Haaren, N. von (2020). Recycleshell: Wood-only Shell Structures Made From Cross-Laminated Timber (CLT) Production Waste. *Journal of the International Association for Shell and Spatial Structures, 61(2),* 125–139. https://doi.org/10.20898/j.iass.2020.204.045

Schindler, C. (2009). *Ein architektonisches Periodisierungsmodell anhand fertigungstechnischer Kriterien, dargestellt am Beispiel des Holzbaus.* ETH Zurich. Retrieved from https://doi.org/10.3929/ethz-a-005956976

Verband HIGH-TECH-ABBUND im Zimmererhandwerk e.V. (2019). *www.lohn-abbund.de* Retrieved from https://www.lohn-abbund.de/lohn-abbund/

West, J., & Kuk, G. (2016). The complementarity of openness: How MakerBot leveraged Thingiverse in 3D printing. *Technological Forecasting and Social Change*, 102, 169–181. https://doi.org/10.1016/j.techfore.2015.07.025

Zwerger, K., & Olgiati, V. (2012). *Das Holz und seine Verbindungen: Traditionelle Bautechniken in Europa, Japan und China* (2nd rev. and exp. Ed.). Basel: Birkhäuser

References

Aitchison, M. (2017). A House Is Not a Car (Yet). *Journal of Architectural Education*, *71*(1), 10–21. https://doi.org/10.1080/10464883.2017.1260915

Amt der Vorarlberger Landesregierung (Ed.). (2018). *DIGITALE AGENDA VORARLBERG: Arbeitsprogramm zur Forcierung der digitalen Transformation am Standort Vorarlberg*. https://vorarlberg.at/documents/302033/1054430/Digitale+Agenda.pdf/25a05adc-e0da-96e1-8bcb-2b3bc5fd636b?t=1634551346796

Anderson, C. (2013). *Makers: The new industrial revolution*. Random House Business.

Baer, D. (2014). *Mark Zuckerberg Explains Why Facebook Doesn't 'Move Fast And Break Things' Anymore: Facebook is growing up, swapping its grow-fast, fixit-later mentality for a more mature business strategy.* https://www.businessinsider.com/mark-zuckerberg-on-facebooks-new-motto-2014-5

Barley, S. R. (2020). *Work and Technological Change*. Oxford University Press. https://doi.org/10.1093/oso/9780198795209.001.0001

Batran, B., Bläsi, H., Schaaf, B., Köhler, K., Kässer, M., Hillberger, G., & Frey, V. (2021). *Lernfeld Bautechnik: Fachstufen Zimmerer ; mit vielen Beispielen, projektbezogenen und handlungsorientierten Aufgaben sowie zahlreichen mehrfarbigen Abbildungen* (10., überarbeitete Auflage). *Bautechnik, Ausbau*. Handwerk und Technik.

Belliger, A., & Krieger, D. J. (Eds.). (2006). *Science studies*. *Anthology: Ein einführendes Handbuch zur Akteur-Netzwerk-Theorie*. Transcript.

Bock, T. (2015). The future of construction automation: Technological disruption and the upcoming ubiquity of robotics. *Automation in Construction*, *59*, 113–121. https://doi.org/10.1016/j.autcon.2015.07.022

Brockhaus (Ed.). (2019, December 12). *Zimmerer.* Brockhaus Enzyklopädie Online.

https://brockhaus.de/ecs/permalink/5676BDEC7A94F7D98596B2CC663BE57E.pdf

Bundesministerium der Justiz. (1999). *Verordnung über die Berufsausbildung in der Bauwirtschaft vom 2. Juni 1999 (BGBl. I S. 1102), die zuletzt durch Artikel 1 der Verordnung vom 20. Februar 2009 (BGBl. I S. 399) geändert worden ist: 4. Abschnitt Zimmerer/Zimmerin*. https://www.gesetze-im-internet.de/bauwiausbv_1999/BJNR110200999.html#BJNR110200999BJNG004500000

Comenius, J. A. (1658). *Orbis sensualium pictus: Der Zimmermann.* Verlagshaus Michael Endter. https://de.wikisource.org/w/index.php?title=Seite:OrbisPictus_130.jpg&oldid=3120612

csxlab. (2012). *Precut - Modern Japanese Timber Construction*. https://www.youtube.com/watch?v=SRHDW47MlmE

Doelling, R. J. (2016). *Abbund – Verfahren zur Planung und Umsetzung eines Dachabbunds im Vergleich*. https://www.energie-experten.org/bauen-und-sanieren/dach/dachkonstruktion/abbund

Dornmayr, H., & Riepl, M. (2021). *Unternehmensbefragung zum Fachkräftebedarf/-mangel; Fachkräfteradar 2021.* Wirtschaftskammer Österreich. https://ibw.at/resource/download/2320/ibw-forschungsbericht-207,pdf

Flath, C. M., Friesike, S., Wirth, M., & Thiesse, F. (2017). Copy, Transform, Combine: Exploring the Remix as a Form of Innovation. *Journal of Information Technology*, *32*(4), 306–325. https://doi.org/10.1057/s41265-017-0043-9

Frey, C. B., & Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerisation? *Technological Forecasting and Social Change*, *114*, 254–280. https://doi.org/10.1016/j.techfore.2016.08.019

Friesike, S., & Sprondel, J. (2022). *Träge Transformation: Welche Denkfehler den digitalen Wandel blockieren. Was bedeutet das alles? Nr. 14188*. Reclam.

Gaitzsch, H. (2022). *Hundegger P8 Abbundanlage ohne Hobelmaschine zu verkaufen*. https://zimmerer-treff.com/market/detail/1415/hundegger-p8-abbundanlage-ohne-hobelmaschine-zu-verkaufen

Gerner, M. (2002). *Die Kunst der Zimmerer: Meisterwerke aus Europa, Amerika und Asien*. DVA.

Gerner, M. (2007). *Fachwerk: Entwicklung, Instadsetzung, Neubau*. Deutsche Verlags-Anstalt.

Giesecke, M. (1998). *Der Buchdruck in der frühen Neuzeit: Eine historische Fallstudie über die Durchsetzung neuer Informations- und Kommunikationstechnologien* (1. Aufl.). *Suhrkamp Taschenbuch Wissenschaft: Vol. 1357*. Suhrkamp.

Golden, E. M. (2017). *Building from tradition - local materials and methods in contemporary archi*. Taylor & Francis Ltd.

Graubner, W., & Grunder, W. (2016). *Holzverbindungen: Gegenüberstellungen japanischer und europäischer Lösungen* (2. Auflage). Deutsche Verlags-Anstalt.

Hans Hundegger AG (Ed.). (2022). *Hundegger, Die Unternehmensentwicklung*. https://www.hundegger.com/de-de/unternehmen/unternehmensentwicklung

Henschelmann, K. (1999). *Problem-bewusstes: Französisch-Deutsch : ein Arbeitsbuch*. *Narr Studienbücher*. Narr.

holzmagazin.com. (2021). *Serie: Digitaler Holzbau: Wer sich nicht auf das digitale Zeitalter einlassen will, ist heute schon abgehängt.* Starmühler Agentur & Verlag GmbH. https://www.holzmagazin.com/themenfokus-digitaler-holzbau/2790-digitaler-holzbau-1-die-zukunft-hat-begonnen#special

Howe, H. E. (1955). Teaching Power Tools to Run Themselves: In an electric lab at MIT, engineers now are. *Popular Science* (167, No. 2), 106–109, 222, 224. https://books.google.at/books?id=vyUDAAAAMBAJ&lpg=PP1&hl=de&pg=PA108#v=twopage&q&f=false

Jeska, S., Saleh Pascha, K., & Hascher, R. (Eds.). (2015). *Neue Holzbautechnologien: Materialien, Konstruktionen, Bautechnik, Projekte*. Birkhäuser.

Kaufmann, M. (2019). *Abbund ohne CNC*. Facebook. https://www.facebook.com/pg/Kaufmann-Zimmerei-und-Tischlerei-GmbH-1614783175431729/photos/?tab=album&album_id=2445555045687867

Kolb, J. (2010). *Holzbau mit System: Tragkonstruktion und Schichtaufbau der Bauteile* (3. Aufl.). De Gruyter. http://www.degruyter.com/search?f_0=isbnissn&q_0=9783034611800&searchTitles=true https://doi.org/10.1515/9783034611800

Krauth, T. (Ed.). (2003/2018). *Die Bau- und Kunstzimmerei: Mit besonderer Berücksichtigung der äusseren Form* (Repr. nach d. Orig. aus d. Jahre 1895). Vincentz Network GmbH & Co. KG.

Kumano, W. (2022). Japanische Holzverbindungen. In C. Ferrer, T. Hildebrand, & C. Martinez Cañavate (Eds.), *Touch wood: Material, Architektur, Zukunft.* Lars Müller Publishers.

Lanz, K. (2020). *Aus Überzeugung automatisiert: Holzbau-Meister Mario Dankl im Interview.* Holzbau Austria.

Latour, B. (2006). Über technische Vermittlung:: Philosophie, Soziologie und Genealogie. In A. Belliger & D. J. Krieger (Eds.), *Science studies. Anthology: Ein einführendes Handbuch zur Akteur-Netzwerk-Theorie* (pp. 483–528). Transcript.

Lindner, J. B. (2018). *Digitalisierung wird Holzbau verändern: Aber was bedeutet das für das Handwerk?* https://www.holzkurier.com/holzbau/2018/05/digitalisierung-wird-holzbau-veraendern.html

Loeffelholz, T. (n. d.). *Unterschiedliche Arten des Abbindens*. Retrieved June 22, 2022, from https://heimwerk.org/dachstuhl-abbinden

Lohmann, U. (2010). *Holzlexikon* (4. Edition). Nikol.

Maier, W. (2009). *Leis Houses, Vals - Peter Zumthor, Haldenstein*. https://www.waltermair.ch/

McAfee, A., & Brynjolfsson, E. (2018). *Machine, Platform, Crowd: Wie wir das Beste aus unserer digitalen Zukunft machen* (P. Seedorf, Trans.). Plassen Verlag.

Opderbecke, A. (2013). *DasHolzbaubuch: Für den Schulgebrauch und die Baupraxis*. Vincentz Network.

Pallasmaa, J. (2015). *The thinking hand: Existential and embodied wisdom in architecture* (Repr). Wiley.

Phleps, H. (1989). *Der Blockbau: Ein Fachbuch zur Erziehung werkgerechten Gestaltens in Holz* (Unveränd. Nachdr. der. Ausg. Karlsruhe, 1942, [Nachdr.]. Bruderverl.

Schindler, C. (2009). *Ein architektonisches Periodisierungsmodell anhand fertigungstechnischer Kriterien, dargestellt am Beispiel des Holzbaus*. ETH. https://doi.org/10.3929/ethz-a-005956976

Schneider, S. (2022). *Abbund; Die vier Arten des Abbindens*. https://baubeaver.de/abbund/

Seike, K. (1990). *The art in Japanese joinery*. Tanko-Weatherhill.

Sennett, R., & Bischoff, M. (2008). *Handwerk* (3. Aufl.). Berlin-Verl.

Spiegel (1964). Automation in Deutschland. *Der Spiegel*(14). https://www.spiegel.de/spiegel/print/index-1964-14.html

Sproull, L., & Kiesler, S. (2001, 1991). *Connections: New ways of working in the networked organization*. MIT Press.

Staatssekretariat für Bildung, Forschung und Innovation. (2013). *Bildungsplan zur Verordnung über die berufliche Grundbildung Zimmerin EFZ / Zimmermann EFZ (Nr. 30303).* https://www.becc.admin.ch/becc/public/bvz/beruf/show/30303?lang=de

Ulm, B. (1983). *Ein spätgotischer „Reißboden" in der Pfarrkirche zu Hörsching*. Oberösterreichische Heimatblätter. https://www.ooegeschichte.at//fileadmin/media/migrated/bibliografiedb/hbl1983_2_121-132.pdf

Verband HIGH-TECH-ABBUND im Zimmererhandwerk e.V. *www.lohn-abbund.de.* Verband HIGH-TECH-ABBUND im Zimmererhandwerk e.V. https://www.lohn-abbund.de/lohn-abbund/

Wada, I. (2022). *Shawood; Superior quality driven by customer needs*. https://www.sekisuihouse-global.com/shawood/quality.html

Wilhelm, j. (1668). *Architectura civilis*. Vorarlberger Landesbibliothek.

Wirtschaftskammer Österreich (Ed.). (2019). *Berufsbeschreibung: Zimmerei (Lehrberuf).* Institut für Bildungsforschung der Wirtschaft. https://www.bic.at/berufsinformation.php?brfid=1482&bg=8&bw=1

Wirtschaftskammer Österreich (Ed.). (2022). *Zimmerer/Zimmerin*. https://www.wko.at/branchen/ooe/gewerbe-handwerk/handwerkslehre-Zimmerer.html

Zeman, R. (2022). *Vorarlbergs neuer Landesinnungsmeister: Ein Interview über Ziele, Pläne und Chancen*. https://www.holzbauaustria.at/news/2022/01/manuel-feuerstein-vorarlbergs-landesinnungsmeister.html

Zumthor, P. (2016). Das Zusammenspiel von Hand und Kopf: Ein Gespräch mit dem Schweizer Architekten Peter Zumthor. In C. Thun-Hohenstein, R. Franz, & T. Zickler (Eds.), *HandWERK: Tradiertes Können in der digitalen Welt.* Verlag für Moderne Kunst.

Zumthor: Spirit of Nature Wood Architecture Award 2006. (2006). Rakennustieto.

Zwerger, K., & Olgiati, V. (2012). *Das Holz und seine Verbindungen: Traditionelle Bautechniken in Europa, Japan und China* (2., überarb. und erw. Aufl.). Birkhäuser.

List of Figures

Images that are not annotated with an external source have been provided by the author.

Curriculum Vitae

Research Interests

Carpenter Profession, Digital Transformation, Traditional Craft, Modern Manufacturing, CNC-Technology

Education

University of Liechtenstein, Vaduz *March 2018 – December 2022*
Research Assistant and PhD Candidate
Institute of Architecture and Planning
Fürst-Franz-Josef-Strasse, 9490 Vaduz

Leopold-Franzens-University of Innsbruck, *February 2006 - March 2012*
Master of Science in Architecture (Dipl.-Ing.)
Bachelor of Science in Architecture

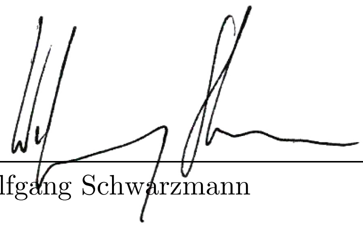
Declaration of Authorship

Digital transformation and crafts:

How is the profession of the carpenter changing due to modern joinery robots?

I hereby declare that the paper presented is entirely my own work and without the use of any unauthorized assistance. Any content which has been taken verbatim or paraphrased from other sources has been identified as such. This paper has not been submitted in any form whatsoever to an examining body. Co-authorships involved in the studies have been acknowledged by name. Previously published work has been cited as such.

Vaduz, 19.10.2022



Wolfgang Schwarzmann