FROM SLIM TO SMART

HOW EMPATHIC DESIGN CAN HELP UNDERSTAND A CRAFTSMANSHIP-DRIVEN FACTORY'S MANUFACTURING CAPABILITIES FOR PRODUCT AND PRODUCTION IMPROVEMENT.

Master Thesis Industrial Design Engineering

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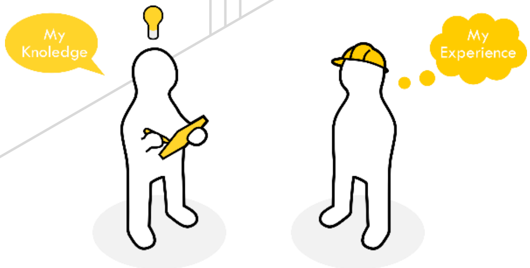

UNIVERSITY OF TWENTE. + arco contemporary furniture

INFORMATION

How empathic design can help understand a craftsmanship-driven factory's manufacturing capabilities for product and production improvement.

MSc Thesis

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I. Preface

I started this research in good spirits after I had just lifted myself up from a difficult period. However, during the research, there were still incidents and circumstances beyond my control that hindered the progress. Despite all setbacks, I was still able to complete the executive part of the research without major delay. However, some parts have suffered under the circumstances. Ultimately, it was the reporting that took the most time. I have enjoyed my time at Arco, it was, however not during the best time of my life.

I have learned a lot during over the course of this research, and not just on the subjects of this report. I am therefore grateful to the factory workers at Arco for what they have been able to teach me about their profession. I am also thankful for the guidance from Gerben Schreurs as my supervisor at Arco. Although I did notice that he did not always know how to manage me, I learned a lot from him about how he managed the rest of his team and how he handled problems within the company.

When it comes to the academic side of this research, I have learned many new things about academic research in general and have been able to develop myself further in this area. I would like to thank Wouter Eggink for his patience and guidance during the writing of this thesis. Although the reporting derived from our initial idea and became more traditional, it still helped to first look at reporting in a different way. And on the topic of reporting, there was another group of people outside of this assignment who helped me a lot. My friends checked my report several times and helped me express myself when I was unable to.

Ultimately, the process of this research was not ideal. There were many external factors that had an influence and I have most likely not always made the best moves myself. Still, I'm sure I did the best I could. Although this thesis was indicative of a difficult period in my life, I see it as proof of my own perseverance.

II. Summary

This research started with an assignment from Arco to improve the production process of their Slim table. Early on, the decision was made to use a human-centered design (HCD) approach for researching the factory. This decision was substantiated by the literature review, which showed that the human value in manufacturing is gaining more attention in the current industrial developments (industry 4.0 and 5.0). Design thinking offered a way to apply HCD in the factory by creating a frame that defines the factory workers as the users of a product that is the factory itself and the production process as the interaction. Through this frame, various HCD methods were compared and empathic design was eventually selected based on preconditions set by the company. Gigamapping was also employed as a method for documenting and processing the collected data from the factory research. The Empathic factory research provided a detailed understanding of the production process and revealed some areas for improvement. However, it did not lead to a clear solution. The research therefore continued with a re-design process.

The redesign process began with further exploration of the factory and the Slim table itself in search for solutions. The product development team at Arco gave feedback on the factory research and the exploration, and helped to generate some ideas for new concepts. Three main concepts were formulated and further developed, of which one ended up similar to an existing solution, while the other two were equally promising. The concept that required the least amount of investment to make a prototype was eventually selected as the final concept. Unfortunately, the sandwich material that was the main feature of the final concept turned out to be too flexible and it did not result in a strong enough table. Nevertheless, after re-evaluating the factory research, the redesign process and the prototyping insights, three possible design directions could still be proposed for future development.

The fact that the redesign did not deliver did not mean that it was an unsuccessful research. On the contrary, both the factory research and re-design proved the usefulness of an empathic design approach in the factory. Empathic design helped to understand the production process from the workers' point of view, and to appreciate their knowledge and skills. This informed the design of concepts that matched the capabilities of the factory as well as its workers. The use of empathic design also showed that a HCD method can be applied in the factory with minimal adaptation of the method itself. This was made possible by the design thinking frame. With some adjustments to prevent the mistakes that were made in this research, the frame could be a useful tool for applying other HCD methods in the future as well.

III.REPORT STRUCTURE

The research consists of several chapters that have influenced each other in different ways, and not necessarily in the current order. Even sub-chapters have their own structures. A visualization of the report structure (**Fig. 1**) shows the general structure of the research.

The introduction **(1)** introduces the assignment with some context. It also formulates the research question and the research approach for applying HCD in the factory. The literature study **(2)** investigated why it would be useful to apply HCD and further explored the literature of HCD. A dive into design thinking introduced frame creation, which helped in the selection of empathic design as the main HCD method and in devising a strategy for the factory research. Gigamapping was also introduced in the literature research as a visual documentation method for the factory research results.

The results from the factory research **(3)** informed the redesign process **(4)**. Although the factory research, and in extension the redesign process, were based on HCD methods, they were also guided by the original assignment. The redesign process therefore led to a set of design recommendations that focused on improving the Slim table and its production process more from a technical perspective.

To answer the research question, the literature research, factory research and the re-design were evaluated in the discussion **(5)** to form a conclusion **(6)** on the application of HCD in the factory. While the re-design result functioned as the conclusion for the assignment from Arco.

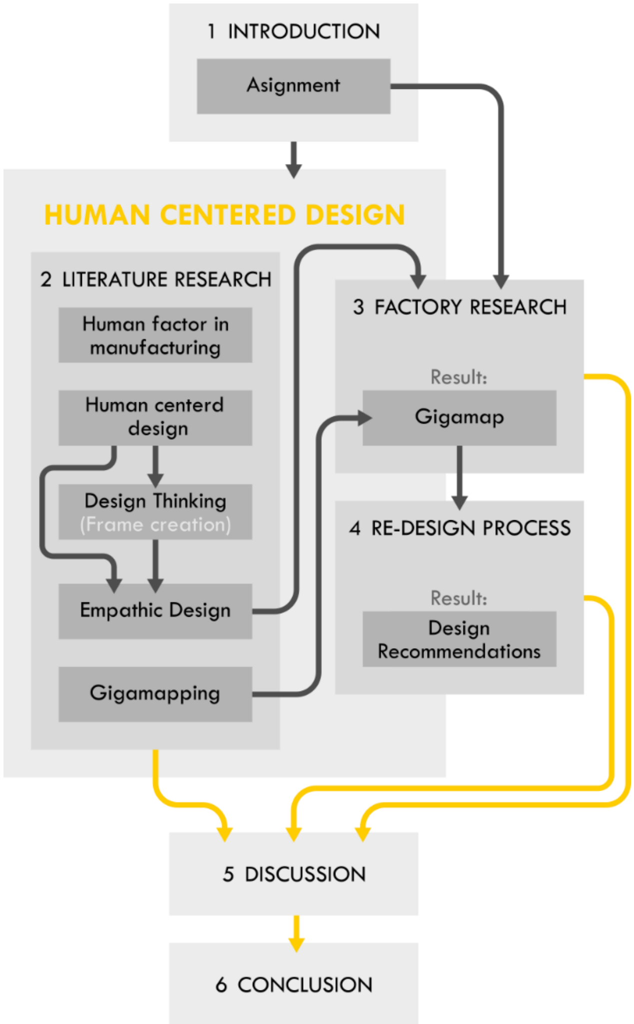


Figure 1: Visualization of the report structure.

IV. Content

V. List of figures

1 Introduction

1.1 CONTEXT

The Slim table is a product of Arco, a Dutch furniture company, and this reports will revolve around the production of that table. However before anything can be discussed it is important to know what the Slim table actually is, what its parts are to and its variants.

1.1.1 The company

Arco is a 118 years old furniture manufacturer with a broad portfolio of tables, chairs and some small furniture. Tables however, remain their specialty and remain large part of their business. Arco has made quality their priority and values a high level of craftsmanship in their products. All tables are produced in Arco's own factory. By continually innovating they try to bring the traditional craftsmanship to the 21st century. (*About Arco*, n.d.)

1.1.2 Values

Arco strives to make beautiful products that matter and add value. By consciously opting for an understated style and the use of high quality materials Arco wants to ensures their tables will last. By combining the knowledge and expertise of their craftspeople with new technologies. Arco tries to make sustainable choices wherever it can to limit the negative impact on the environment. In addition they offer lifelong repairs and refurbish tables where possible. (*About Arco*, n.d.)

Motto:
We are Arco, we make tables.
For this generation.
And the next.
And the next.

Figure 2: Marketing material of Slim table in living room.

1.1.3 The Slim table

One of the tables in Arco's portfolio is the Slim table (**Fig. 3**). A table referred to as an "impossible-looking" minimalist design (*Slim*, n.d.). The table consists of a sandwich construction of steel and honeycomb, enclosed by wood veneer for a natural look. The production process of the Slim table is twofold, the interior construction is produced in one factory and the table is covered with veneer and finished in another factory. Both factories are under Arco's own management.

> "Some people will feel that the composite structure of the Slim Table undermines its authenticity, but this is actually what makes it authentic. The inherent properties of the different materials have been used as honestly as possible: metal for its strength and wood for its tactile and aesthetic qualities. Without innovation is minimalism quickly becoming a dead end."
> Designer of the Slim, Bertjan Pot, (*Slim | Arco*, n.d.)

Figure 3: Arco Slim table with two Sketch chairs.

1.1.4 Parts of the Slim

The Slim tables main feature is how simple it looks, however underneath the veneer it is actually quite a complex table. The main parts of the underlying construction are the legs and the sandwich assembly (**Fig. 4**). Internally all parts have Dutch names that had to be translated for this report. A more literal translation is used for some of the parts to simplify the transition between Dutch and English. During the assignment there was constant switching between discussion in Dutch and reporting in English. It also makes the part names easier to understand within the company without needing an explanation of what each part is.

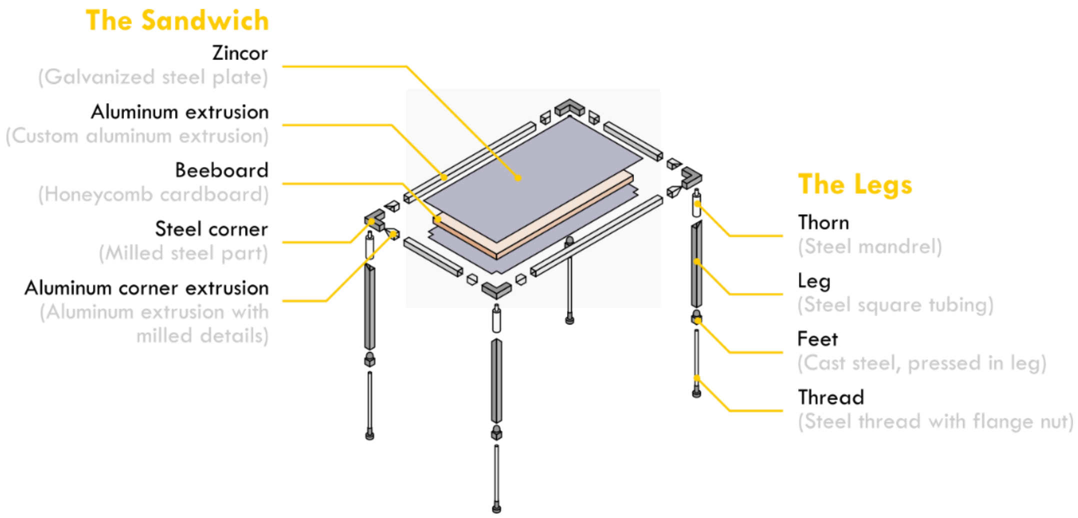


Figure 4: Simplified exploded view of Slim table with part names and description.

1.1.5 The Slim family

From the first iteration of the Slim table multiple variants have been developed throughout the years. Building on the designer Bertjan Pot's goal for the Slim family: "Without innovation, minimalism quickly becomes a dead end."

Slim (2006)
The original design of Bertjan Pot, fully realized for production. With a length up to 280cm and a width from 60cm to 100 cm.
(*Slim*, n.d.)

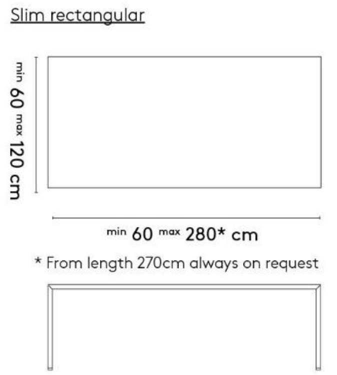


Figure 5: Dimensions of Regular Slim dimensions

Slim Plus Round (2018)
In addition to the square and rectangular versions of the Slim table, Arco developed a round version with a diameter of 160 or 200 cm. (*Slim+ Round | Arco*, n.d.)

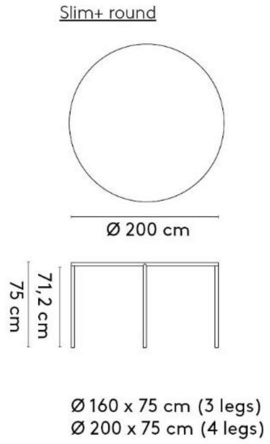


Figure 6: Dimensions of Slim Plus Round dimensions.

Slim Plus (2011)
Slim Plus is the larger version of the regular Slim table and meets the demand from both consumers and business users for a larger table. by only being a little thicker, the maximum length of the table is increased to 360 cm while still looking seemingly impossible. (*Slim Plus | Arco*, n.d.)

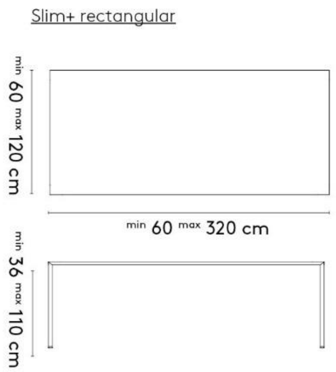


Figure 7: Dimensions of Slim Plus dimensions

Slim Flex (2022)
The Slim Flex is a multipurpose side table. By adding wheels to one set of legs the table becomes easy to move around and can be used as an extension to the Slim or on its own. (*Slim Flex | Arco*, n.d.)

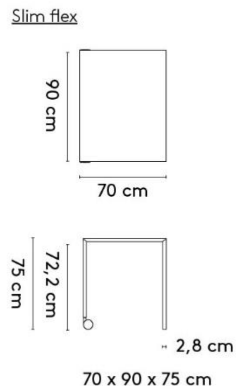


Figure 8: Dimensions of Slim Flex dimensions.

1.2 THE ASSIGNMENT

1.2.1 Company assignment

Arco has been producing Slim tables for over 15 years. Several improvements have already been made or tried out in the production process during that time. However, the resulting table still has its flaws. For example, the connection between the legs and the tabletop needs to be adjusted by hand for each table. As a result, each leg only fits in one place and legs have to be numbered. This and other elements in the production make the production of Slim tables a labor intensive process. Therefore, Arco would like to see the production be improved.

1.2.2 Research question

Finding improvements for Arco will require a research into the production process of the Slim table. Reducing the amount of labor in the process would be the obvious choice. However, Arco also values the craftmanship that goes into and is exuded by their products. Craftsmanship is inseparable from human labor. Additionally, being a student at the Human Technology Relation track at the University of Twente, it is natural to consider the human-aspect to be at the core of the research. The project will therefore take the 'Human-Centered' approach to further investigate the role of human workers in this so-called 'Craftmanship-driven production process'. Resulting in the following main research question, as well as a set of sub-questions to help answer the main question:

How can a human centered design approach help improve craftmanship driven production processes?

Sub-questions:

1. What is the future for humans in craftmanship-driven production processes?
2. How can human-centered design be applied in manufacturing process optimization?
3. How does research of production processes, grounded in human-centered design aid in the design process?

1.3 RESEARCH APPROACH

This research is bringing together the different perspectives on the project from three stakeholders. First, Arco is the initiator of the assignment in search of improvement to the production process of the Slim. Secondly, this report is a master thesis written for the University of Twente. This requires this project to concern human-centered scientific research, including the related academic methodology. Thirdly, the author's own insight and approach. The research will be focused on the use of hands-on methods to investigate the main question of the research, as well as the use of a primarily visual style of reporting

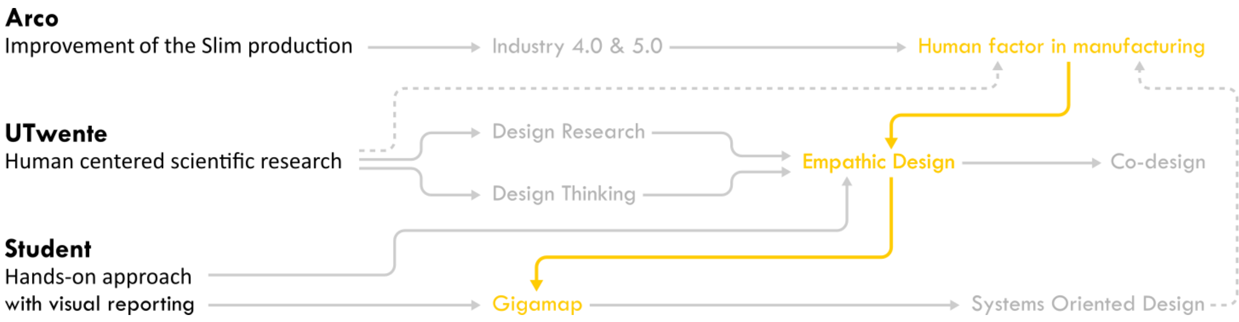


Figure 9: Research topics structure (main topics are yellow, sub topics are grey).

The literature study revolves around three main topics based on the above mentioned requirements from each stakeholder (**Fig. 9**). Arco values the craftmanship in their production, the first topic therefore focused on the human factor in manufacturing in the context of the current industrial developments in industry 4.0 & 5.0. The second topic was finding an appropriate human centered research method, which requires understanding the Design Research field as it offers an variety of methods. Design thinking was also included to help connect human centered design research and process optimization, as the related literature has already focused on bringing design methods to other fields. Empathic Design was eventually selected as the main method to investigate the current production process. The Empathic design method also fulfills the need for a more hands-on research approach, as it allows researchers to get up and close with the users, or in this case the factory workers. The third topic was the use of a Gigamap for visually processing the data. Because Gigamaps originate from systems oriented design, the production process was also approached as a system. The selection of each main topic was made through the sub-topics and together they form the basis of the literature study.

A (re)design process will continue the design research to further develop improvements to either the table or the production process for Arco (plan A). The design process will also functions as an evaluation of the added value of Empathic design for process optimization. If it were to be the case that the research would not yield significant improvement opportunities there is an alternative design goal. The development of a extending Slim table (plan B), a longer standing wish from both Arco, as well as its customers. By having to options for the design process the human centered research approach can be evaluated on its added value to the process, regardless of the research results.

2 Literature research

2.1 HUMAN FACTOR IN MANUFACTURING

Arco is a 115-year-old company that has always valued the craftsmanship of its factory workers in pursuit to deliver high quality furniture products. The factory worker is an important part of the manufacturing process and is not easily replaceable. What exactly is the part humans play in manufacturing and what does the future hold?

2.1.1 Craftmanship

One of the values that Arco wants to express through their products is craftsmanship. However, there is limited literature on craftsmanship within the factory environment.. Well, craftsmanship can either refer to a person who is skilled at making things, especially by hand, or to a product that shows high quality or skillful workmanship (Cambridge dictionary, n.d.). It is the latter that best describes the value Arco wants to convey. However, not every well-made product can convey craftsmanship. For a product to show craftsmanship, it needs have a level of quality and precision that would not be possible without human involvement. For the purpose of this research, craftsmanship will be defined as: the ability of humans in the production process to intervene and improve the quality of the outcome. Therefore, the rest of the literature research will focus more on the human role in manufacturing in general.

2.1.2 Job security

There has been a lot of development in the industry in since the first industrial revolution, often with the premise that each new development would replace human labor. Luckily for the factory worker, early machines, first steam-powered and later electric-, still needed to be operated. Sometime later, the job security would be challenged again, the robot, and it was bound to take their jobs away. Yet again, did numerous early predictions that all factories would be soon be filled with robots, without any human operators, not come true (Wang, 2018). After all, humans are still present in factories today and will probably do so for the foreseeable future. The concerns of losing jobs is in part due to the tendency of popular media to overstate the extent machines will substitute human labor. This view ignores how automation can complement labor to increase productivity (Autor, 2015). Likewise, a qualitative study in the South-African apparel industry suggests that the job loss in that industry due to automation is negligible. In some cases, automation even increased employment, contrasting previous predictions (Parschau & Hauge, 2020). These studies suggest that previous concerns about job loss seem to be unfounded. Even with the increased automation, humans seem to have a continuing and irreplaceable role to play in the manufacturing industry.

2.1.3 Historic development

Humans still be part of the manufacturing process. However, their role in the production process is ever changing. Although an individual may lose his job because of a new machine, there still has to be someone to operate the machine. So far, three mayor changes have occurred that are considered to be industrial revolutions. Literature on this topic denotes these as industry 1.0 to 3.0 (Nardo et al., 2020); Thoben et al., 2017; Wang, 2018). The first revolution happened with the introduction of the steam engine and truly introduced the occupation of factory worker. The second industrial revolution was characterized by standardization and simple hard-wired automation, laying the foundation of mass production with the assembly line. Industry 3.0 brought more sophisticated automation, increasing speed, quality and processing flexibility, with advanced robotics and programming making its way into the factory. The mechanization of industry happened at the cost of skilled craftsmen as now anyone could become part of the manufacturing process. Most factory work only focus on a part of the manufacturing process. With industry 2.0 and 3.0, the tasks for human workers would decrease, as machines and robots could perform increasingly complex operations. Although new machines required new skills to operate, the overall level of required skill for the factory seemed to decrease (**Fig. 10**).

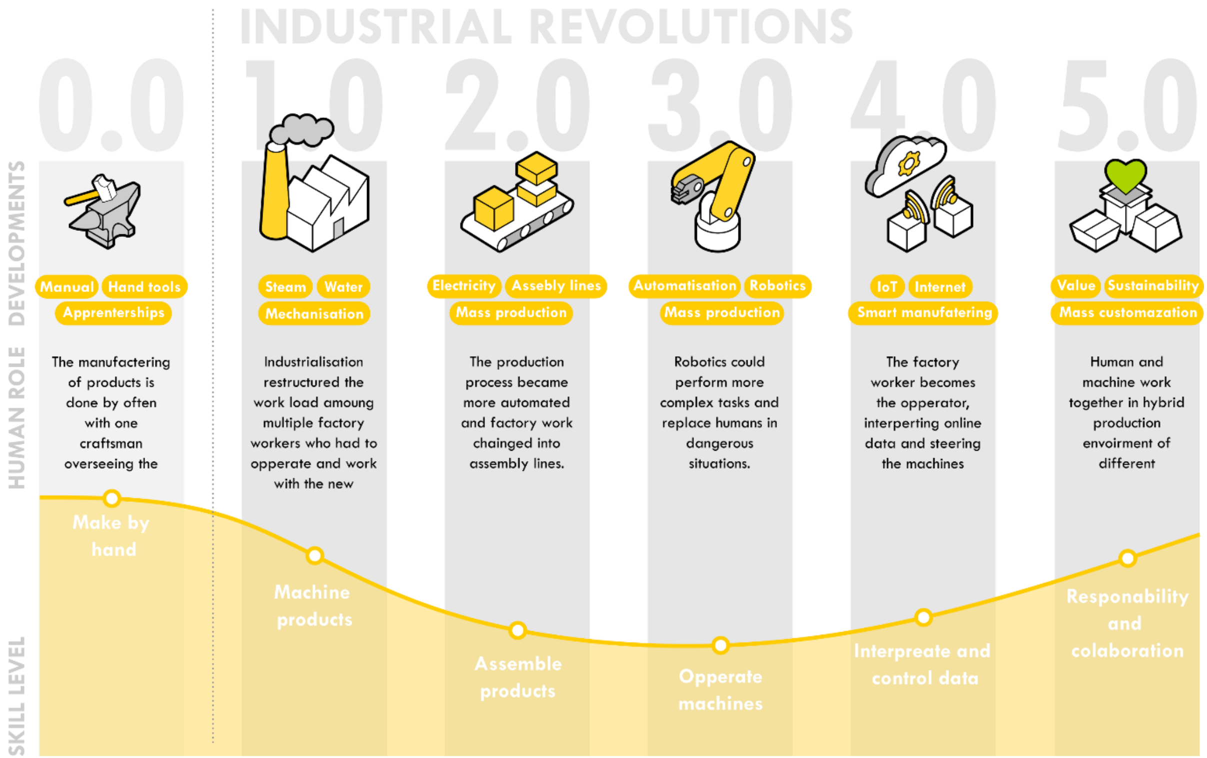


Figure 10: Timeline of the industrial revolution and the changes in required skill level from factory workers.

2.1.4 Industry 4.0

Currently, we are in the fourth industrial revolution, industry 4.0. Throughout the entire industrial development, the machines have increasingly taken over skills from humans. This triggered the necessity for humans to acquire new skills (**Fig.** 10). This effect started in industry 3.0 with machinery becoming more complicated to operate and it truly takes off in the digital revolution of industry 4.0. Industry 4.0 aims for smarter factories by utilizing 'Internet of Things' and similar technologies to connect every aspect of production into one fully integrated system. This requires machines and storage systems to communicate data and act autonomously in a so-called cyber-physical systems (Thoben et al., 2017). The factory of the future will be a hybrid system, with both robots and humans (Wang, 2018) using combinations of manufacturing techniques (Zhu et al., 2013). Humans remain a necessity in combining the digital with the physical world and one of the key challenges for the future of industry 4.0 is establishing a skilled workforce to this end (Wang, 2018). New skilled factory workers are needed for the transition into industry 4.0 to succeed. Factory workers that have the knowledge of traditional production methods and are accustomed to the digital interaction with machines.

2.1.5 The human value

Arco has followed the industrial developments over the course of its history. It has embraced new innovations and technologies and is working on its own transition into industry 4.0. Current developments involve the digitization of Arco's entire product portfolio, integrating the sales with the production process. However, in contrast to previously observed trends, Arco has always valued the skill of its factory workers. Skilled craftsmen are essential to deliver the high quality standards that Arco strives for. With the right investments humans can develop their skills and technology can increase their productivity. Arco already utilizes this in a hybrid manufacturing environment with CNC-machining (Computer Numerical Control) and manual retouching for optimal quality and efficiency, among other things. Manual labor should not be seen as a drawback of the production process, but as a valuable resource instead.

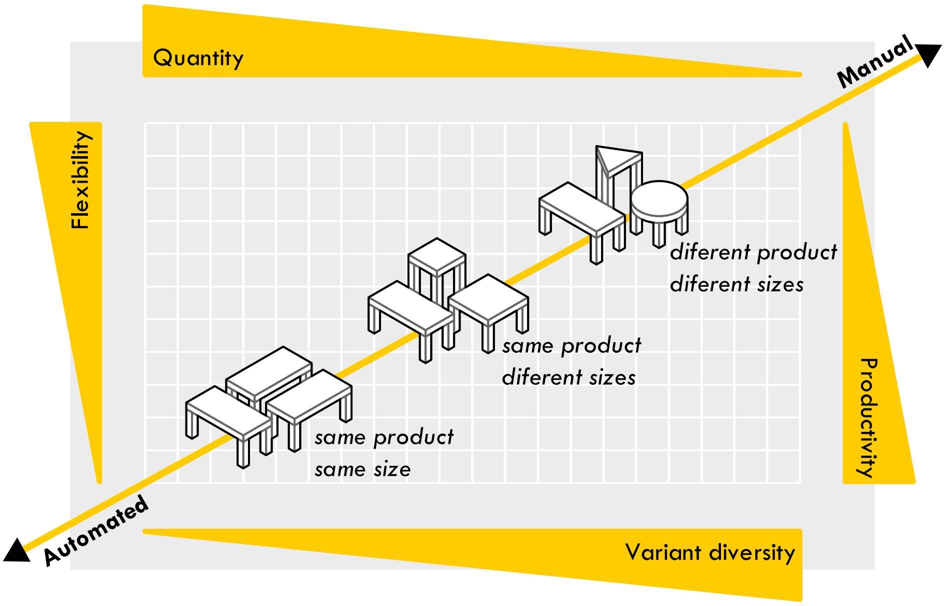


Figure 11: Comparison of automated and manual manufacturing adapted from (Lotter & Wiendahl, 2009).

Quantity refers to the number of products that a person, machine, factory, or system produces in a given period of time.

Flexibility is the quality of being adaptable to change or be changed as a result of circumstances.

Productivity is the measure of the efficiency of a person, machine, factory, or system in converting inputs into useful outputs.

Variant diversity refers to the ability of a manufacturing system to produce a wide range of product variants with minimum changeover time and cost.

There is an inherent relationship between the ratio of automation and manual labor and the effect it will have on the final product. A visual comparison of variable assembly systems (Lotter & Wiendahl, 2009) was adapted to represent that relationship for the manufacturing of furniture **(Fig. 11)**. Hybrid manufacturing can be seen as a spectrum based on the ratio between manual and automated processes. This ratio influences four variables: **Quantity**, **Flexibility**, **Variant diversity** and **Productivity**. For example, full manual production allows for variant diversity in production, the quantity that can be delivered will however be limited. This distribution is not fixed however, as with each new technological development in the industry more complex automation will be possible. Likewise, new tools and better procedures can also improve the results of manual labor. However, the relative relationship of the variables within the spectrum stay the same.

2.1.6 The future

While industry 4.0 is still developing, the next version, industry 5.0, is already being discussed and seems to take a different direction. The European Commission formally introduced the fifth industrial revolution in 2020 with three main topics: Human-centric, Sustainable and Resilient European Industry (Breque et al., 2021). Throughout the industrial development, the introduction of new technologies has reduced the need of manual labor for more efficiency. This has reduced the involvement of the human worker in the pursuit of increased efficiency for cheaper products. The developments and research for industry 4.0, like the ones before it, are therefore mainly technology-driven. Industry 5.0, however, is not. It is a value-driven initiative that drives technological transformation with a particular purpose (Xu et al., 2021). Industry 5.0 is also not a direct continuation of the industry 4.0, nor is it an alternative. It represents goals and values which the industry should preferably develop towards, by looking beyond industry 4.0, while simultaneously suggesting developments the industry should develop right now. With industry 5.0, the perspective on industrial revolution has shifted. By taking a step back from the developments themselves, new research is steered toward common goals that would benefit all involved parties.

When the human factor is discussed in industry 4.0 literature it is often about its relation with technologies, making it not truly human-centric. However, industry 5.0 does explicitly focus on the human role in manufacturing. Workers should be involved in the digital transition to ensure that both companies and workers will benefit (Breque et al., 2021). As earlier mentioned the skill requirements for factory workers are increasing again. Education, training, re-skilling and up-skilling are among the most pressing issues (Xu et al., 2021). Industry workers should not be considered as “expense” but instead should be seen as an “investment” in order to benefit from the relative strengths of both technologies and workers (Breque et al., 2021). Whereas 4.0 understands the benefit of human labor 5.0 really acknowledges the human value and strives for a better work environment to support that.

2.1.7 Human emphasis

Innovations and developments in manufacturing have been focusing on new technologies for increased productivity. In the last few years, research has been shifting from solely focusing on efficiency to other values in manufacturing, including a renewed appreciation for human factory workers. For Arco, skilled craftsmen have always been essential to deliver the high quality standards it strives for. Where Arco’s emphasis on craftmanship in large scale production would previously be seen as old-fashioned, it is now ahead of the curve. This research should therefore place more emphasis on the human worker and not just the technology for future developments in manufacturing processes, for the benefit of Arco and for other industries. Human centered methods could therefore be explored for process optimization to benefit both the industry and its workers.

2.2 DESIGN RESEARCH

The previous chapter concluded that humans have and will play an important role in manufacturing. Humans have already been a major focus in design research. How can that knowledge contribute to researching manufacturing processes?

2.2.1 The history

Human-centeredness is a core quality of design, as products have to fulfill their users' needs after all, and Human centered design (HCD) has gradually developed into a field of expertise of its own (van der Bijl-Brouwer & Dorst, 2017). Placing humans at the center of design started just after the second world war with studies in ergonomics to increase efficiency in production by fitting tasks better to the human capabilities. What started off in the factory has now developed in to a field focusing on the intricate interactions between humans and their environment. Understanding that development may help connect HCD to factory research.

The studies in ergonomics would help define the physical constraints of human interaction, but lacked insight in how human would actually interact with products (van der Bijl-Brouwer & Dorst, 2017). The focus of HCD therefore shifted from just ergonomics to investigating the interaction of humans with products directly. This was first done in controlled test labs, but researchers later realized that the way people use products is also dependent on the context and environment they are in. This led to de development of methods for more contextual user research in the 1990s, such as contextual inquiry, testing prototypes in the field, and ethnographic methods that were borrowed from the fields of anthropology and sociology (van der Bijl-Brouwer & Dorst, 2017). Researchers and designers started to acknowledge that the interactions people will have with products cannot be fully defined or anticipated in the design process (van der Bijl-Brouwer & Dorst, 2017).

The new context-oriented research methods were rich in data, However they lacked clear answers for designers (van der Bijl-Brouwer & Dorst, 2017). This resulted in a gap between user research and design practice. HCD methods that tried to close the gap formed according to three principles (van der Bijl-Brouwer & Dorst, 2017). The first principle tried to focus the feedback from users by asking them to react on descriptions or scenarios of product interaction, instead of letting them interact directly with the product. The other two principles tried to close the gap by bringing the world of designers and researchers and world of users closer together. By either inviting user in to design process through participatory design, or by inviting the designers in to the world of the users through empathy stimulating techniques. To further understand the opportunity of HCD in factory research requires an overview of all available methods

Although the methods have been refined over the decades, using them in the factory context again may require a step back. Towards versions of the methods that are closer related to the more objective factory studies where it all started. However where there used to be a connection between human centered studies and the industrial context there is now a disconnect. New methods have been developed independently from any industrial application, focusing mainly on user interaction studies in everyday life. Newer methods also haven't replaced older ones completely, and methods can even be used simultaneously.

2.2.2 The current landscape

The development of HCD over the last decades has created a landscape of different research methodologies with tools and practices that are shared and discussed among the different methods. All with the same goal of gaining and applying knowledge about human beings and their interaction with the environment in design. The different Approaches to design research have come from a research-led perspective and from a design-led perspective and are practiced with two opposing mind-sets. There is the expert mind-set, where design researchers consider themselves to be the experts that work for the people. And there is the participatory mind-set, in which design researchers see the people as the true experts in their own domains. Design researchers with a participatory mindset design with the people and see them as valued co-creators. This distinction between the two mindsets and approaches comes from Sanders for her evolving map of design research (Sanders, 2008) (**Fig. 12**). Others have made additions to the map too show the relative position of new methods and tools in the design research spectrum. However, the original map still gives the clearest overview of the design research landscape without becoming too crowded.

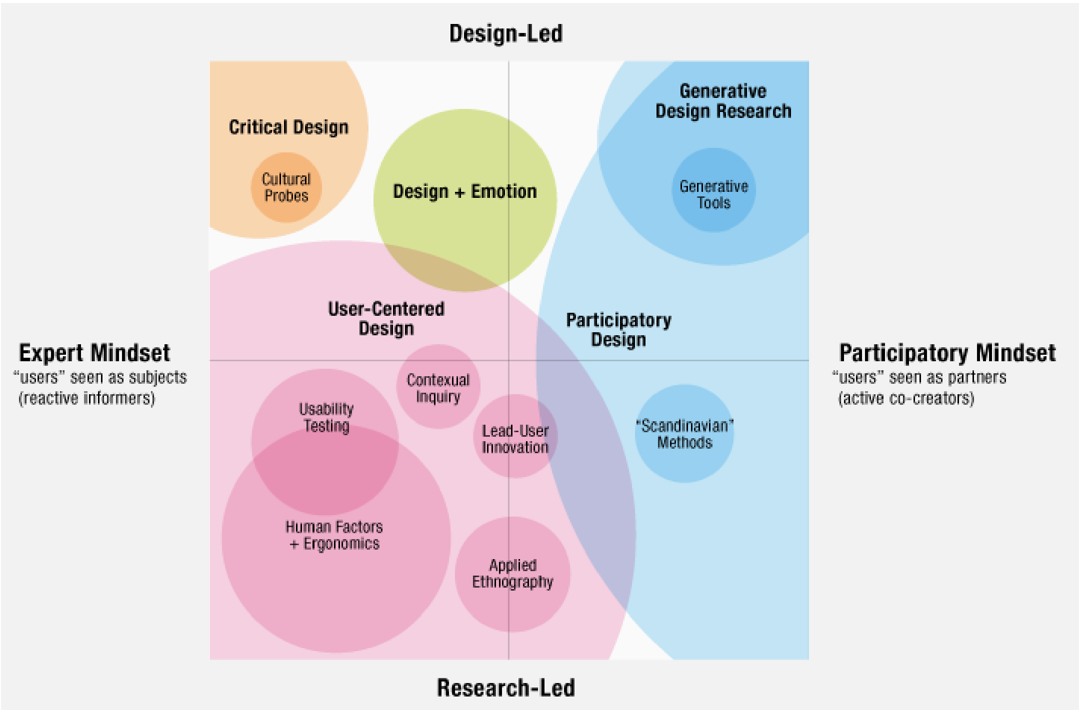


Figure 12: Map of design research types. (Sanders, 2008).

<u>The User-centered design</u>
In user-centered design researchers collect, analyze, and interpret data in order to develop specifications or principles for the design of products and services.

<u>The Participatory design</u>
Participatory design is an approach to design that attempts to actively involve the people who are being served through design.

<u>The design and emotion</u>
This approach tries to understand how the emotional response of products affects user experience.

<u>The critical design</u>
Critical design evaluates the status quo and relies on design experts to make things that provoke our understanding of the current values people hold.

<u>The generative design</u>
Generative design empowers everyday people to generate and promote alternatives to the current situation. Both critical design and generative design aim to generate and promote alternatives to the current situation but with opposing mindsets.

2.2.3 Application (part 1)

Diving into the history of Human Centered Design has given insight in the development over the last decades and the different directions It has taken. Now it offers a variety of design research methods, each with their own philosophy. However, almost all are focused on understanding or improving interactions between products and users. What we are facing is a production process improvement problem. A problem that would be more at home in engineering research. At this point we can therefore not make a well-reasoned decision on what the appropriate method would be. However there is a field in design that has already figured out how to use design in another context. This field has become known under the name 'Design Thinking'. By first looking into Design Thinking we could find the right approach for selecting the most appropriate design research method.

2.3 DESIGN THINKING

While design research has been developing, design has also been gaining popularity as an approach on other fields. This use of design, also known as "design thinking" concerns the application of design methods to innovation processes that support businesses and in the social and public sector(van der Bijl-Brouwer & Dorst, 2017). How can it help bridge the gap between human centered design research and process optimization?

2.3.1 Problem solving

The term design thinking is used to differentiate between the way designers work and the wat they think from design as a product quality. Mostly used to communicate the practice to fields outside design (e.g. Business and public institutions) that showed interest in the creative problem solving of designers. One of the more powerful features of design thinking is the emphasis on identifying the right problems to solve in the first place (Luchs et al., 2015). The way one thinks about the problems becomes just as important as the process of solving them. The core of that thinking according to Dorst is frame creation (Dorst, 2011), a tool all designers are familiar with but often don't realize. Design thinking is a research field that has already been focusing on bringing design research to new contexts. Understanding the core of design thinking will help define the strategy for using HCD in an factory environment.

Dorst starts his explanation of frame creation with basic logical reasoning **(Fig. 13)**, *What + How leads to a Result. A thing* (WHAT) can be observed (RESULT) to show certain behavior according to a working principle (HOW). *What + How = Result*. If we do not now the result yet we can reason what the result will be based on the thing and working principle. For example, if we have a ball, and we know how gravity works, we reason that it will fall. There are other forms of reasoning, but we won't go in to that for now. What we will cover is how this form of reasoning translates to design.

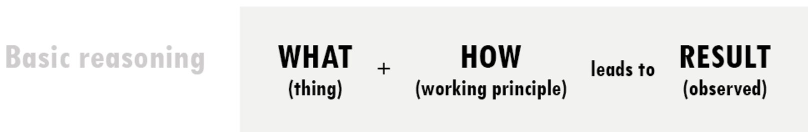


Figure 13: Basic reasoning (Dorst, 2011).

2.3.2 The core

Designers aspire to create value for the end user as the result. Therefore we could replace the result in the basic reassigning for value (**Fig. 14**). For designers the 'What' is what they need to design. If it is a redesign of an existing product the 'How' may already be known, as the working principle does not change compared to the previous product. However, if both the 'Thing' and 'How' are unknown we are faced with a complex problem of two variables with endless possibilities. A designer will approach such problems by imagining a 'How' for the problem, they frame the problem. In other words, they create a frame for the problem that defines what the 'How' will be. If the frame is correct can only be determined by first finishing the equation, designing a 'Thing' to see if it results in the desired value. This process is no science and the firsts frame may not even be correct, but experienced designers become better and better in defining the right frames.

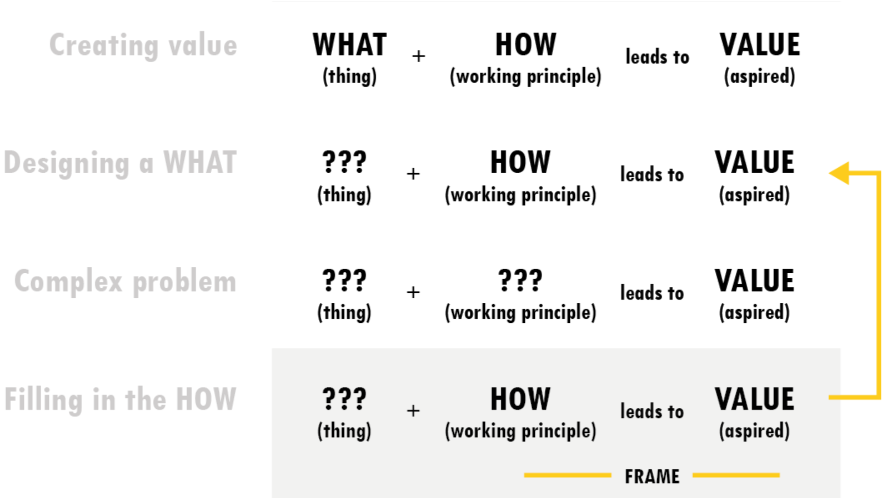


Figure 14: Frame creation for creating value (Dorst, 2011).

2.3.3 Framing the factory

Formulating the right frame should now help determine how to approach the problem of improving a production process with human centered design methods. It should first be mentioned however, that the creation of a frame and filling in of the equation is great for explaining what design thinking is, but it is by no means a step-by-step plan. Design is supposed to be a natural process. As mentioned above, designers often already use frame creation without realizing it. Even the frame for this research has actually already been created in the assignment proposal, but hasn't explicitly been discussed as a frame yet. The original aim of this research was to find a way to learn from the factory workers what could be improved in the manufacturing process by using human centered design methods. Those methods are usually used to examine user interactions with products. This means that for the factory the interest lies at the intersection of workers with the factory, where the humans interact with their environment. By framing the factory workers as users of a product and the factory as that product, the production process becomes the interaction between the two. The problem has now become a user interaction problem, exactly what design research has extensively covered. This way of framing the problem will now help to find the right HCD method and determine how to apply the chosen method.

2.3.4 Application (part 2)

By combining both the gathered knowledge on HCD with the approach of process optimization as a user interaction problem, an appropriate design research method can be selected. The method should create a detailed understanding of the current production process to find improvement opportunities. The factory workers deal with the process every day making them the experts of the production process through their experience. The assignment therefore requires a method that gets close to the workers. In the language of the Design Landscape Map, A method with a participatory mindset. However there was a direct request from the company that the research should not interfere with the day to day production process, nor should the workers be bothered in their routines. There should therefore be a balance between an expert and participatory mindset. Where the value and knowledge of the workers is acknowledged, but the designer holds the agency over the decisions in the design process. With the preference towards Design-led approaches we end up in the Emotions and Design bubble (**fig. 12**). Within that bubble we find Empathic design, a method that uses a combination of observation and participation of both user and designer to form a connection between the two. A connection that the designer can utilized in the design process. Human centered design started off in the factory and it is now time to bring it back in to the factory through Empathic Design.

2.4 EMPATHY IN DESIGN

Just as human centeredness is an inherent part of design, so is empathy. Designing products will always require some form of empathy to imagine how the users would interact with them. Empathic Design however, has grown beyond just designing for interaction into an entire research field. But what does it mean to use empathy in design and research?

2.4.1 Origin

One of the principles of HCD is to bridge the gap between user research and design practice focused on bringing the designer into the world of the user through empathy stimulating techniques (van der Bijl-Brouwer & Dorst, 2017). The adjective 'empathic' in relation to design was introduced in the late-1990s with the realization that the customers' responses on questionnaires was not enough to develop successful products. This led to the view that designers should be more sensitive to users, be able to understand them, their situation, and feelings: to be more empathic (Kouprie & Visser, 2009). Human and social sciences already offer objective scientific observational methods to learn from people's behavior. However, observations by themselves are not enough to be useful to design. We cannot observe people's thoughts and feelings. This is where empathy comes in. Empathy is our intuitive ability to identify with other people's inner states based upon observation of their outward expressions, their behavior (Fulton Suri, 2003).

Research on empathic design started with the need to inspire design by creating a contextual understanding of peoples experiences through personal engagement. However, later research shifted its attention from exploring everyday life, towards using empathic design for social questions and services. The practice and the mindset remained the same, but research was geared to finding ways to inspire and sensitize not only designers, but also other stakeholders (Mattelmäki et al., 2014). Today, "Empathic Design" refers to the empirical research techniques that provide designers access to how users experience their material surroundings and the people in it, including themselves as key characters of their everyday lives (Koskinen & Batterbee, 2003). Empathic design became a method to get closer to problems people experience that would otherwise go unnoticed or be poorly understood. It creates a deeper understanding of people's needs by emphasizing the emotional connection between designer and user.

2.4.2 When

Empathy has a natural place in the product design process. Designers think about the user at all stages of the design process and it takes empathy to understand what is best for the users. However, to use 'Empathic design' methods in the product development process requires attention (Koskinen & Batterbee, 2003). This starts with understanding when to use the methods. Empathic design is a design research approach that is directed towards building creative understanding of the users experience (Postma et al., 2012). That understanding should inspire new ideas for the formations of new product concepts. Therefore, the best place for these methods is the early, conceptual part of the product development process. When the range of options for design is typically still open (Koskinen & Batterbee, 2003). Knowing this, the designer can approach the users at the right moment in the design process with the right intensions. By strategically applying empathic methods early on in the research process the designers mind is still open without preconceptions of solutions. Through explorations of the peoples interactions, new opportunities can be identified for improving people's lives. Only by taking the time to really see the world through the users eyes, can empathy help discover problems that the people would not have mentioned or could not be observed otherwise.

> *"Through observation, we become informed, and through empathy, the human connection, we are inspired to imagine new and better possibilities for people."*
>
> (Fulton Suri, 2003)

2.4.3 Connecting

To make informed guesses about which alternatives to explore, and where to go in the product development, it is crucial to understand how the users see their world (Koskinen & Batterbee, 2003). That is why the human centered connection between user and designer is central to design. The most effective way to ensure that human centered principles are embodied in design is for designers to discover the significant issues for themselves, rather than just be told about them. There are three useful ways to accomplish this, that range from the more objective, at the top, to more subjective (Fulton Suri, 2003):

- **Looking at what people really do**, either in their current natural context or with prototypes we expose to them.
- **Asking people to participate**, by letting them make records of their behavior and context, or expressions of their thoughts and feelings.
- **Trying things ourselves,** to gain personal insights into the kinds of experience others may have.

The true value of these methods, however, still depends upon the empathic interpretation by the designer (Fulton Suri, 2003). As mentioned before, observation by itself is not enough. It is therefore up to the designer to take an active role in exploring other people's behavior and experiences. This can be achieved with combinations of activities such as: shadowing, interviewing, visual and verbal storytelling, experience prototyping and role-playing(Fulton Suri, 2003). When connections are made with real people, it enables designers to respond with ingenuity to real needs (Fulton Suri, 2003).

2.4.4 Tools

Various studies have reviewed empathic tools and listed them (Dimla, 2015; Fulton Suri, 2003; Martin & Hanington, 2012; Thomas, 2013). With various names often describing similar techniques. Figure 15 provides an overview of tools that fit with the empathic mindset, ordered according to the three principles to form connections. Some tools may be applicable in more than one principle, however they are listed where they are considered most effective. Furthermore, most tools are characterized by their qualitative nature and often dual purpose. For example, "experience diaries" create an overview from the users perspective of their day. Additionally, they also give insight in what users value the most, as that is most likely best represented in the diary overviews. "Story boarding" and "experience mapping" are also worth mentioning. Not only are they applicable in all three principles, their function also changes. It could be used to document either the observations of researches, or their experiences when they tried things out themselves. While when the user are asked to participate it becomes an collaborative exercises in documenting their own experience, with similar qualities as the "experience diaries".

Principle	Tools	Description
Looking at what people realy do	Shadowing, Ghosting	Observing the user in their own context.
	Interviewing	Asking questions directly and witness their reactions to questions.
	Contextual Interviews	An variations on interviewing where the users are interviewed in their own context. Making them more comfortable and allowing them to show what they mean.
Asking people to participate	Story boarding, Experience mapping	Creating a visual timeline of an experience, either by the designers or the users.
	Verbal storytelling, Visual storytelling	Using photos, drawings, collages to let users explore and express their experiences. Showing not only there experience but also their perception of it.
	Experience diaries	Letting users keep written or photo diaries shows how they experience their world. Similar to storytelling, hover instead as a single activity it is done over a longer period of time.
Trying things ourselves	Role-playing	Play an scene according to a script or by improvisation toe explore the finer details of an experience. Either with our without the users.
	Experience prototyping, Empathic modelling, simulated experience	Imitate the experience similar to the target user to experience yourself (e.g. blindfold yourself to imitate blindness).
	Participating	Not an actual tool, however, in some cases you can simply participate in the same activity as the user. Creating your own experience. (This will be further explored in the empathic framework.)

Figure 15: A selection of research tools useful for empathic design (Dimla, 2015; Fulton Suri, 2003; Martin & Hanington, 2012; Thomas, 2013).

2.4.5 Framework

Although empathic design does offer qualitative research tools, how to use them seems to be up to the interpretation of the designer. Empathic design is not a clear cut strategy with a list of steps that should be followed, neither should it be. As a design research method, its strength lies in the freedom of the approach. However, some guidance is appreciated. When designers have more knowledge about the fundaments of empathy, they can choose specific techniques and tools and use them in the right order (Kouprie & Visser, 2009). The 'Empathy framework' was created to show that empathy includes both cognitive and affective efforts, and that empathy can be enhanced by a stepwise process (Kouprie & Visser, 2009). The framework was based on the principle that a designer steps into the life of the user, wanders around for a while and then steps out of the life of the user with a deeper understanding of this user(Kouprie & Visser, 2009). That principle was translated into the framework as a process consisting of four phases (**Fig. 16**). These phases are (1) discovery, (2) immersion, (3) connection and (4) detachment. Flexibility in repeatedly stepping in and out of the users life throughout the design process is a key element of designing with empathy (Kouprie & Visser, 2009). The different perspectives of the designer in each phase become more explicit in the framework, giving designers better insight into what roles the designer should take. The four phases of the empathy framework form the basis for a strategic application of empathic design. In each phase the relation of the designer with the user changes, therefore, different tools need to be used accordingly to establish the empathic connection. When designers do not see the advantages of empathy in design, the results can be unsatisfying (Kouprie & Visser, 2009). The framework shows that Empathic design requires motivation and a structured investment of time. Insights into the process of empathy through the framework will help designers to use their time effectively.

Discovery

The process starts with the designer approaching the user. He makes a first contact with the user, either in person or by studying provoking material from user studies. The designer's curiosity is raised, resulting in his/her willingness to explore and discover the user, his/her situation and experience.

Immersion

After the first encounter with the user's experience, the designer takes an active role by leaving the design office and wandering around in the user's world (data from qualitative user research). The designer expands his knowledge about the user and is surprised by various aspects that influence the user's experience. The designer is open-minded, interested in the user's point of reference. He is being pulled into the user's world, and absorbs without judging.

Connection

In this phase, the designer connects with the user by recalling explicitly upon his own memories and experiences in order to reflect and be able to create an understanding. He makes a connection on an emotional level with the user by recalling his own feelings and resonates with the user's experience. At this phase both affective and cognitive components are important; the affective to understand feelings, the cognitive to understand meanings.

Detachment

The designer detaches from his emotional connection in order to become 'in the helpful mode' with increased understanding. The designer steps back into the role of designer and makes sense of the user's world. By stepping back out to reflect, he can deploy the new insights for ideation.

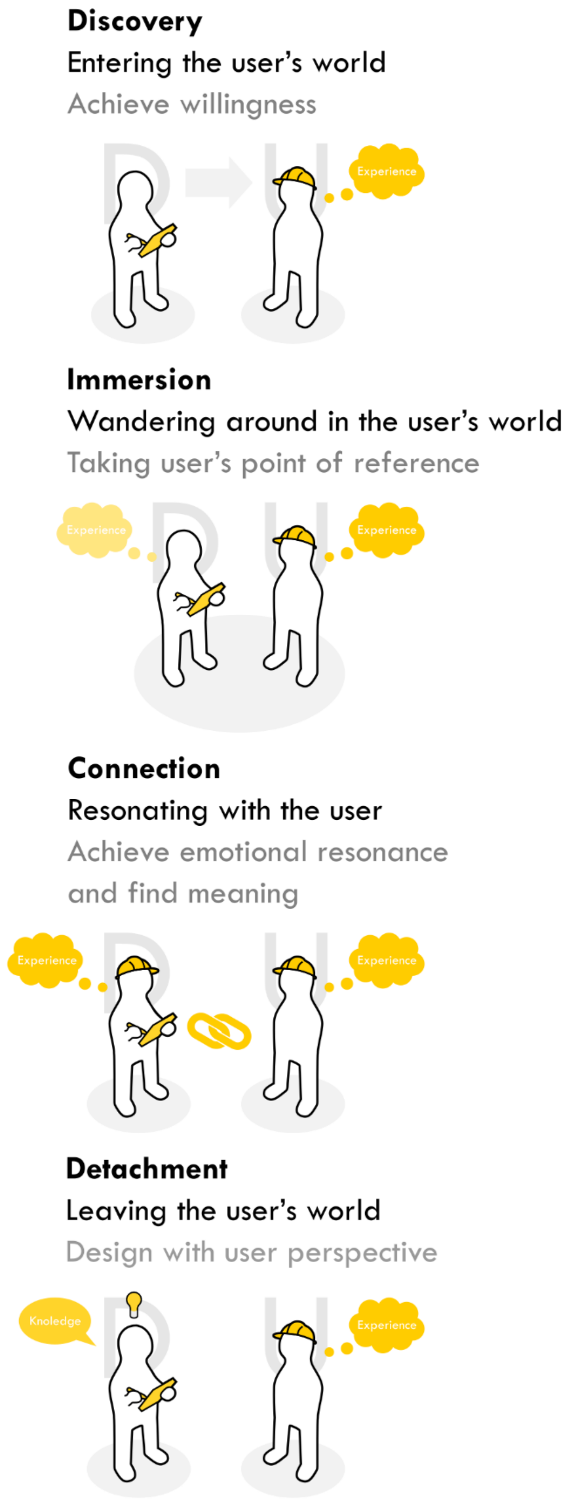


Figure 16: Empathy in design framework adapted from process (Kouprie & Visser, 2009).

2.4.6 Challenges

Using empathic design in a factory is unknown territory. We should therefore be prepared for possible pitfalls and challenges that we may encounter. Starting with the preparation of the research. The empathic framework already identified three key elements of empathy in design (Kouprie & Visser, 2009): (1) the process requires motivation (2) Flexibility to switching between experiencing and reflecting, and (3) the process requires time. Luckily, motivation has more then been established throughout the literature study. The flexibility will need to be learned throughout the process, which increases the importance of planning already on its own.

Throughout the process other stakeholders will have to be involved (e.g. engineers, floor managers, etc.). Understanding their position towards empathic design is important for successful communication. A study on the implementation of empathic design at Philips Research in multidisciplinary teams described several challenges that they encountered (Postma et al., 2012). They noticed that it could be hard for some to adopt empathic approaches and step away from more rational approaches. The involvement of users was often still seen as a one-off activity, instead of engaging users as experts throughout the process. Empathic design did help to create a deeper understand of the users, however the method lacked the basis to communicate that understanding to new team members. The challenges they encountered mainly arose from differences in expectations from empathic design between the multidisciplinary team members and communication with stakeholders. They also had team members joining later in the process while the time spend on the process is such an important part of empathy. Although this research will be caried out solo, the lessons they learned do apply to those that will later be involved. Understanding how they may view the empathic process will help anticipate possible miscommunications.

And finally there is empathy in itself. There can be too much empathy, if we relate so strongly to another person's feelings and viewpoint that we lose sight of other important issues. It is essential to balance subjective empathy with objective observation (Fulton Suri, 2003). The empathic research will therefore have to supplemented with subjective analysis's to contextualize the findings.

2.4.7 Conclusion

Finding improvements in the production process required a deeper understanding of the process. With an aim for the human centered approach and the constraints set by the assignment the search for a design research method started. Empathic design offered a way to learn from the factory workers while they could continue their activities. Although, the original interest for empathic design was based on the tools it presented. A closer look at the literature showed the bigger potential of learning from the personal experience of the factory workers. Through the empathic connection designers become informed and motivated to improve the users experience. While empathic design is not a strict process, the empathic framework has still offered a platform on which a strategy can be based. A strategy where we first learn about the production process up-close from the factory workers and conclude by taking a step back to objectively analyze the personal insights. The main goal is to learn from the workers and empathic design has provided an answer on how that can be achieved.

2.5 EMPATHY IN THE FACTORY

Before we can use empathic design in the factory, we need to reconsider how the frame, that we created earlier to select the method, applies to the factory. There are also some caveats to using Empathic design in a factory setting that need to be discussed. What are they and how will they effect the research?

2.5.1 Frame

Based on design thinking we created a frame where the factory workers are seen as users and the factory as the product. With Empathic design in mind as research method, the frame can be further refined (**Fig. 17**). The machines and tools the factory workers use form the interface between worker and factory. Within the frame, the table that is being produced is not just another product for the user, instead it is the goal of the interaction. In the same way that washing clothing is the goal of using a washing machine, making the table is the goal of the manufacturing process. With user interaction studies, improvements are made to the interface to improve the user interaction. This is how Empathic Design will help improve the table while focusing on the production process.

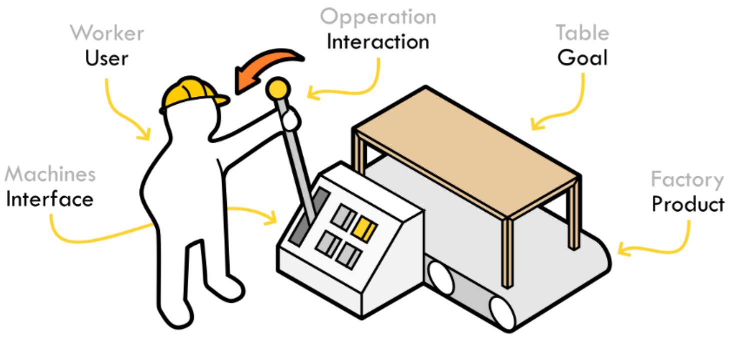


Figure 17: Visualization of the framing used for empathic design in the factory.

2.5.2 Roles

The ultimate goal of improving the process is to increase productivity. However, this may not be the same as the goals of a factory worker. There is a key difference from regular user interaction studies that need to be taken in to account. Being a factory worker is not their entire identity, there is a person behind the worker. Two factory workers may even have the exact same function on the factory floor, while their personality could be widely different. Yet, by directly following the frame we created, they would be identical. The people that work in the factory are not inherently factory workers, they are actually playing the role of a factory worker.

Empathic design aims for an emotional connection with the users. However, the emotions that a factory worker may have towards the factory can be a representation of their role as a person or of their role as factory worker. A person may want to do a job that is as simple as possible while it pays as much as possible. While a factory worker may want to perform optimally and produce as much as possible. There can therefore be a disparity between the goals of the factory worker and the goal to improve the production process. However, there is no distinct line between the two roles, as a factory worker that is truly invested in his or her job doesn't just do it from the perspective of a factory worker, it can also come from personal motivation.

Further investigation into the extent of these roles is out of the scope of this research. However it is safe to say that distinction between the roles will need to be taken in to account throughout the research. The goal of the research is to improve the production process from the perspective of the factory workers. The optimal work conditions from the workers point of view may be competing with the ideal manufacturing process. With each remark a factory worker may give on his or her working conditions, it is therefore important to consider from what point of view it came.

2.5.3 Tool Selection

Knowing what to expect from the workers we can determine how to approach the workers. This will be possible through the tools from empathic design. Finding improvements in the process requires a deeper understanding of the process. Due to its complexity, together with its long and mostly undocumented history, that knowledge was not easily obtainable. However, it was present within the factory workers. With some having decades of experience even the historic knowledge was still present, although scattered. Unfortunately, the research is not supposed to interfere in the daily activities. A selection of tools was therefore made that would keep the research as undisruptive as possible (**Fig. 18**).

Story boarding	To create an overview of the entire process.
Shadowing	To observe the factory workers while they perform operations.
Contextual interviews	To ask for further details on the operations they are performing or to gain more context on the production process.
Participating	To gain first-hand experience in production process. Taking up the role as factory workers.
Experience prototyping	To gain first-hand experience for when participation would risk the products quality.

Figure 18: Tool selection for Empathic design in the factory.

The different tools will each yield different data. However, we already established that there is no hard line for when a remark from the workers should be considered or not. It is therefore important to have a complete overview of the process. To examine if the wishes of one would not interfere with productivity somewhere else in the process. With a full overview in mind each remark can be considered based on the full context. This is where Gigamapping will play an important role.

2.6 GIGAMAP

The search for a visual reporting style started off as a personal requirement to reduce the writing load and after considering other methods the choice fell on Gigamapping. However, Gigamapping did not just became a form of documentation, it also became an inherent part of the research. But what is Gigamapping and how was it be used?

2.6.1 Visual tool

Assessing the importance of gathered data requires an overview of all the data in context to each other. However, It is difficult to create a clear overview of complex data through text alone. Visualizing the data helps to process the information and gain new insights. Methods such as 'Annotated portfolio' (Gaver & Bowers, 2012; Löwgren, 2013) and 'Visual essays' (Arthur & Martin, 2008) were first considered. Through strong visual storytelling they can create open representation of research that leaves room for interpretation. A quality that suits design research where conclusions aren't always clear. However, the goal of this research is to find improvements in a production process. Therefore, the research requires a more concrete approach that could capture the finer details. Gigamaps embrace complexity by representing data across multiple layers and scales to construct a rich picture of real-life (*Systemic Design Association*, n.d.). Details are not lost in a Gigamap but embedded in deeper layers. Creating a Gigamap will help to gain an overview of complex data in this research. It is an extensive visual mapping method that could connect the subjective observations from empathic design to objective data from the production process.

2.6.2 Creating Gigamaps

Gigamaps are the main tool in Systems Oriented Design, a continuation of the idea from design thinking to use designerly methods for complex problems. Although, systems oriented design addresses the increasing complexity of the design process by developing systems thinking in design practice with concepts, techniques and methods developed by and for designers. (*Systems Oriented Design*, n.d.). Based on the believe to see complex problems as complex systems and that by understanding the system the problems can be solved. Gigamaps are used to develop that understanding. With making large amounts of information and their relations in the larger systems instantly accessible (*How to Gigamap*, n.d.). Although no Gigamap is the same, as they are tailored to their specific research and use cases, there are common features. These are the most important features of the Gigamap:

1. **Visual:**
   The use of visual thinking to understanding and represent complex systems.
2. **Extensive:**
   Super-extensive mapping across many sections, layers and scales in a single diagram
3. **Data rich:**
   Different kinds of data from different sources is combined and their relationships are defined.
4. **Map first, read later**
   Early stages focus on getting the data on paper. Later in the process the data can be restructured to make it more readable. This can happen multiple times.
5. **Accessible:**
   Although it is a design tool, there is low initial threshold to start, with room to learn and progress while mapping.
6. **Cooperative:**
   Combining perspectives and align views through (multidisciplinary) co-design and co-creation.
7. **Internal:** Gigamaps are process tools and are not necessarily meant to communicate outside of the involved stakeholders or organizations.

Gigamapping, the process of creating a Gigamap, is as important as the result. It is through the process of Gigamapping that the data is analyzed and truly understood. Using the wrong medium here can stop the flow, and it will influence your way of thinking. The use of Low-threshold media such as cheap paper is therefore encouraged. In later stages the map can be digitized and restructured. While Gigamapping, gaps in the current knowledge can be identified that demand further investigation. The creation of a Gigamap, therefore, doesn't have to be a single session but can involve multiple intermediate sessions of research. There is also no checklist on what should be in the Gigamap, it all depends on the project or research. It is up to the maker of the Gigamap to decide what and how to include information.

2.6.3 Mapping the factory

Gigamapping could serve as method to bring designers, users and other stakeholders together, however, that function will be fulfilled by Empathic Design as the main focus of the research. The Gigamap will, however, be used as a visual processing tool (point 1) to bring the qualitative data from empathic design and the quantitative data from the factory together (point 3). Working on paper is encouraged to stimulate collaborative creativity (point 4). However, in the years since the publications on Gigamapping digital tools have evolved to better accommodate creative collaborations, with even full online software suites. We are therefore les bound to working on paper and can use digital tools to our advantage. The Gigamap will be able to evolve while information is gathered and will help to process that information.

Although Gigamapping is often a group activity (point 6), in this research it will be done solo. This will offer flexibility for how and when to work on the Gigamap. However, as with any visual, the target group needs to be considered for successful communication. Because the Gigamap is meant to an internal tool (point 7), the engineers and management of Arco are the main target group. This also means that the Gigamap does not need to explain everything, e.g. certain industry standard practices. In the end the Gigamap should be a visual representation of the result. Further internal discussions will then be facilitated by utilizing the Gigamap for insights.

2.6.4 Examples

Gigamaps are devices for designing knowledge about complex systems, while also being the designed artefacts themselves that represent that knowledge (*Gigamap Exemplars*, n.d.). They are both the means and the result. An example of a Gigamap would help explain its properties, however there is no correct example that could be given. Each map involves a design process to reach a graphic interpretation that is tailored for its particular situation. The three examples below were therefore selected based on how they inspired the Gigamaps in this research (*Gigamap Exemplars*, n.d.).

Timeline Gigamap: Caring for Caregivers

The production process of the slim table could also be represented as a timeline in a Gigamap. Information about the process could branch out from the main timeline, similar to the example below. The map was inspired by service blueprints. The theme of this investigation is the caregivers, the family and friends of severely ill people and how to build services to support them. It is a detailed and generative Gigamap, depicting a redesigned process.

(Ingrid Herigstad and Marianne Sælensminde, AHO 2014 via *Gigamap Exemplars*, n.d.).

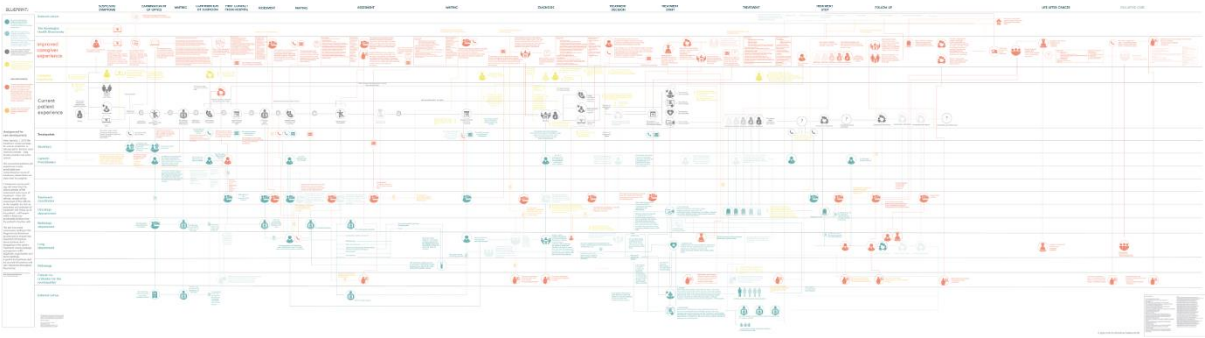


Figure 19: Timeline Gigamap for Caring for Caregivers.

Network Gigamap: Office Design for Norwegian Immigration Authorities

In the production process all steps are connected. Mapping out the relationships like the example below could help gain insight in how the different steps affect each other. The map represents a concept for redesigning new first-line offices for the Norwegian Immigration Authorities. By mapping a balance between the objects and the relations, the relations can be better diversified.

(For UDI by Lea Brochard, Nicoletta Aveni, AHO 2011 via *Gigamap Exemplars*, n.d.).

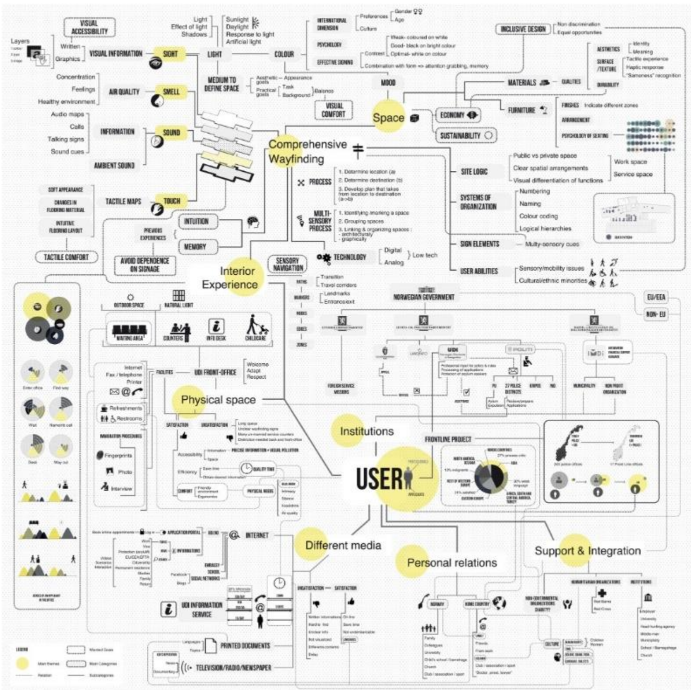


Figure 20: Network Gigamap for Office Design of Norwegian Immigration Authorities.

Organizational Gigamap: Company overview

Gigamaps are not limited to one type of data. The example below shows how different types of data that would otherwise be seen as separate could be connected. This map was designed to give a total overview of a company's organization and activities, by showing all aspects of the company operation from production facilities to economic and marketing aspects. (For MEDEMA, Julian Guribye and Christian von Hanno, AHO 2011 via *Gigamap Exemplars*, n.d.).

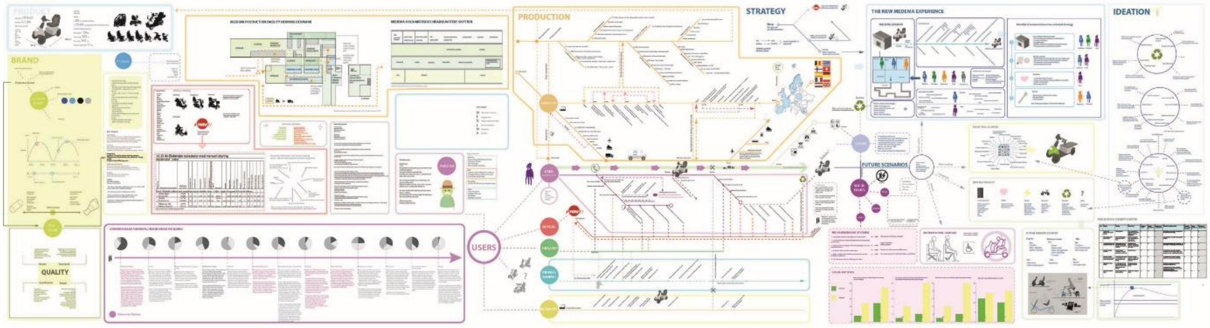


Figure 21: Organizational Gigamap for a company overview.

3 Factory research

3.1 APPROACH

With any field research it is important to devise a strategy for gaining information, to both efficiently and effectively use your time. Empathic design will form the basis of our factory research and the empathy framework will guide the investigation step by step.

3.1.1 Strategy

With full access to the factory we can investigate every setup in the process, however visiting the factory will not be of any use if we do not know what to do. The different ways to gain information should therefore first be considered, as each phase in the empathy framework requires different insights. The tools from empathic design that were selected earlier will be utilized in the research, as well as some other methods. Based on the goals of each of the phases in the framework, a plan is formulated that used the different tools to gather information from the factory workers (**Fig. 22**). The plan describes the actions we will take to execute the research. The Data that is collected from the research will directly be incorporated in the Gigamap. Starting off with the general production outline while further enhancing it with the data on the human interaction from Immersion and Connection. Adding layers of human interaction to the Objective timeline created in Discovery.

Looking back at the Empathy framework we can see that the Discovery phase had unknowingly already started on the first day of the assignment, when I was introduced around the factory. The next step in Discovery was to create an overview of the process before immerging ourselves in the factory. We need to know what operations come before and after the one we are following to understand the role of the operations in the entire process. A timeline will therefore be created that is based on how the product develops throughout the manufacturing process. Immersion is where we open ourself up for information from the factory workers. We want to further detail the time line from Discovery, however we still let ourselves be surprised by any additional information. In this step we get to know the exact actions the factory workers take to complete their tasks. By utilizing multiple tools from Empathic design we can gain access to different levels of immersion. We will go from observing, to listening, to experiencing the work ourselves. In the Connection phase we analyze data to better understand the relationship between the steps of the process, by looking back at our own experience and that of the factory workers. Results will be communicated with the stakeholders to clarify and correct any uncertainties. In Detachment we disconnect from the factory workers and contextualize the findings with an objective analysis. At the end. the continuation of the assignment will then be discussed with the stakeholders based on the identified improvement opportunities.

Framework	Plan	Documentation
Discovery: Entering the user's world. Achieve willingness. Story boarding	1. Going around the factory introducing yourself and the research subject to the factory workers. 2. Visiting each station in the factory and identify the general steps in the process.	GIGAMAP
Immersion: Wandering around in the user's world Taking user's point of reference. Shadowing, Contextual interviews, Experience prototyping, Participating	3. Observe the factory workers in their in their job. 4. Talk with workers about their jobs and daily activities 5. Work with the factory workers and try the work where possible.	
Connection: Resonating with the user. Achieve emotional resonance and find meaning. Root cause analysis	6. Analyzing the steps to understand the role of each operation process. 7. Identify problems and improvement opportunities in the process. 8. Meeting with the foreman of the factory to discuss findings and check for errors.	
Detachment: Leaving the user's world. Design with user perspective. Cost analysis	9. Gather and analyze quantitative data to contextualizes findings of the research. 10. Determine what directions should be further explored.	

Empathic tools: Story boarding, Shadowing, Contextual interviews, Experience prototyping

Other tools: Participating, Root cause analysis, Cost analysis

Figure 22: The factory research strategy based on the Empathy framework.

3.1.2 Planning and Execution

With the strategy formulated it was time to go into factory. The original idea was to collect the data layer by layer, going deeper with each visit. However, this ended up not working. After the first factory visit at Ocra it became clear how much data was gathered while performing the work. To prevent any loss of data, additional time was needed to fully document the experience after each visit. The planning for the rest of the process at Arco was therefore adjusted to clear time for documentation. Manufacturing happens on a by-order-basis with a new planning each week. Planning a factory visit could therefore only be done one week in advance.

Usual user studies require time throughout the day to compete all facets of the interaction. Luckily, investigating the factory took less time, as the operations were often repetitive by themselves. Multiple cycles could therefore be observed in a short amount of time. However, It was still difficult to follow each step chronologically while leaving time open for documentation. Therefore, the order the different departments in the factory were visited did not match the process order. Additionally, while some steps in the process happened continuously others only happened a few times a week. Visits were therefore stretched out across the week.

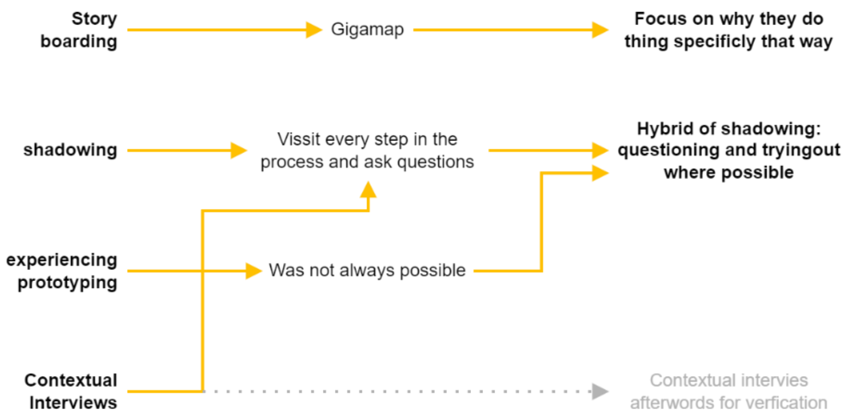


Figure 23: Execution of factory research.

The importance of the strategy became clear early on. The three main tools of the Emerging phase were imagined as separate visits to keep the information structured. However, in planning the imagined visits overlapped and started to happen simultaneously, blending all three **(Fig 23)**. Conversations flowed naturally to different subjects during the shadowing. More structured Contextual interviews were still considers for verification at the later stage. Some operations could not be done without risking the product, making most visits already a hybrid between shadowing and experiencing. The experience was therefore not equal in all stages. here are some examples:

- At Ocra I could assemble the frame but there were some intermediate steps that would require more experience. Handling the sheets wrong could lead to un fixable creases and the second glueing step required speed and experience.
- Edge banding had a learning curve, after which it could be done alone.
- Retouching was hard and mistakes would be costly so I could not tried.
- It was easy to help with sanding, but I missed te expertise to know what to do.

The framework and Gigamap, however, helped to keep a grip on all the information. Keeping the information structured even when it was gathered out of order. Shadowing and contextual interviews happened continuously even after the Immersion, with the office close to the factory allowing for quickly going in and out to ask further questions. Stepping in and out of the workers lives. All while continually refining the Gigamap, that helped both understand and display the complexity of the data. In the end structured contextual interviews were no longer conducted, instead casual conversations happen over time that kept introducing small bits of information.

3.2 GIGAMAPPING

The choice for the Gigamap was made independently from the empathic design method, however the mapping technique eventually played an essential role in the factory research. Building the understanding of the process.

3.2.1 Empathic Gigamapping

Gigamapping aligned well with the Empathic design process. The first visits were meant to gain insight into the process and this was captured as a process diagram that formed the basis of the Gigamap. This was in line with Discovery phase of Empathic design where the subject of the research is first explored. In Immersion the Gigamap helped capture the increasing complexity of the gathered data. To form the connections you have to understand the production and that understanding was developed through Gigamapping. When it was time to disconnect from the workers the insights had to be put in context. The Gigamap then helped identifying where more data was needed to make informed decisions on the production process.

When things did not go to plan, Gigamapping also helped to structure the empathic process. Originally the plan was to go into the factory multiple times, with each visit advancing the empathic process according to the framework. The first visit would give the general outline and form the first layer of the Gigamap, while subsequent visits would add detail in layers to the Gigamap. However, due to the previously discussed planning difficulties subsequent visits were not always possible. The different steps in the factory strategy merged together and the resulting information was often dense and chaotic. However, when assessing the visits the existing outline of the Gigamap helped to organize the data. Additionally, the large scale of the map also allowed to work on multiple parts separately. Although the execution of the factory research did not go as planned, Gigamapping could handle the chaotic input well, when forming a structured overview.

3.2.2 Iterations

Gigamapping is a continuous process with multiple iterations. Throughout this research three distinct versions can be distinguished and each has played a different role in the process.

> **The Paper Gigamap:**
> A draft on paper to form the base structure.
>
> **Gigamap V1:**
> The first fully developed digital Gigamap that merged all data.
>
> **Gigamap V2:**
> A restructured digital Gigamap to improve visual communication.

The Paper Gigamap helped to form a visual timeline of the production process with the right order and structure. Then new information was added in layers (**Fig. 24**). The process was further explored by breaking down the sub steps and the changes for specials. This was all still fairly linear, however it became more complex when the interrelated connections were added. Context was provided by exploring the history of the slim, the movement though the factories, the machines used, and production cost. New information was continuously added through the different iterations, although in some information was removed from later iterations to improve the readability of the Gigamap.

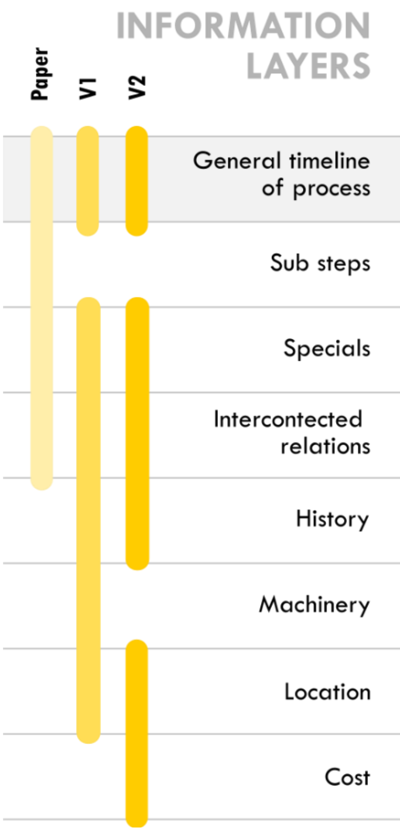


Figure 24: Layers of information in the Gigamap iterations.

3.2.3 Paper Gigamap

The Gigamapping process starts off on paper to stimulate creativity (**Fig. 25**). The production process will form the basis of our Gigamap similar to a timeline. However, instead of progression of time, progression is defined by the physical progression of the table through the process. During the first visits to the factory the general steps of the process were inventoried. Whether it was considered a step or not depended on how much the composition of the table would change at that point. This ruled out most movements of material as steps. Each step was then visualized, printed and cut out. On a large piece of paper the printouts could then easily be moved around to visualize the process. When the structure was clear, lines were drawn to represent the flow in relations between the different steps. Both the selection process before production and the chances for special orders were added. While the empathic process continued detailed sub-steps were added at each step, if applicable. Even after work on the first digital version started, started the sub-steps were still added to the paper Gigamap as they were identified in the research. The Paper Gigamap was less extensive then the first digital map. However it did have the most detailed description of the process steps.

Figure 25: Part of the paper Gigamap, full version in Appendix A. 94

3.2.4 Gigamap v1

When the interconnected relations became too complex to clearly visualize on paper, the switch to a digital map was made. Additionally, because the process is relative linear, paper Gigamap became a few meters long. Drawing three meter long lines even for simple connections, became quite cumbersome. The digital version helped with the more extensive relationship between steps, that would often had be moved when new information was introduced. Although the switch to a digital Gigamap was made fairly soon in the process (as the literature on Gigamapping recommends working on paper as much as possible), it did not limit the capabilities. Images and documents could also easily be added in the digital version.

The first version of the digital Gigamap (**Fig. 27**) had 5 layers of information, each represented in a different color in the Gigamap (**Fig. 26**):

1. The main process in **black** lines, which is identical to the paper version. With an thick grey arrow to highlights the general flow.
2. The **red** lines indicate where parts of the process are dependent or in any other way influenced by other steps.
3. The **blue** lines represent deviations in the process for special orders. This includes all possible deviations at once, as including all combinations would be unnecessary.
4. The **green** line connects the various steps to the machines and workstations used in the production process and to map with the locations and movement through the factories.
5. **Purple** shows historic versions of the different steps in the process, where parts of the table might have changed over time.

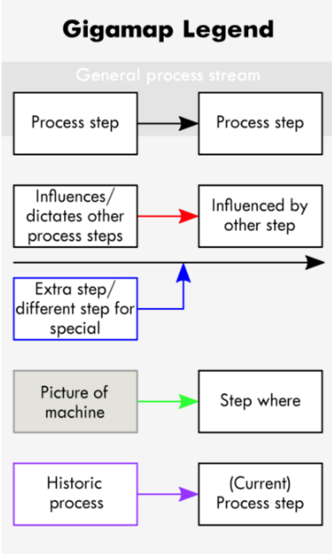


Figure 26: Gigamap v1 legend

The first digital Gigamap was used throughout the research process. however, it was never fully finished, as due to unforeseen circumstances the source files were lost. Luckily, it already contained enough information to continue the research process. Making changes to the Gigamap would require to Fully remaking it and at the time that was deemed inefficient.

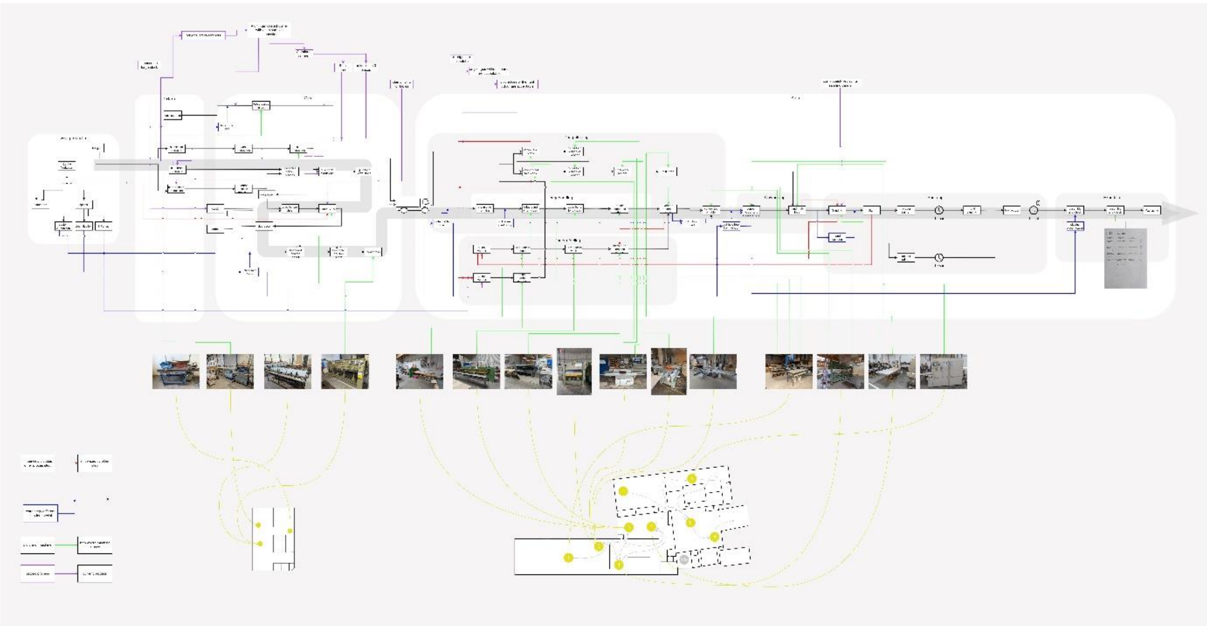


Figure 27: Gigamap v1 (Full resolution can be found in Appendix A.2)

3.2.5 Gigamap V2

At the end of the factory research the Gigamap v1, although unfinished, contained enough information to continue improving the production process. This was possible because as creator of the Gigamap you have a full understanding of the map. However, in the final documentation of the research the Gigamap was remade to update the information and restructure it for better communication. The V1 Gigamap was created by adding more and more data on top of what was already there. Within the graphical software it was easy to zoom in and out and add information in any scale. Ironically enough, all information ended up at the same scale, making it hard to have an overview when zoomed out. Therefore, to increase readability of Gigamap V2 the information was divided across different scales. Zoomed out v2 gives an overview that tells the story of the production process, while details can be explored by zooming in. Although, the Gigamap V1 was mainly used throughout the research process, the paper Gigamap still had additional information that had not been included in V1 yet. As the Gigamap already had to be restructured, the information from the Paper Gigamap as well as the cost analysis could be included. In anticipation of chapter 4, certain information that emerged there has already been included in the Gigamap as well. As work on the Gigamap V2 started after most of the research was already completed. The Gigamap V2 is the final result of all knowledge of the production process that was accumulated throughout the research including the design phase.

3.3 ADDING CONTEXT

Insight into the production cost would help contextualize the human centered insights from the empathic research. Knowing the costs would help identify focus points from the companies perspective to justify possible investments.

3.3.1 Four tables

The slim table is manufactured on demand in various sizes and the cost for production varies between each of them. Luckily the data was already available in the form of Bill Of Martial (BOM. It is the same data that Arco already uses to calculate their costs and it is updated each year, therefore it is considered to be fairly accurate. A sample of four slim table (**Fig. Fout! Verwijzingsbron niet gevonden.**) was used to simplify the cost analysis, while still representing the variety in the production process.

Selection of representative table sizes.

The Slim	**The Slim Plus**
160x90cm +75cm legs	240x105cm +75cm legs
280x90cm +75cm legs	360x105cm +75cm legs

Figure 28: Table of Slim tables used for cost analysis

The selection included small and large sizes of both the Slim and Slim Plus, that were also the most commonly produced sizes. Arco and Ocra use separate BOM and there was inconsistency between what amount the sandwich cost. The BOM from Ocra was only recently created and the cost were not yet updated in that of Arco. This incontinence was therefore solved by substituting the cost for the sandwich within Arco's BOM with that of Ocra's. Now, with the combined BOM's, the four tables should give a realistic representation of the average production process cost and the differences between sizes.

3.3.2 Cost variation

The distribution costs are the main interest the analysis. Visualizing the data will help in understanding the ration between the various cost. By plotting the cost for each part per table next to each other, we can see how the cost varies between the table sizes (Fig. 29). Some costs (e.g. the legs) remain equal independent of size, while others (e.g. the tabletop) seem to rise the increased size of the table. Excluding the a few outliers the calculated averages also seem represent the costs well. Although the exact values have bene left out for discretion, the ratios between different parts are still clear, which is the main interest. Overall it seems that even though the total cost difference between models can be big, the cost do not vary as much for the different parts of the production process.

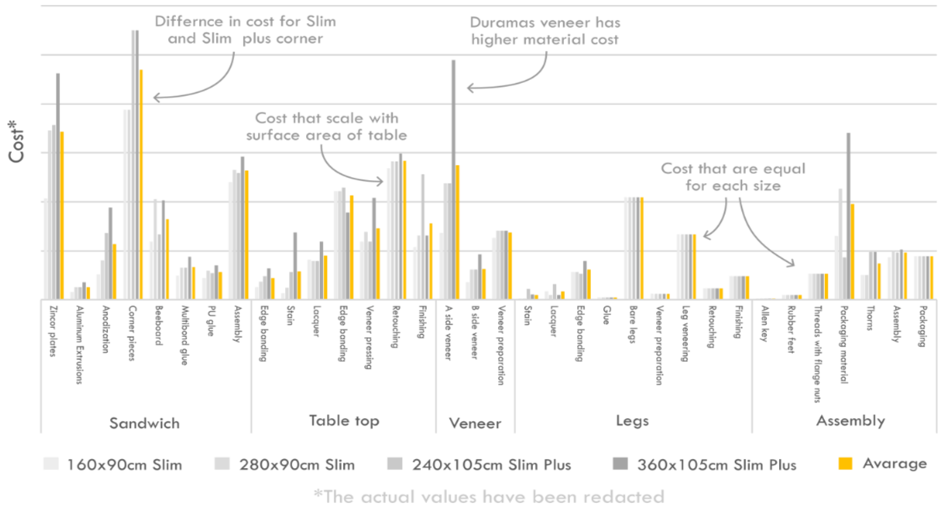


Figure 29: Cost comparison for between four Slim table models. (Full data set in appendix B)

3.3.3 Cost ratio

By visualizing the average cost in as different way we can gain different insights from the data. The production costs have been divided over five parts (left **Fig. 30**) with the tabletop being split in three. The cost made at Ocra are separated from Arco's as Sandwich and Tabletop respectively, and the veneer is also separate as it is a significant cost on its own. There is also the cost for the Legs and for the Assembly, where the legs and tabletop are together. There are several thing we can deduct from this visualization. The most expensive parts of the production are the sandwich construction and the table top. The difference, however, is that the cost for sandwich comes mainly from materials, while for the tabletop it is almost entirely labor. This is especially noticeable when you only look at the material cost (bottom right **Fig. 30**), then the sandwich remains the highest cost while the table top becomes the lowest. The time each production stage takes can also be calculated from the cost dat. Because the labor cost is based on hourly wages, the ratio of cost equals the ratio of time. Dividing the labor cost over the production stages in the factory shows that the Sandwich assembly and Retouching cost the most and thus take the longest time in the production (top right **Fig. 30**). Solely based on the cost data it can be concludes that the biggest impact in cost reduction could be made by cheaper sandwich construction or a simpler retouching process that takes less time.

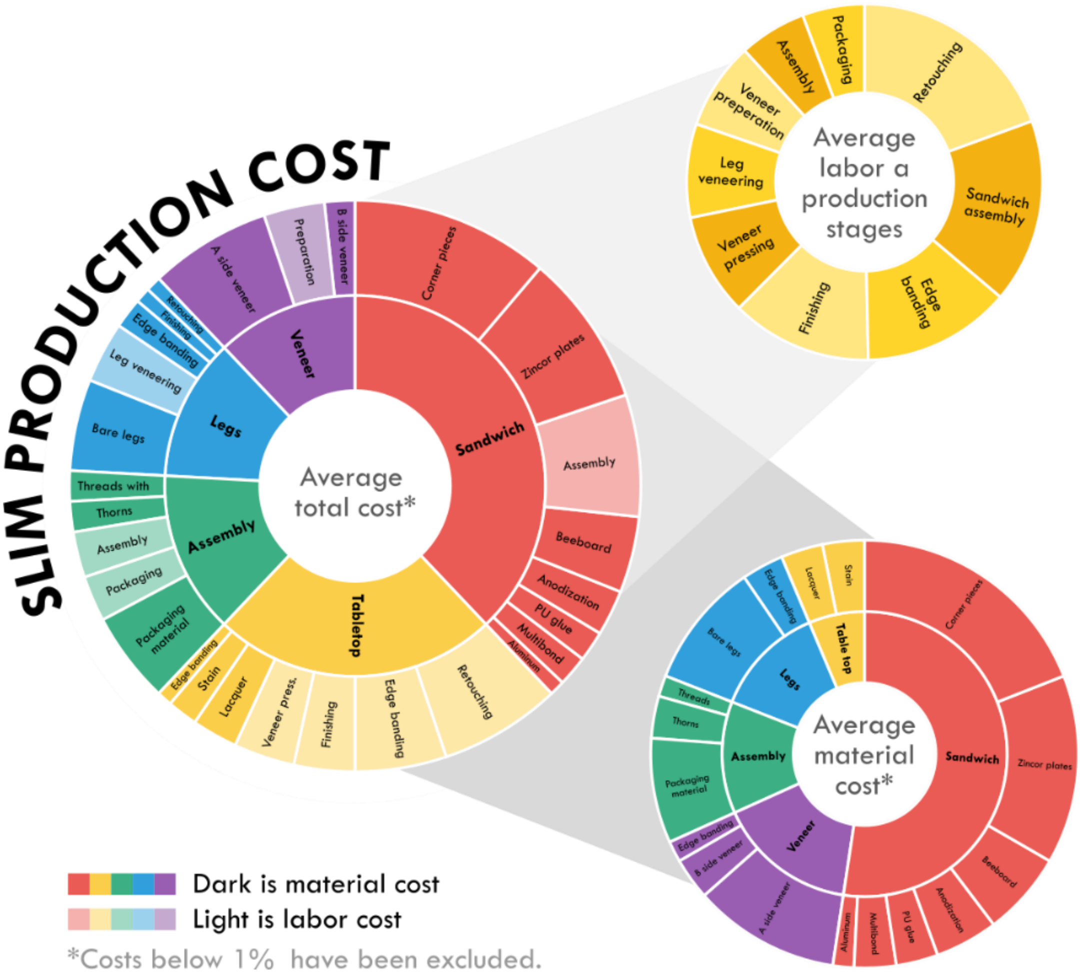


Figure 30: Ratio of average material and labor cost for the Slim production process.

3.4 EVALUATION

During the time spent in the factory, several opportunities for improvement were identified. To evaluate their importance, experts and stakeholders in the factory were consulted. However those parties had to be informed first.

3.4.1 Root causes

The complex visualization of the Gigamap brings together a rich set of data. However, it requires a fully comprehensive understand the Gigamap to grasp the information it represents (especially since Gigamap v1 was still used at this point). Unfortunately, the stakeholders that needed to be involved were not used to these kind of visuals as non-designers, had little time to examine the Gigamap, or both. Other methods were therefore necessary to effectively communicate the results from the Gigamap and effectively drive the discussions. The problems that needed to be discussed had to be separated from the Gigamap to make them clear to the stakeholder. To stay in line with the rest of the research methodology a visual method was once again preferred.

Problems known beforehand and problems that were identified during the research were traced back to their origin by following them through the Gigamap. This resulted in a 'root cause analysis' with 9 different tree diagrams, that together focused on three main topics: Technical problems, issues from factory workers, and sustainability. The last topic was added as it is relevant for future development of the table. The diagrams were refined through various iterations. The first iterations was based on concerns directly from the factory workers. The second iteration formed after a discussion with the assignment supervisor to include the interests from the company. The third iteration (**Fig. 31**) was formed after the stakeholder discussions, to further refine the diagrams as part of the factory research conclusion.

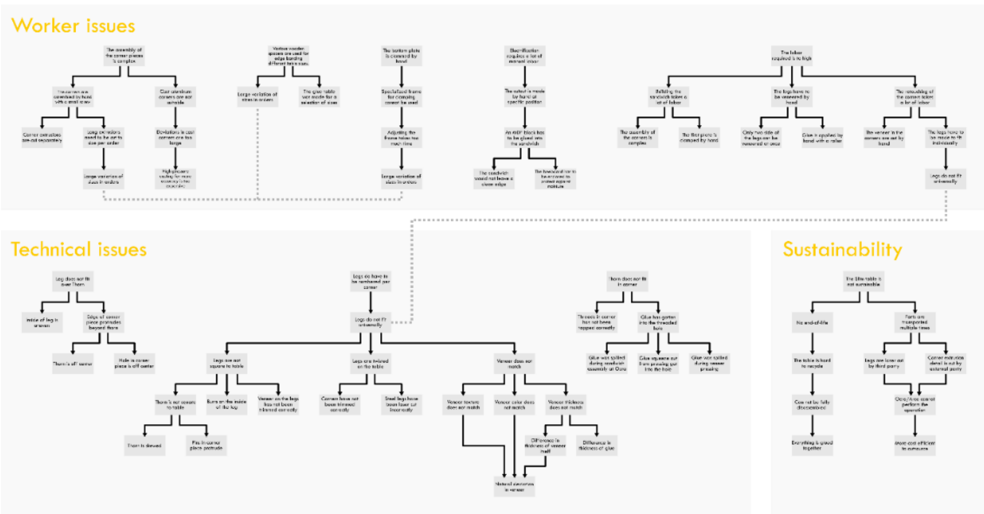


Figure 31: Root cause analysis tree diagrams. (larger version in diagram appendix C)

3.4.2 Stakeholder discussions

Through the empathic process and the creation of the Gigamap a connection was established and the goal to improve the process was internalized. Various stakeholders in the factory process were approached to discuss the possibilities for changes in the process. Additionally, the discussions with the stakeholders helped to verify if the understanding of the production process was correct and if parts were missing. Stakeholders included the two foremen from the factory floor, the head of purchasing, the head of product development and the financial director. The dates and order of the discussions is listed below, a summary of each discussion can be found in Appendix D. One stakeholder discussion that is actual missing is that of Ocra's foreman. The foremen had only just started and was so temporarily. He could therefore not help beyond what the factory workers at Ocra had already told.

- **BERNIE** - *(Former) Purchasing manager* 20-4-2022
- **HAYCO** - *Foreman, oversees: finishing, assembly and packaging* 20-4-2022
- **NICK** - *Foreman, oversees: machine shop, veneer preparation and retouching* 21-4-2022
- ~~OCRA~~
- **GERBEN** - *Head of product development* 21-4-2022
- **JAN** - *Financial director* &
  GERBEN - *Head of product development* 26-4-2022
- **CARLO** - *Former Head of product development* 12-7-2022

The stakeholders were presented with the root cause tree diagrams and Gigamap to discuss the identified problems and possible solutions. Whenever necessary, feedback was incorporated into the diagrams at a later time. Various developments in the past and the usefulness of some procedures also came up during the discussions. The factory research seemed mostly accurate and required only minor changes. One of the most important conclusion from the discussions was that whatever the solution for a problem may be, it would be hard to find any support within the factory if it would take longer to do than current procedures.

After the first four stakeholder discussions were completed, the newly gained insights were included in the final presentation that summarized the factory research results. A final stake holder discussion was with the *Financial director and Head of product development* to discuss the continuation of the assignment (options A or B as stated in the approach (chapter 1.3)). There was more to gain and less uncertainty in process optimization compared to developing a new extendable Slim table. It also became clear during the discussion that a solution should focus on improving consistency in the production process. Two opposite directions for a solution were discussed, either use automation to reduce human error and increase consistency, or eliminate tolerances by manual adjustment. However, implementation of any solution may also require changes to the Slim table itself. Therefore, the construction of the Slim table needs to be understood as well. To know what is possible and to not dismiss ideas too early on in the process. The discussion therefore concluded that the assignment would continue focusing on improving the production process, starting with additional research on three areas: automation, tolerances and construction.

An additional unexpected conversation happened when a former head of product development was present in the factory that worked on the introduction of the Slim. The development of the Slim table from the first prototype to the first years of production were discussed. Although research had already given an idea of the history of the slim, It was this last conversation that brought everything together into a coherent story.

3.5 RESULTS

Gaming is part of the process as well as the result. The main result of the factory research is therefore a Gigamap with the most important data incorporated in it.

The final Gigamap

A Gigamap is both part of the process and an end result. The Gigamap v2 that has already been discussed in the Gigamapping chapter (Ch. 3.2) is also the final Gigamap of the factory research. It consists of 4 main parts. The first part is the Production process and form the fills the largest part of the Gigamap. It includes all the steps that were identified d in the process, ordered by department. The more important procedures have now been split up in multiple steps for more details. The other three parts of the Gigamap offer context to the process in the form of location, history and cost.

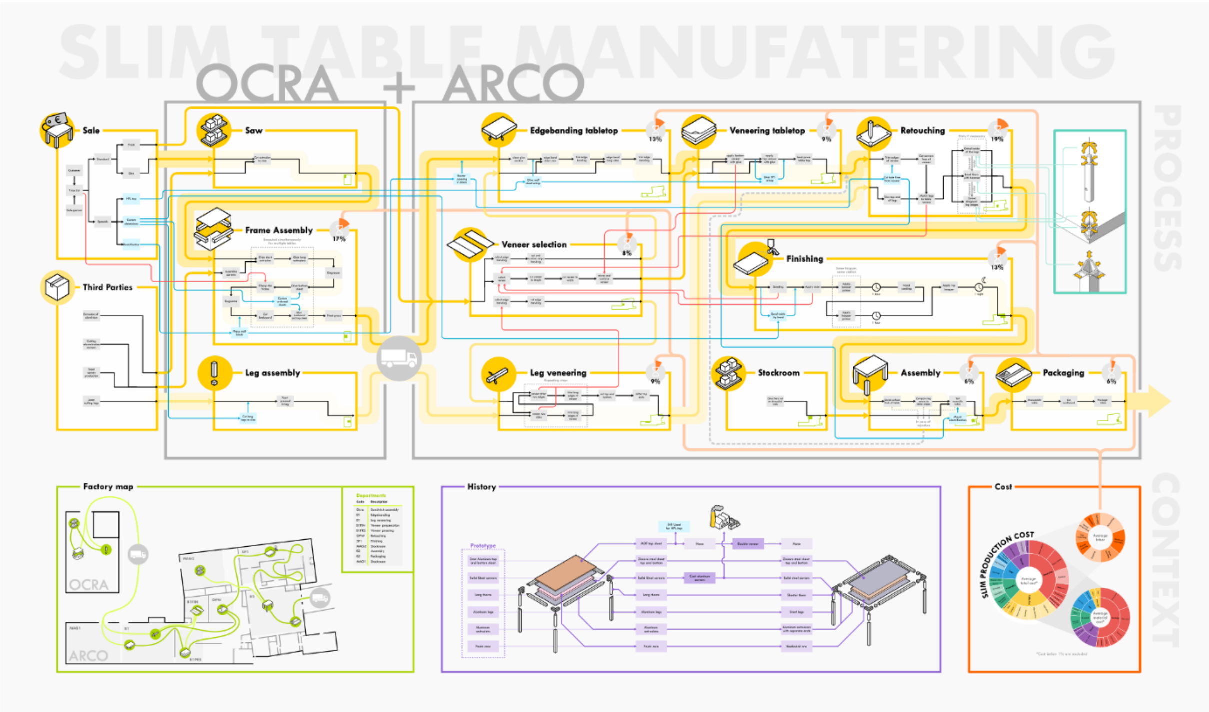


Figure 32: Gigamap v2 (Full resolution can be found in Appendix A.2)

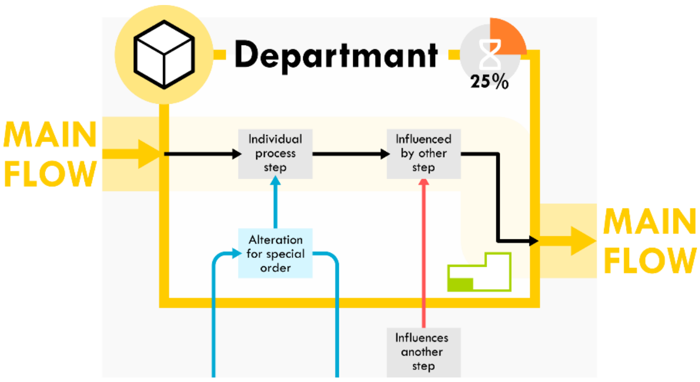


Figure 33: Simplified visualization of the data representation the final the Gigamap

The process diagram

Although the production process is fairly linear, when including the special variants and the connections between different steps it becomes quite complex. The Gigamap embraces this complexity and helps to visually make sense of the situation. The main part of the Gigamap represents the production process and each layer of information is represented by a different color (**Fig.**

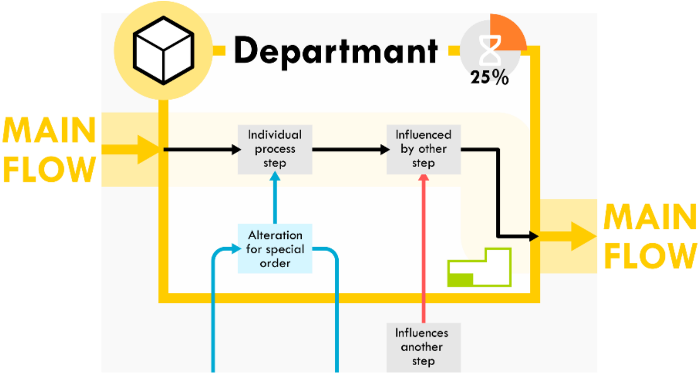
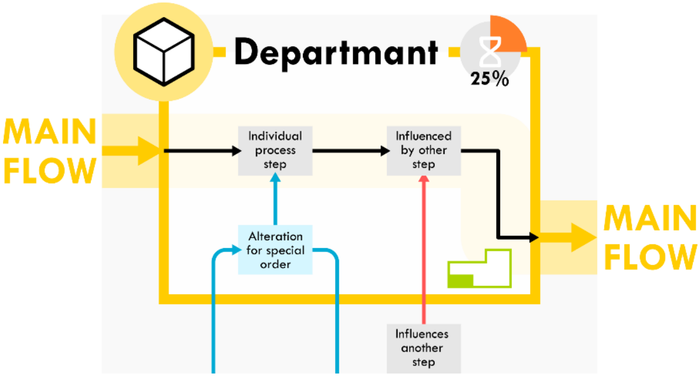


Figure 33). Yellow lines represent the main flow of material from department to department. The black lines and grey boxes show the process within each department. Red lines show which steps in the process indicate the procedures of other steps. The blue lines and boxes show alterations that may occur for special orders.

Context

Additional context to the process is given below the process diagram and on the side in the form of Location, History, Cost analysis and:

- The map on the bottom left shows where departments are located and the route the material travels within the two factories. A small green icon also shows the location of each department



  in the process diagram (**Fig.**
- Figure 33).
- The history of the production process and changes in parts of the Slim are included in the purple area in the middle. Although the exact moment of changes could not be determined, the development of each part from the first prototype to the current version has been included.
- The Cost analysis at the bottom right shows the distribution of average cost for the main parts of the table in a pie graph, as well as two separate graphs for just material and labor cost. The latter is also visualized at each department with a small orange pie graph.
- The last type of context is within the process diagram at the top right. It shows where deviations occur in the corners of the Slim table and how they are linked to the retouching process

Insights

During the execution of factory research, there were already some improvement possibilities identified in the production process. During the Gigamapping process, these possibilities were analyzed with the rest of the data from the factory. This has resulted in several key insights:

- The cost analysis has shown that the main cost of the production process is the construction of the sandwich and the retouching of the table corners to fit the legs. With the sandwich, it mainly comes from material cost while retouching cost comes from labor.
- Although it is understandable that the operations are manual due to their complexity, the current process seems to work against itself. Trimming the legs and corners by hand can introduce inconsistency while the whole purpose of retouching is to make the legs fit the corners of the table.
- Although the use of the cast aluminum corners has been dismissed in the past, there are still several problems in the production process that could still be solved by using them. The aluminum corners are cheaper, would simplify the assembly of the sandwich at Ocra, and allow for adjustments to the corners.
- There were also other insights from the production process that would not significantly improve production. A good example is that larger screws in the corners assembly at Arco would benefit workers by making assembly easier. However, it would not change anything in the production process while most likely still requiring an investment cost.

3.6 CONCLUSION

Through empathic design, insights were gathered directly from the factory workers and Gigamapping helped comprehend the complexity of the process. Together they have given detailed insights on the production process.

3.6.1 Factory research

Every step in the production process of the Slim has been optimized over the years to achieve the best results as effective as possible. Although large scale changes have often been deliberate, the workers themselves have also contributed on a smaller scale. By finding the best order of operations, how to handle materials or how to place them on the workbench, all to make the process easier for themselves. Nevertheless, some of the current procedures are not necessarily the most efficient. Many of the current problems in the process come from deliberate decisions to accommodate other parts of the process. There will therefore not be a simple solution for improving the production process, because almost everything in the process is interconnected and any change at one stage will most definitely affect other as well.

The research set off with the goal to reduce labor and reduce the tolerances in the corners. As expected, the assembly of the sandwich and retouching were the largest costs of the production process. With the labor at the retouching stage being the largest single cost in the process as this is where all deviation throughout the process have to be adjusted to meet the final requirements. Although they may have a smaller contribution to the cost, other parts of the process are also still dominated by manual labor. The variability in table sizes makes it difficult to mechanize some procedures as they would need constant adjustment for each table size. Doing the work by hand is in those cases still faster than adjusting machinery. Besides just the amount of labor, other problems in the production process have also been identified. This included small annoyances for workers that could be avoided (small screws in the corners), as well as larger scale conflicts between departments, where ones work has to accommodate the other (veneer preparation). The main purpose of the retouching stage is to deal with deviations that arise elsewhere in the production process. Therefore, to improve the retouching process, as well as other stages in the process, will require changes across the entire process or even to the Slim table itself.

As a high quality furniture brand, Arco has set high standards for all its products. However, looking at all the problems in the manufacturing process their seems to be a simple solution. Reducing the required tolerances of the Slim table. This would help reduce cost and simplify labor in the production process. Unfortunately reducing the tolerances could also lower the perceived quality of the table. Taking into account the large history of Slim tables that are already on the market would also mean that there would exist two versions of the table of different quality. Altogether is this an undesirable situation as it could damage the Arco brand. The reducing of tolerances is therefore off the table.

3.6.2 Follow up

The factory research has focused on finding improvements in the production process through empathic design. By following up with a design process added value of Empathic design can be evaluated. The main goal of the design process will therefore be to translate the research findings into a practical solution for Arco. In the research approach, two options were considered for the design process: improving the Slim production process or designing an new extendable Slim. The latter was mainly introduced to still evaluate the value of Empathic design if the factory research was not able to identify significant improvement opportunities. However, in the stakeholder discussion with the financial director and head of product development it was concluded that the factory research results were sufficient enough to continue with the improvement of the production process.

Despite that the factory research has resulted in a clear and detailed overview of the production process, it is still unclear how improvement could actually be accomplished. The factory research has mainly focused on the process and has so far lacked a detailed evaluation of the Slim table itself. During the aforementioned stakeholder discussion three areas were already identified that are worthy of further investigation: The potential benefits of automation for efficiency and accuracy, The causes and solutions for corner tolerances issues, The structural design and materials that give the table its strength. The design process will have to start by exploring these three identified areas first, followed by steps such as ideation, concept development, prototyping and testing.

4 Re-Design process

4.1 RE-DESIGN APPROACH

With the factory research conclude new insights into the productions process gas been gathered. Now the resulting ideas for possible improvements need to be further develop into practical solutions.

4.1.1 From research to design

The original assignment from Arco was to find improvements in the production process. The first step was an in-depth research on the current process utilizing Empathic design methods, which revealed several opportunities for improvement. However, the immersion in the factory may also have resulted in a bias towards the current production process. To overcome this challenge, the second step will involve a separate design process. It will allow for creative exploration of alternative solutions, while still being informed by the factory research findings. Not only will the design process help translate the research findings into a feasible solution, it will also evaluating the effectiveness of empathic design for process optimization.

4.1.2 Design process

The course of the design process was not set from the start and depended on the result of each preceding step (**Fig. 34**). The first step involved further exploring the problem through three different themes: automation, tolerances and reconstruction (as discussed in the stakeholder discussions). The intension was that each theme would lead to a concept that could be evaluated on their feasibility. However, not all themes resulted in clear concepts. An intermediate feedback session was therefore conducted with the product development team at Arco where the results from the three themes were discussed. The session helped formulate three main concept ideas that were each further refined and one was further developed for prototyping.

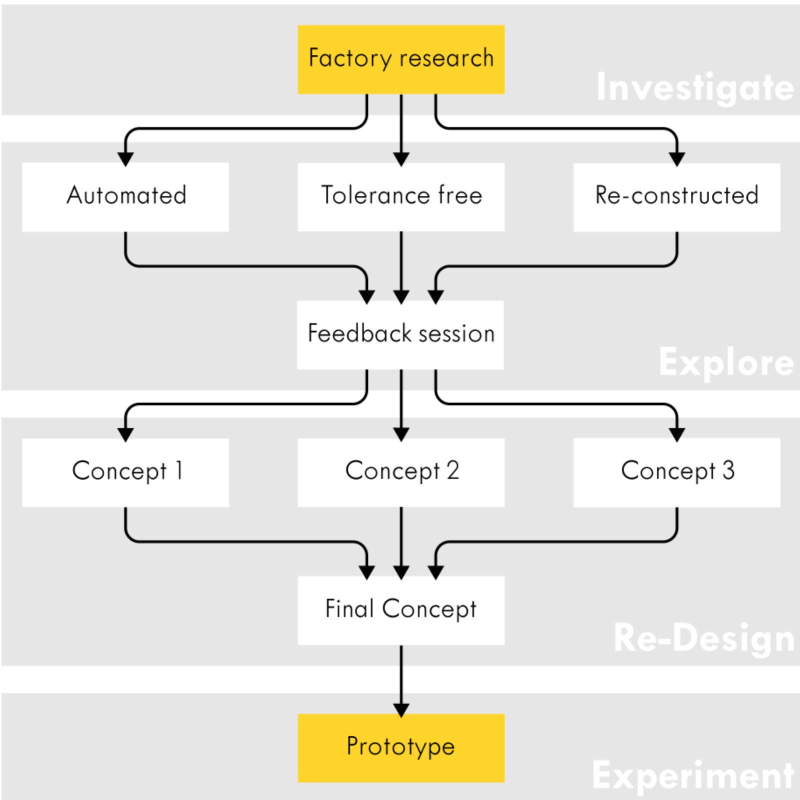


Figure 34: Visualization of the Re-design process.

4.2 EXPLORATION

Although the factory research resulted in many new insights, the possibilities for a solution were still unclear. Through exploration of the Slim and its production process, the last gaps in the factory research can be filled

4.2.1 Three themes

The factory research has revealed some areas for improvement in the production process, with the main areas for improvement being the reduction of intensive labor and to increasing the accuracy of the corner construction. However, how these areas could be improved remained unclear. A possible approach to address these areas was already proposed during the Stakeholder discussions. The reduction of labor would be addressed by focusing on automations of the process, while the accuracy would be addressed by focusing on the deviations. The construction of the table would be addressed as well, to explore how it could accommodate improvements in automation or accuracy. This approach formed the basis for three themes for the exploration. Each theme was explored separately and the results are discussed below. (The details of the exploration themes can be found in Appendix D to H)

4.2.2 Theme 1: Automation

To explore how automation could improve the production process, each step in the process was evaluated for what could and should be an automated process. The current process production process of the Slim table requires a lot of manual labor in its production process. Although this is applicable across the production process, a large contributor is the retouching stage. Where each leg has to be fitted to a specific corner of the table. This also makes the legs non-interchangeable, which adds complexity. Automation could help reduce manual labor. It could increasing the consistency to reduce the amount of retouching required. That is not to say that manual labor also has some advantages, such as showing craftsmanship and allowing for the flexibility to produce the different table sizes.

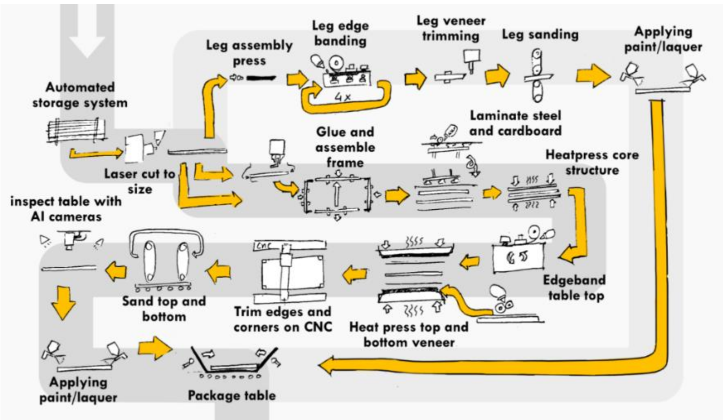


Figure 35: Concept of a fully automated Slim production process.

To explore the feasibility of a fully automated production process, a hypothetical scenario was conceptualized (**Fig. 35**). However, automation does not necessarily imply complete elimination of human labor. On the contrary, developing a hybrid system that combines automation with manual labor might be more advantageous and cost-effective. For the Slim table, keeping most of the production process of the slim table manual is recommended, as it offers flexibility, which is necessary to accommodate the variety of sizes. It will also continue to demonstrate craftsmanship, which are important values for the product and the company. Nevertheless, certain parts of the process would benefit from partial automation to improve the efficiency and consistency of the production process. The parts that would benefit the most from automations are those that are exclusive for the Slim table, e.g. frame assembly and corner cutting. Finding a balance between manual labor and automation is how the production process of the slim table can be optimized.

4.2.3 Theme 2: Tolerances

The analysis of the tolerances in the corners of the table did not lead to a solution or concept. However, it did provide valuable insights in to the relationship between the tolerance and the production process. For the legs to fit right, there are multiple dimensions that need to be within the tolerances (**Fig. 36**). At the retouching stage, each legs is adjusted to fit one corner of the table. The legs therefore end up being unique, as each leg has been adjusted slightly different. A better approach would be to standardize the legs and modify the table corners to match them instead. Unfortunately, this would require changes to the current production setup, as it is difficult to make adjustments without damaging the veneer on the table. One solution would be to make cutting the veneer in the corners more precise and consistent by utilizing CNC-machining. This would in turn, however, require more consistency or different materials in the frame, or the cutting tool would otherwise cut into the steel corners with every operation. A second option to improve the consistency of the production process is therefore to redesign the corner construction entirely. The existing Flex plate already offers an alternative corner construction. However, other alternatives should also be explored.

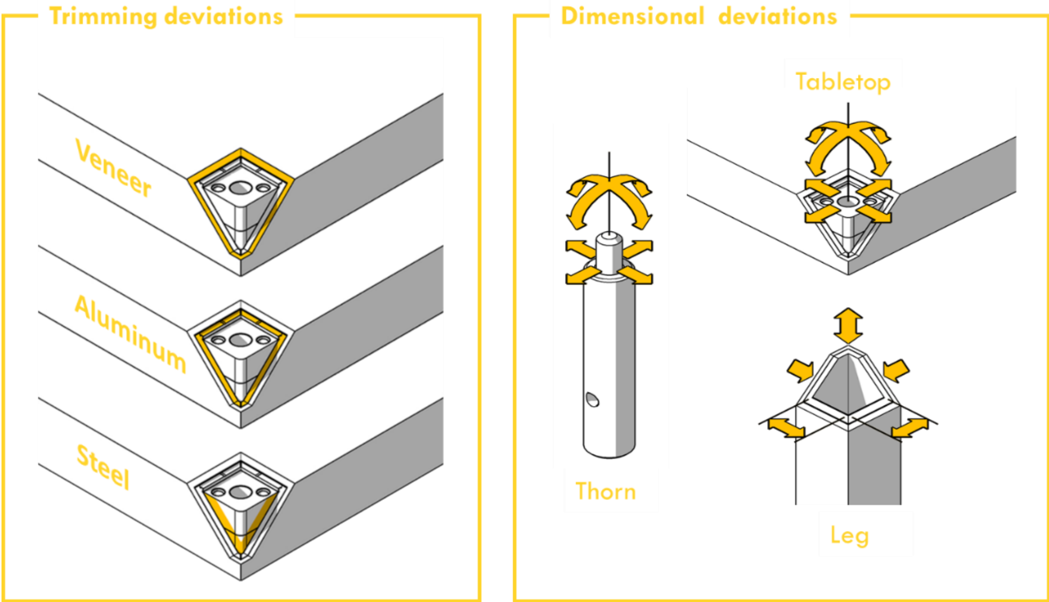


Figure 36: Important tolerances for fitting the legs on the corners of the Slim table.

4.2.4 Theme 3: Construction

The current construction of the Slim table was analyzed to better understand how it achieves its strength* and alternative construction methods and materials were researched. The core of the Slim table is essentially a composite material made of Zincore and Beeboard. During the conception of the Slim table, there may not have existed many alternatives. However, new materials have become available and there is now a larger incentive to develop more sustainable alternatives to existing materials. A new core material for the Slim can reduce the complexity of production by utilizing premade composites, as well as increase recyclability by reducing material variety.

**(Unfortunately, there was one assumption made about the aluminum frame that proved to be faulty. This was only discovered after building the prototype. Up until then it was assumed to be plausible to replace the zincore and it has therefore affected the re-design process. The full implications will be further discussed in the prototype chapter(4.5).*

For the legs, alternatives for the veneer and mounting of the table were explored. From a material point of view, veneering the legs reached a dead end as there was too much uncertainty in whether the materials could deliver the desired quality and properties. Although exploration for the mounting of the legs was not conclusive, there was enough potential to justify further development. However, the final design of the connection will depend on the rest of the table's construction.

There are multiple options for premade composite panels that could be used in the construction of the Slim (**Fig. 37**). However, the requirements for replacing the core material are still uncertain. It is therefore impossible to immediately make the right selection of a core material. However, most composite panels are all essentially the same, with a core material between two sheets. The redesign of the Slim construction should therefore continue without focusing on a singular material. In doing so, the use of premade panels can still be explored without limiting creativity by the restrictions of one material. The redesign would then have to determine the requirements and a selection can be made afterwards.

Figure 37: Inspiration for alternative constructions and materials for slim.

4.2.5 Exploration conclusion

In the factory research, two possible solutions were identified for improving the Slim production process. Either parts have to be automated to decrease variations in the results or the process for retouching the table has to be improved to the point where deviations would no longer be a problem. The idea behind the exploration themes was to take both solutions to the extreme, automate everything no matter the cost, reduce deviation no matter the time, and at the end evaluate what parts of each solution would be feasible. The exploration of the construction was only conceived to support any changes that may require changes to the current design to be implemented. However, the results of the exploration were almost the reverse. Construction became the main source of new ideas for a possible solution, although they were far-reaching. Tolerances resulted in some ideas; however, it mainly gave more insight into how deviation accumulates in the process. While automation became more of a supportive theme for how new machines could be used.

4.3 FEEDBACK SESSION

The three exploration themes have resulted in several ideas for improving the production process although the question remains, what is the best solution for Arco? Involving Arco's own experts may help answer that question.

4.3.1 Expert opinions

The three themes were insightful in exploring possibilities for the Slim table and its production process, yet they did not result in clear solutions or concepts. Nevertheless, there are still plenty of ideas. Until now, the research process has been mostly individual. However, involving experts may bring in new perspectives. The Product development team (PO for 'Product Ontwikkeling' in Dutch) is composed of professionals who have expertise in various aspects of manufacturing (e.g., CNC programming, Planning, Work preparation, etc.). The PO members are therefore ideal experts because they have experience in developing for the Arco factory. All members also have an Industrial Design background that can help in generating ideas. By involving the PO team in the discussion, they can help formulate the concepts that would best fit within the factory based on their expertise.

Ideally, all members of the PO team would be involved at the same time. However, availability of some members was limited. Their involvement was therefore planned as a single feedback session. The content of the session was inspired by co-design methods. To run the discussion as effectively as possible, the session was divided into three stages. Starting off with a presentation that would inform the team members of the research result. Followed by a discussion on ideas for each of the exploration themes. To stimulate creativity and inspire new ideas, samples from the current slim and new materials would be present. At the end of the discussion, we should be able to formulate three new concepts for further development.

4.3.2 The session

There was a clear vision of how the feedback session should have looked. In practice, however, things will always go different. Although the presentation went quite well, there were still quite some questions and that took time away from the discussion. After the presentation the team was instructed to write down any idea they got on a post-it and place it under one of the three themes to discuss afterwards. Despite their Design Engineering background the team sill required some nudging to come up with new ideas. However, after some help from the project supervisor the conversation became more lively and productive.

At a first glance the resulting amount of post-its (**Fig. 38**) may look underwhelming, however, the team just wrote down multiple ideas per post-it. The ideas were therefore still sufficient. Seeing how the team would think about certain problems and solutions was also insightful in and on itself. At the end of the session, there was only limited time left to discuss new concepts. However, three concepts could still be formulated for further development to test their feasibility.

Figure 38: Feedback session, presentation setup (left), during discussion (middle) and results (right).

4.3.3 Results

The feedback session has resulted in a variety of ideas that addressed the issues with the Slim table from different directions. There were, unfortunately, only a few ideas for automation. This may be because the production process is a complex system that makes it hard to suggests single ideas. In addition the concept presented in the Automation theme may have appeared finished enough that did not have anything to add to it. Most of the ideas were placed under Tolerance free and Re-constructed. There is some overlap between ideas from each theme, as some ideas were applicable to more than one. Ideas included specific material or tool uses or different methods. Some ideas even mentioned companies that Arco had worked with or had contact with before. What was lacking however were ideas for alternatives or changes to the corner connection. In the end. the more broader ideas helped inspire the creation of concepts, while the value of more specific ideas will depend on the further development of the concepts when the details become of interest.

The feedback session resulted in three concepts. However some adjustments were made after the session (**Fig. 39**). The first two concepts stayed the same, while a new concept was added to place additional focus on developing a new corner connection. The carbon fiber concept became the fourth. It is also treated as only half a concept and it will not be as far developed as the other three. It was already clear that it would not be feasible, however there was still an interest examining the possibilities. Therefore, instead of continuing with the three concepts directly from the session, the new set of are 3½ concepts is further developed.

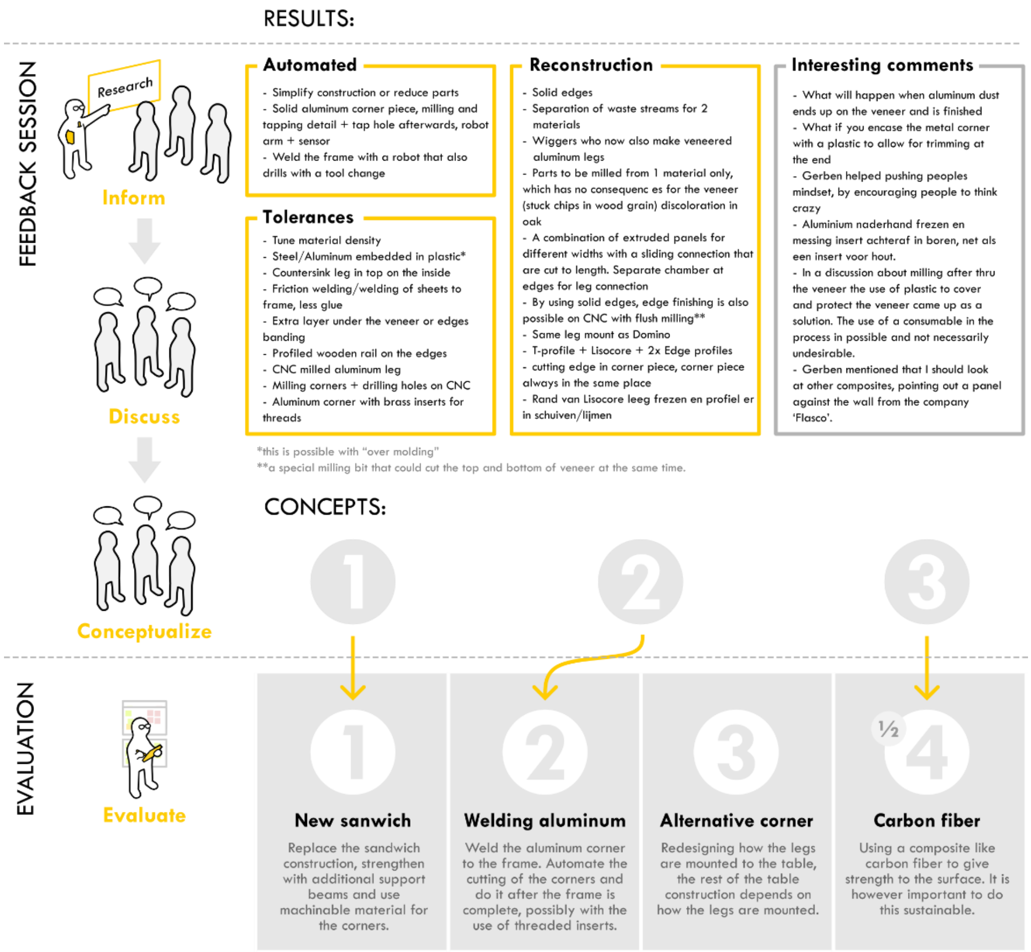


Figure 39: Structure and results of the feedback session.

4.3.4 Conclusion

The three themes were formulated with specific roles in mind. Automation and tolerances were the main focus, while reconstruction had a supportive role. With the concepts formulated, it is clear that these roles have changed. Tolerance-free gave the knowledge necessary to understand what needed to be improved, while reconstruction gave various solutions for how the product could be improved. Automation became a supporting theme that made the proposed solution possible within the factory. The original idea that reconstruction would support ideas from the other two themes therefore became flipped and instead it became the main source for new ideas.

The goal of the feedback session was to identify what concepts would best fit Arco by asking those whose work it is to design and improve for the Arco factory. Although the level of idea generation for the session was misjudged, there were still plenty of ideas. The concepts that were generated during the session determined what direction will be taken in concept development. The most valuable aspect of the feedback session was the discussion itself, as it gave insight into what the PO team thought about the problem from their respective perspectives. After being fully focused on production process, you risk becoming blind sighted for the obvious. Even though some ideas or remarks from the session may not have been new to the research, the feedback from the PO team gave a fresh perspective on possible solutions.

4.4 CONCEPT DEVELOPMENT

The previous chapters presented several suggestions for improving the production process. However, ideas require detail to determine their feasibility. Further developing the suggestions into full concepts will help examined their impact on the production process.

4.4.1 Wishes and requirements

The design process usually starts with setting up a list of requirements to set boundaries for the design. The goal of the first stages of the design process was to explore new ideas. Therefore, purposefully distance was created from the current situation and setting up requirements may have limited creativity. The factory research had already given a good idea of what the table should be, and the main boundaries were already clear: Anything can be changed as long as the appearance stays the same and the table remains strong enough. However, now that it is time to further refine the ideas into concepts, it is also time to clearly set up the requirements of the design (**Fig. 40**). Some requirements that are included were discovered when new alternatives were discussed during the development of the concepts. For instance, the thickness of the edge banding veneer only came up when discussing the material options for automated veneering of the legs. These requirements have already been included in the list below.

Requirements	Wishes
- The tabletop must stay max. 30mm thick - The legs must have the same thinness as the tabletop - The table is fully veneered - The corner detail of the table stays the same - The legs are detachable - When the legs are detached there are on protruding elements underneath the table - The table is variable in both width and length - The Hight of the legs can be customized - First glue edge banding and then veneering for a higher quality result - Thicker veneer edge banding to absorb impacts from chairs when hit	- Reduced complexity of parts - Reduction in material cost - Reduction in production time - Minimal investment in new machinery or tools - Increased sustainability

Figure 40: Table of requirements and wishes for a re-designed Slim table.

4.4.2 3½ concepts

To develop the concepts, new information was gathered by revisiting the factory and checking or testing whether new ideas would work. The Techni show, which was mentioned in the re-construction themes, was attended around this time, as well as a visit to the Wigger factory to discuss the possibilities for automated veneering of the legs. Based on new findings along the way, some of the concepts were modified. For concept 1, a wooden end was introduced to attach the legs to the sandwich. However, this wooden end became a feature that could combine the best of both the Regular Slim and the Slim Flex. For concept 2, the goal of welding the aluminum shifted to improving the current corners in general and utilizing automation, as it became clear that welding might not be feasible after all. The ideas behind Concept 3 and 4 remained largely the same, although concept 3 took a different turn than expected. All concepts are further discussed below.

4.4.3 Concept 1: Premade sandwich

An important problem to solve was how to connect a premade sandwich to the frame. This resulted in a solid plywood table head that utilizes the same leg mounting as the Slim flex. The concepts were developed with Lisocore as a sandwich material in mind. The design should nevertheless still be applicable for other types of sandwich materials. The wooden table head would keep production and assembly simple, as well as adding length to bridge the difference between the longest available Lisocore sheets and currently longest Slim table variant. Various options were sketched (**Fig. 41**), and although the idea was originally meant for a new sandwich material, it is also compatible with the existing sandwich. That would, however, introduce a new problem, as the wood expands differently based on environmental conditions compared to the steel Zincore sheets.

A solid wooden base material for the corners should help with constancy when the entire corner detail could be CNC milled. That may, however, require changes to the flex plate. The design of the plate was therefore explored in relation to the order of operations in the corners (**Fig. 41**). Reducing the size of the plate leaves room for the wood, to make it less fragile or as a buffer between the steel plate and a milling bit. The final design for this concept resulted in an assembly of fewer, already available parts. With an existing conception method for the legs that has already been proven.

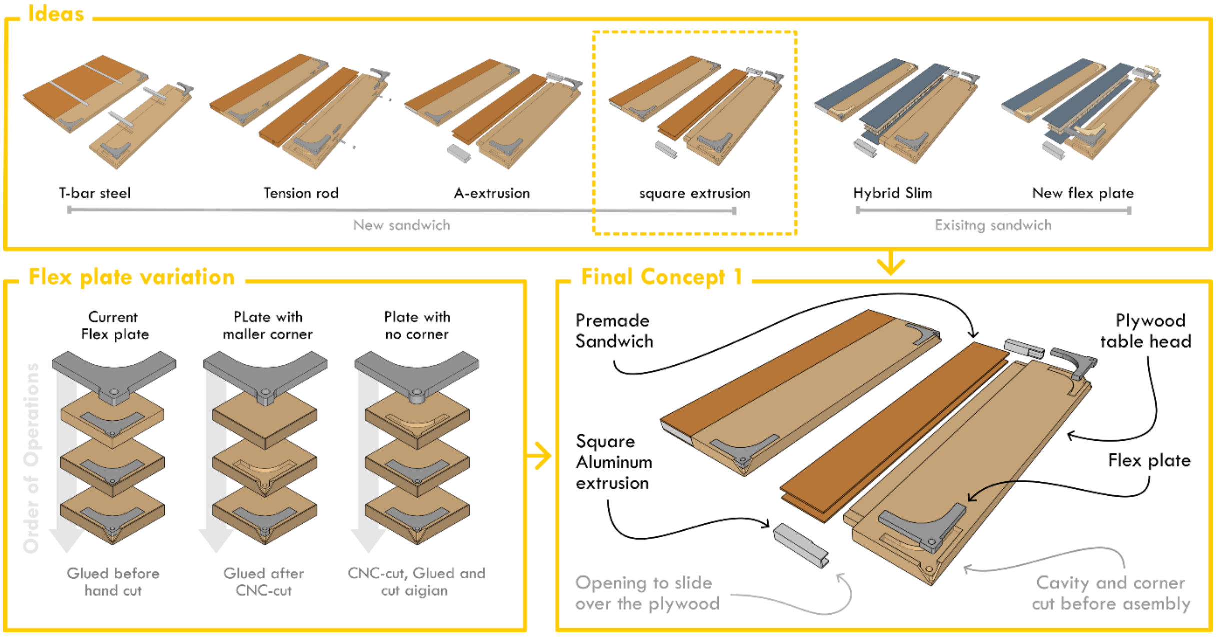


Figure 41: Concept 1, Premade sandwich.

4.4.4 Concept 2: Automated corners

The original idea behind this concept was to find a way to weld or fuse the parts together to decrease production time. The current Slim construction is glued together which requires time to harden. However, most parts are from aluminum, and no definitive answer could be found on welding aluminum. Spot welding corners would be ideal within process, however that does not seem possible with the conditions of the slim. The conductivity of aluminum, combined with the thickness required for the Slim, causes the heat to dissipate too quickly for it to result in an efficient and effective weld (based on conversation at the Techni show). The goal, therefore, shifted to how other ways of automation could be implemented into the construction of the slim. Including the milling of the corners and veneering of the legs.

The challenging part with the corners is the current mix of materials. By reducing the variety of materials in the corner to just aluminum and wood (veneer), it could be easier to CNC mill. Various corner designs are possible without changing the rest of the Slim construction. Two were selected as final concepts (**Fig. 42**). One is similar to the existing cast aluminum corner, however, deliberately with extra material that would be milled to ensure the correct dimensions of the corner. The other variant is more similar to the steel corner, however, with mitered extrusions instead that are milled together with the corner. A threaded insert would be placed afterward, ensuring the correct placement of the threaded hole in relation to the sides. Milling could happen at either Ocra or at Arco, a probe on the CNC-machine could locate the exact position of the corners for an accurate result (A probe could also be a valuable investment for the production of other products). Another possibility, that emerged later in the project, is using a smaller dedicated CNC-mill that would cut each corner one by one and a jig for positioning. The development of this concept has resulted in two possible aluminum corners constructions; it is, however, still inconclusive as there are still many uncertainties.

An additional idea for the automation of the leg veneering is also included. Although it is a separate idea, it does fit with the automated ideas of the corners. The legs require the same edge banding as tabletops. Veneering could be done on an existing machine at Arco. This may, however, require an additional jig (bottom right of **Fig. 42**) to hold the legs as the machine was made for larger tabletops. It is, however, uncertain if the required glue types are compatible with the machine.

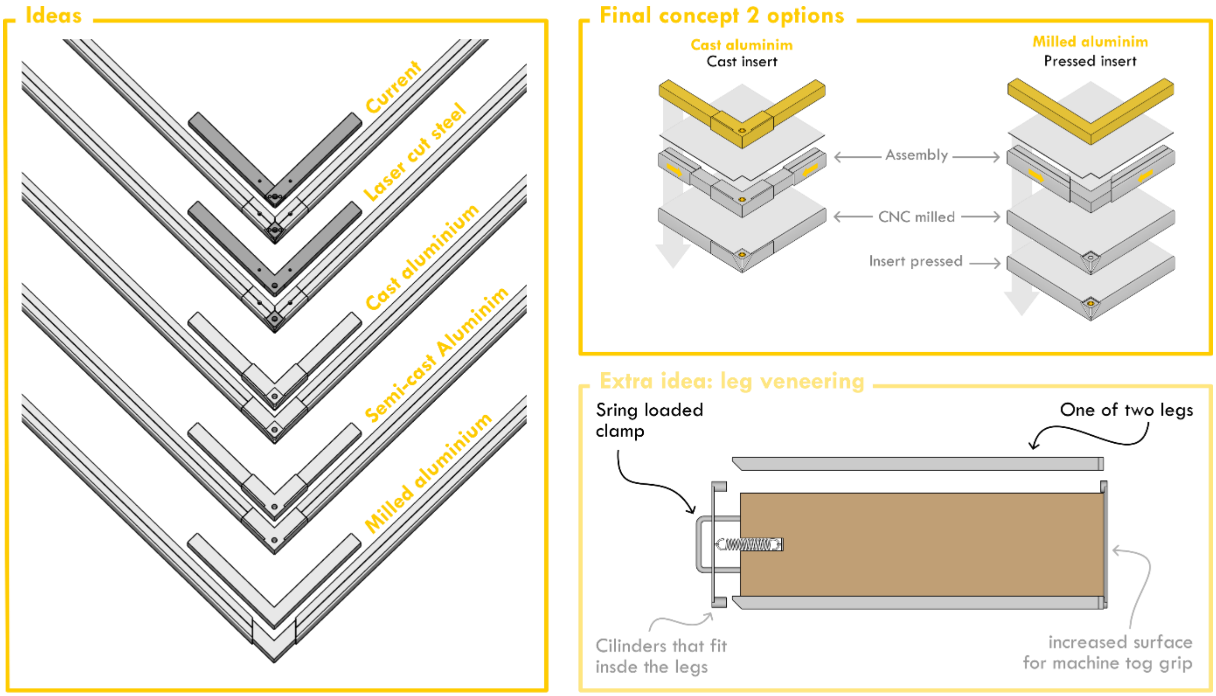


Figure 42: Concept 2, Automated corners.

4.4.5 Concept 3: Redesigned corner

In the development of this concept, something interesting happened. The goal was to redesign the connection of legs to the table. To distance ourselves from the current construction, new connection methods were conceptualized without thinking too much about what would work or not (**Fig. 43**). However, keeping the appearance of the corner connection remained a major constraint. The process therefore started with trying out what different shapes would fit in both the table and the leg. This resulted in a solid corner that would slide into the corner diagonally, as the best alternative option. The final design utilizes a solid steel-L that attaches to the legs with threaded rods, just like the current slim. The steel-L would then slide into the tabletop and be attached with two screws. However, if we take a closer look at this design, we can see that it is actually similar to the flex plate. If the vertical part of the corner is replaced with the thorn, the rest of the design functions the same as the flex plate although with more complex parts. In the effort to come up with a new, possibly better corner connection, the resulting design has looped back to the Flex plate, suggesting that the plate may be the ideal solution.

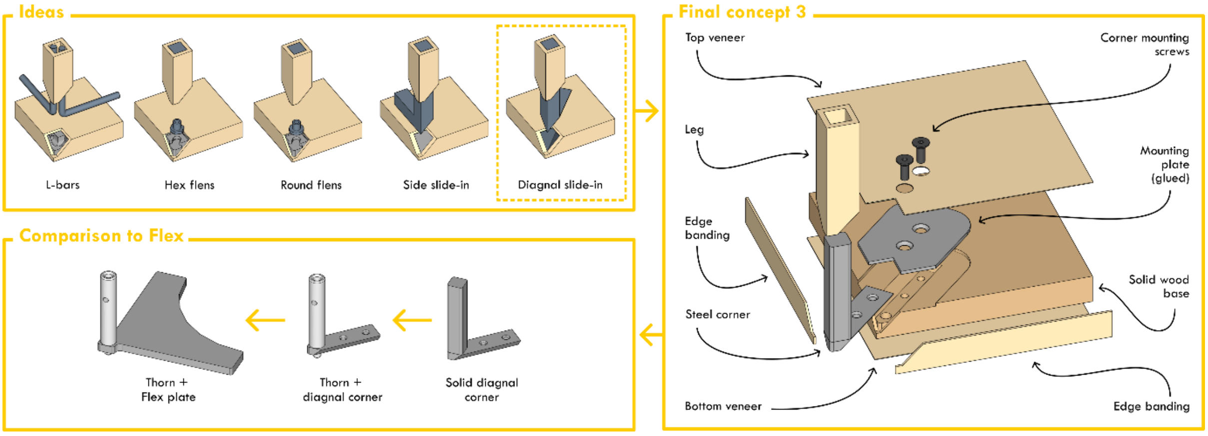


Figure 43: Concept 3, Redesigned corners.

4.4.6 Concept 4: Carbon fiber

Carbon fiber has become cheaper over the years, however has it become cheap enough. Examples can be found of Carbon fiber tables (section 4.2.4). Although, in those cases the use of carbon fiber is also a design feature, justifying higher prices. With the Slim table the design would stay the same and the carbon fiber would be end up covered, the cost of using carbon fiber can therefore not exceed the current cost of the Slim. The cost for carbon fiber in industry application has been declining for years (Shama Rao et al., 2018), as well as becoming more readily available, even for the private sector. In the case of Arco we can already assume they would use premade carbon fiber sheets for tables, as they do not have the facilities to laminate carbon themselves. Arco would not need specialized double curves shapes for the production of tables. Making a rough estimate, the current price for a carbon fiber sheet is, however, still twice the entire cost of a similar sized slim (Full calculation in Appendix J). The current price therefor does not seem low in enough yet.

Carbon fiber is at the center of a lot of development and should be expected to have a lower environmental impact in the future. Sustainability is just as important as the price. A recent paper has analyzed and compared the environmental impact of glass fiber reinforced polymers and Carbon fiber reinforced polymers in the automotive industry (Hermansson et al., n.d.). They concluded that the Carbon fiber has the potential for a lesser impact compared to Fiber glass, however only with certain future developments. Whereas the use of carbon fiber (or other composites) to reduce weight in moving components can reduced cost and environmental impact during the lifetime of the product, for furniture the gain is only in the production and recycling process. Both of these aspects are in constant development, however, it seems that the current situation is not adequate for the use in sustainable furniture.

4.4.7 Concept selection

With all 3 ½ concepts developed, a choice had to be made on what would become the final concept. Two concepts can already be ruled out: concept 3 and 4. The development of concept 4 simply confirmed what was to be expected. While concept 3 looped back into a flex plate, and that was already integrated into concept 1. The choice then remained between concept 1 and 2. First, an objective approach was taken by comparing the two on how they scored on the list of requirements and which ones were important (**Fig. 44**). Some statistics on the amount of parts were gathered for each concept's two variants compared to the current Slim and the variant with cast aluminum corners. While all concepts meet the requirements, fulfillment of some wishes could not be determined yet. Even though the decision was already narrowed down to concept 1 and 2, comparing the fulfillment of wishes and requirements was still inconclusive.

CONCEPT COMPARISON	original	aluminum corners	concept 1.1 Beeboard	concept 1.2 Lisocore	concept 2.1 full corner	concept 2.2 inner corner
Requirements	yes	yes	yes	yes	yes	yes
Wishes						
Reduced complexity of parts			yes	yes	equal	equal
Reduction in material cost			-	-	-	-
Reduction in production time			-	-	-	-
Minimal investment in new machinery or tools			none	none	maybe	maybe
Increased sustainability			yes	yes	no	no
Parts						
Total amount (excluding veneer)	31	27	27	25	25	25
Total amount (excluding multiples)	12	10	8	7	10	10
Corner parts	7	3	3	3	3	3
Difference from original	-	4	4	6	6	6
old parts reused (excluding multiples)		7	7	4	9	9
New parts, unproven (excluding multiples)	-	0	1	2	1	1
New parts, proven (excluding multiples)	-	1	1	1	0	0

Figure 44: Comparison table of Concept 1 and 2 variants.

A broader discussion was initiated with a focus on the prototype. It was still uncertain if Lisocore material would be strong enough for concept 1. There was limited information on the strength available, and the skills to calculate the strength properly were lacking. Although concept 2 would most certainly be strong enough based on previous experiences, feasibility was still uncertain. A prototype would also have required significant investment. While concept 1, on the other hand, could be built with currently available materials and tools at hand. The decision to use Lisocore was also finalized, and the prototype would test both the material and the design of the concept. Concept 1 was therefore chosen as it would be easiest to test.

4.4.8 Final concept

The concept may have been selected, however, it is not ready for prototyping yet. The proportions of the concept drawings were not completely accurate to better show the details of the designs. For the final design, the concept had to be redrawn to determine the accurate measurements for a prototype. Lisocore was also definitively chosen as the sandwich material for the prototype. The concept was redrawn, and the final order of operation for the corners was proposed (**Fig. 45**).

An additional request from Arco was to split the wooden heads of the table into separate corner blocks. Although the reasoning behind using a single wooden table head was to make operations on the sandwich material simpler, the wooden table heads would still have to be customized to the desired width of the table. Splitting the end into blocks creates identical parts that would fit any size, which would simplify the assembly. However, it would also make cutting slots into the sandwich material more complex. The reasoning was that if the ends would work split in blocks, they would also work as a single piece. Splitting the wooden end blocks would therefore provide a richer test scenario.

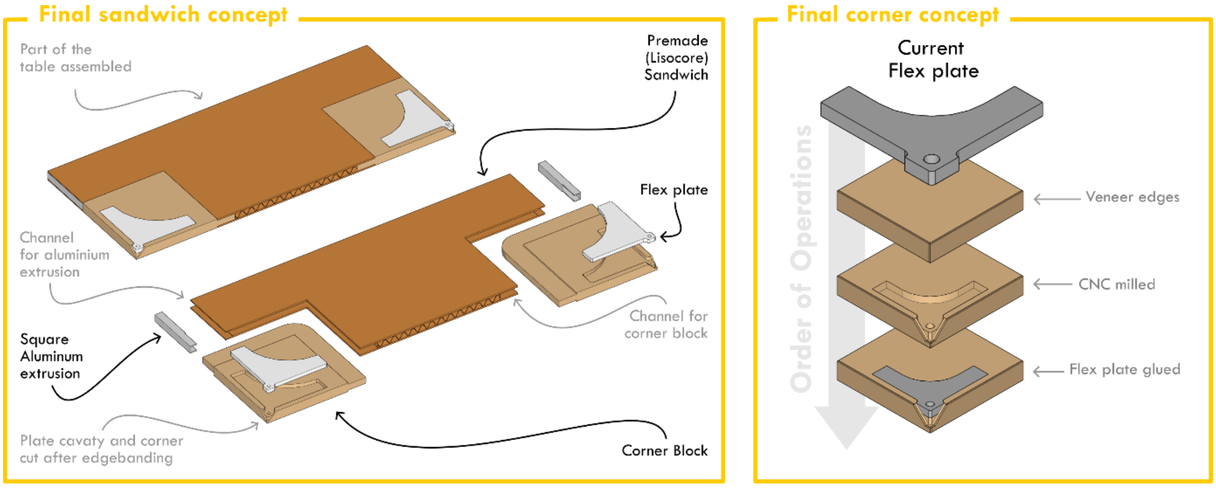


Figure 45: The final concept for an alternative Slim construction.

4.5 PROTOTYPE

With a full scale prototype the strength of the final design can be tested. The prototyping process itself will also serve as a test for the feasibility of the production process.

4.5.1 Cost calculation

The design would only be acceptable if the costs are at least similar to the current slim. The prototype will only be developed up to the veneering stage, as that will be sufficient to evaluate its effectiveness. A valid cost comparison can nevertheless still be made, as every step from there on would be equal to the regular slim. The cost of the prototype can be compared to the regular Slim by using the bill of materials for the Slim Flex and Regular Slim of the same size (**Fig. 46**). Additional operational costs for the prototype were estimated based on similar operations for the Slim Flex and regular Slim. A quote from the supplier was used to calculate the cost of the Lisocore material. An additional quote for an order of 400 sheets was also requested to calculate cost for if the design were to be implemented. The prototype costs €270.30, which is €49.63 more than a regular slim table of the same size. However, based on cost for the larger order, the new design is €10.82 cheaper. This is a rough estimate and prices may change. However we can safely say that the new design has the same cost as the current one.

Parts	Unit	Amount	Cost		Per unit
Flex blad (70x90)		**Total**	45%		
Flex plate	pcs	4	12%		3%
Stabil plywood	pcs	0,5	15%		29%
Sawing (B1.1)	min	5	1%		0%
CNC machining	min	24	4%		0%
Edge veneer	m	4	3%		1%
Glue plate + edges banding (B1.2)	min	60	10%		0%
Slim top (280x90cm)		**Total**	**100%**		
Sandwich	pcs	1	85%		85%
Edge veneer	m	9,75	2%		0%
Edge banding	min	75	13%		0%
Prototype (280x90cm)		**Total**	114%	97% *	
Lisocore	pcs	1	34%	28% *	
Delivery	%	1	11%	0% *	
Cutting to size**	min	10	2%		
Aluminum extrusion	m	5,6	4%		
Flex plate	stuk	4	12%		
Stabil plywood	pcs	0,5	15%		
Cutting to size (b1.1)**	min	5	1%		
CNC machining**	min	60	10%		
Assembly**	min	60	10%		
Edge veneer	m	9,75	2%		
Edgebanding**	min	75	13%		
		Totaal materiaal	77%	70%	
		Totaal arbeid	23%	23%	
		Verschil sandwich	14%	-3%	

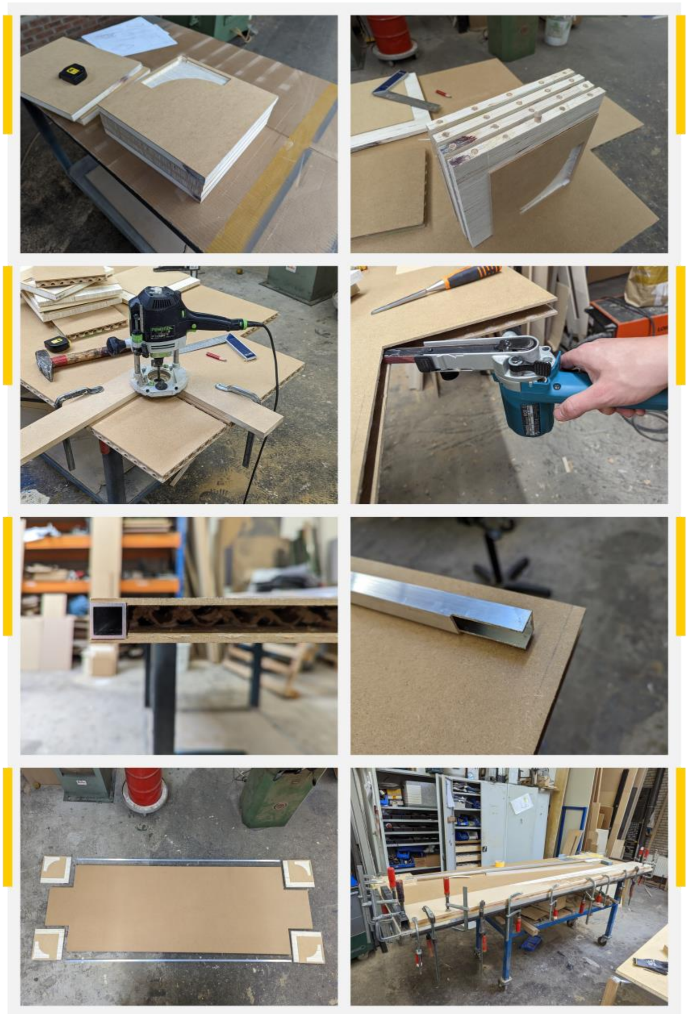
* Lower cost at scale, calculated for 400pcs

** Estimated cost

Figure 46: Cost calculation for the prototype (values are in percentage of Regular Slim for discretion)

4.5.2 Building process

The prototype was created with the help of the resident prototype builder at Arco (Walter). Due to limited resources and availability of the CNC in the factory, most of the protype was built by hand (**Fig. 47**). A the core of a Slim Flex table was used as the base for corner blocks. Changes to the envisioned order operations had to be made along the way to prototype possible. One oversight was the that the Stabil sheets for the comer blocks was made of vertical glued slats. After cutting away the top layer the core slats became fragile and therefore had to be reinforced with wooden dowels. After the sandwich was fully assembled and the Flex plates still had to be glued in it however became already clear he the table top was not rigid enough to support even its own without bending. The prototype was however still completed and it was used as an opportunity to further examine the comer connection.



Flex table base cut in four separate corners.

Edges of the corner blocks trimmed down and strengthened with dowels.

Corners cut with plunge router and template.

Hollowing out the inside of the corners with power file.

Aluminum bar beining test fitted in the Lisocore panel.

Enns of an aluminum bar cut to fit over corner blocks.

Table top parts layed out on floor.

Blocks and Aluminum bars glued and clamped in place.

Figure 47: Prototype construction process.

4.5.3 Adjusting corners

The process of attaching the legs to the table involved some challenges and discoveries. After the Flex plates were glued in and the corners were cut, the legs would normally have to be adjusted to fit the table properly (i.e. square to the top and not twisted). However, an alternative approach was taken to examine and experiment with the procedure. The Flex plates had a subtle difference between their top and bottom sides. This was due to the laser cutting method that created a slanted edge on the plates. The direction of the slant affected how the legs would align with the table top. In addition, the Flex plates also have some room to move within the pockets that were milled out for them. Walter remarked that adding screws to the plate could help keep them in place during the glue-up. A third issue was that the holes in the Flex plates were not perfectly centered in relation to the side edges of the corners. However, there seemed to be a consistency in this deviation. The hole was often closer to one side than the other (except for one corner where both edges were off). When a thorn was attached, the edges that were further from the hole would protrude beyond the thorn. The decision was made to only file down the protruding edge until the leg would properly fit. The filing was done by hand, which made it difficult to do consistently. However, adjustments were made carefully to maintain a flat edge as much as possible.

The prototype uses the Slim Flex corners, which differ from the regular Slim as they lack the aluminum extrusion layer in the corners. This results in a gap with regular Slim legs. On the slim flex this is resolved by grinding the legs' horizontal edge to compensate for the difference. The standard Slim legs are however still used to test the horizontal edge untouched. Throughout the adjusting process, the corners were tested with various legs. After the adjustments, some misalignment between surface of the legs and the table's sides remained. With sharp edges it was easily noticeable, both visually and by feel, however additional sanding to round of the edges helped to conceal it, without changing he aesthetic of the corners too much. One thing could, however, not be resolved. To fit multiple legs on the same corner, you inevitably need loser tolerances. Although it did not impact how square the legs were to the table it did allow the legs to spin slightly along the vertical axis when attached. A solution would be to let the end user or installer orient the legs correctly, just before fully tightening the leg. In the end 6 different legs would properly fit on each corner (3 were already adjusted and finished, 2 were only trimmed and 1 was trimmed for the Slim Flex) with 4 different thorns. The adjusting process has given new insights into the deviations of the corners and strengths of the Flex plate. The observations are hover not conclusive, as the sample size was still small. It did however show that an alternative procedure could help make the legs fit universal.

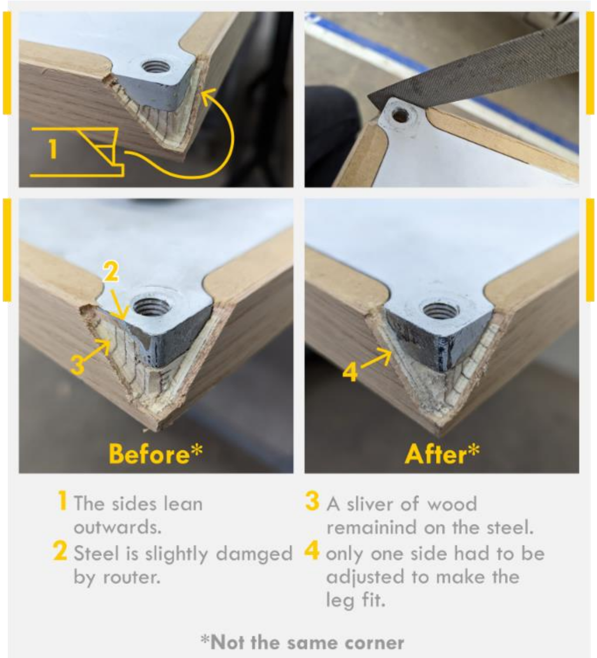


Figure 48: : Making adjustments to corner of the prototype.`

4.5.4 Prototype result

At first sight, the prototype looks successful (**Fig. 49**). The initial expectations were optimistic. However, throughout the building process, it became clear that the sandwich material was too flexible. What was not clear until taking a closer look was that even the short sides were flexible enough to bend. To test if steel bars could work as an alternative to aluminum, steel bars were clamped to the table surface. However, even then the table could still flex under load. Despite these issues, some aspects of the design still worked well. The connection between the corner blocks and the sandwich material was strong, and the veneer adhered well to the Lisocore. The resulting table was even light enough for one person to carry, although it was hard to handle due to its size.

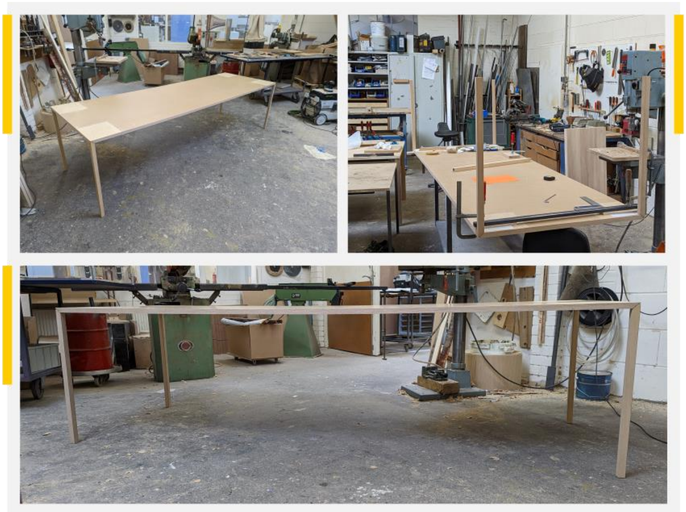


Figure 49: The resulting prototype.

As was already mentioned in the re-construction theme, there were some faulty assumptions when analyzing the current construction. This became evident after the sandwich was completed, just before gluing in the Flex plates. The main mistake was to underestimate the contribution of the Zincor in providing stiffness to the construction while the strength of the aluminum extrusion was overestimated. The Zincor added tensile strength across the surface of the table that the Lisocore was not able to match, and the aluminum extrusions did not add enough rigidity. As a result, the prototype does not meet the strength criteria for a Slim table.

There was still a surprising upside to the prototype as the building process gave new insights into the connection of the legs. The adjustments were made while checking various combinations of legs and thorns. Although the legs were not always perfectly square, they were always within the tolerances to not be visible to the naked eye. The vertical spin in the legs could be fixed by holding the legs in the right position while tightening the rods. However, that is a compromise that is up to Arco to decide on. In the end, the corners still look like they are supposed to for a slim table. The process did, however, take a looser approach to Arco's aesthetic requirements.

4.6 RE-DESIGN EVALUATION

From the prototype it became clear that the design in general was not a successful alternative to the Slim. The design process itself has however still delivered valuable information and because there is no clear final design, we need to look back at the rest of the design process to find it.

4.6.1 Exploration

As the first step of the design process was the exploration phase, which aimed to fill some gaps in the factory research. Whereas the factory research had mainly focused better understanding the process and problems, the exploration would focus more on the product and on finding solutions. The exploration was also separated in three themes, each focusing on a different aspect of the problem: Automation, Tolerance free, and Re-construction.

- The automation theme showed how various operations could be automated through an fully automated process concept. Automation will, however, never take over the process, some steps have complexity and variation better suited for manual work. The true benefit of automation is improving consistency in the productions process. however, the true benefit can only be determent by calculating the full investment cost and gains in production.
- The tolerance free theme revealed how complex the tolerances are in the corner detail and how each deviation affects the final outcome. The factory research already showed what adjustments were made, this theme helped to also understanding why they were made. The theme provided a better basis for evaluating changes in the process and developing new concepts.
- The Re-construction theme investigated what made the current construction work so well and what alternatives could be considered. New materials were discovered that could simplify the assembly. The theme generated many ideas that formed the basis of some of the concepts.

The three themes were each setup with the goal of developing separate concepts in mind. However, through their execution and the rest of the design process their purpose changed. In the end the design process has still delivered a concept for each theme. The proposed introduction of a smaller CNC is an example of a concept that used automation to improve the process. With the prototype a new process was developed to improve the tolerances by changing procedures, which is similar to the solution that was envisioned for tolerance free. And finally, although it did not work in the end, the final concept did deliver an alternative Slim table with new materials and construction, for Re-construction.

4.6.2 Concepts

Redesigning the Slim table was a challenging task, especially after being immersed in the current production process. A bias towards the exiting construction had to be overcome to explore new directions with more freedom. Some initial ideas were therefore still pursued, even if they already seemed unfeasible, to still broaden the exploration of new ideas. They would also help in better understanding the current design and production process of the table. Concept 4 was already seen as ½ a concept and was only developed as a test calculation for carbon fiber. While concept 2 was ruled out as it did not improve beyond the Flex plate. Therefore, out of the initial 3½ concepts that were further developed two remained. Concept 1 already incorporated the flex plate as addition to the premade sandwich material as the base of the table. Concept 2 showed a new type of cast aluminum corner with a different way to cut the aluminum extrusions, however the feasibility within Arco was still uncertain. Concept 1 was selected as final concept and further developed into a prototype. However, opportunities in concept 2 were therefore overlooked. The focus was on current factory setup, while new machinery, such as a small CNC for just the slim corners, could have been further explored.

4.6.3 Prototype

The prototyping process was a valuable learning experience for the design. The process has resulted in a thin lightweight table that resembled a Slim table. The connection between the Lisocore and wooden blocks was strong and fairly easy to construct. However, the Lisocore was not rigid enough at the thickness required for the Slim, even with additional support structures. The resulting table was therefore not strong enough. Nevertheless has the prototype shown that an alternative approach in preparing the corners could help make the legs fit universally. Instead of adjusting the legs to fit the corners of the table, the corners of the table were adjusted to fit different legs. This way of adjusting was also quite time-consuming and it may not be feasible with the current Slim construction. However, changes to the process and construction could help to better facilitate these type of adjustments. In the end the prototype may not have been a successful slim alternative, however, it was still a successful prototype. It revealed the limitations of the new design, while giving additional insight into the table construction and the leg and corner adjustment procedures.

4.7 DESIGN RECOMMENDATIONS

The prototype may not have been a successful alternative, However, based on the evaluation of the re-design, combined with the insights from the factory research, there are still recommendations that can be made for future development of the Slim table.

4.7.1 No final concept

During the design process there were two potential concepts, the final design was selected as it would be easier to construct within Arcos factory. By using insights from the prototype and the rest of the research to re-evaluate original concepts, three new options were formulated. These options range from least to most disruptive. Each option has been formulated with the goal to utilize existing parts wherever possible while simplifying the assembly process to minimize the operations. Where they differ is their approach in removing manual operations from the corner details. Veneer was however left out, as Arco already has the expertise and the equipment to deal with any natural inconsistency or defect that may occur in the veneer. Although the three options are largely based on ideas that have already been discussed before that have been re-evaluated, they will still require further development and testing before implementation is possible.

4.7.2 Option 1 (least disruptive)

Whenever the production process was discussed with factory workers, the cast aluminum corners would almost always come up. Workers would mention either what they preferred or disliked about the corners compared to the steel corners. Although the workers at the retouching stage disliked the cast corners, at Ocra they preferred for simplifying the assembly of the frame. Within Arco the use of the cast aluminum corners have been dismissed due to an increased amount of rejects. The main issue was the dimensional variety of the casting process. Nevertheless are the cast corners still used by a US based manufacturer as part of a licensing deal. The previous problems with the cast corners needs to be investigated and instead of inserting them in an existing production process, should the process attune to the cast corners. The cast corners should be reconsidered as a solution an improvement to the slim table (**Fig. 50**). If the past problems can be resolved the production process could greatly benefit from the cast aluminum corners.

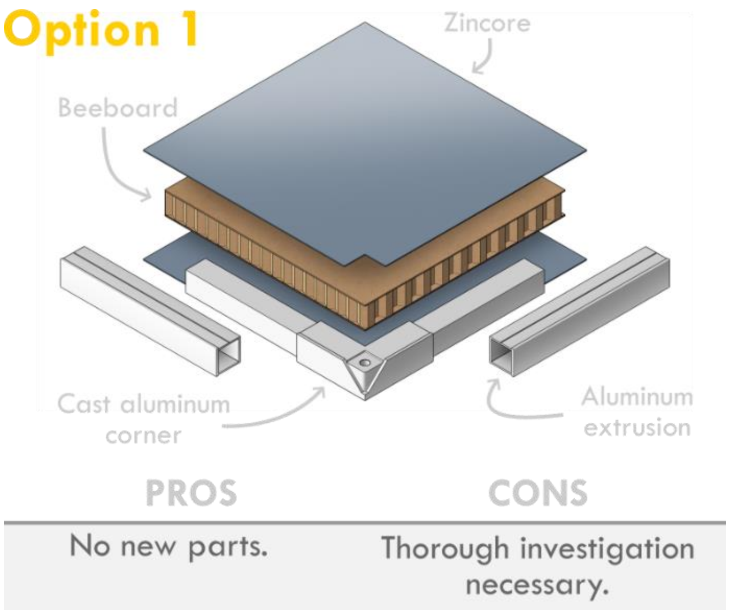
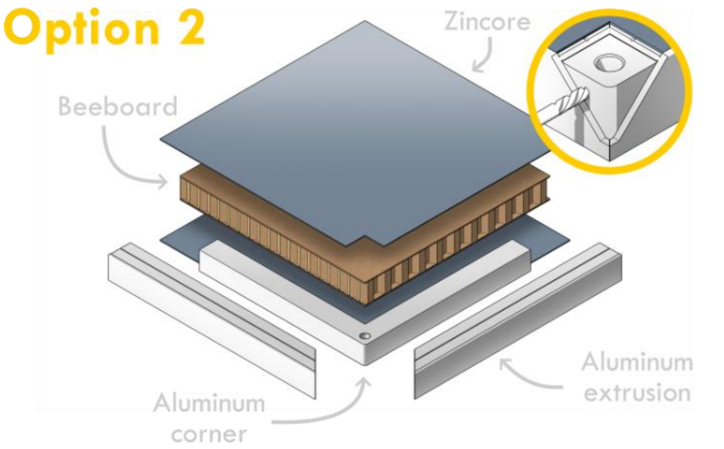


Figure 50: Design recommendation option 1.

4.7.3 Option 2 (most expensive)

Consistency and accuracy of the corner assembly could be increased by milling the corner details after the sandwich was assembled. If cast the aluminum corners shaped like the current steel corners are used, the entire corner assembly would be made of aluminum, making it relatively easy to mill. The aluminum extrusions would also only need to be miter cut as the rest of the details could be milled with the rest of the corner. To keep waste streams separated the milling could be don at Ocra. Milling the corners after the table is assembled is however challenging. The small details in the corners would require a CNC with at least a 4 degrees of freedom to achieve the sharp diagonal edges in the corner detail. The milling bit would need to travel perpendicular to the sided of the table (**Fig. 51**). Although, it would not have to fit an entire slim table, as it could cut one end of the table at a time. An investment in a new CNC milling machine would still be necessary.

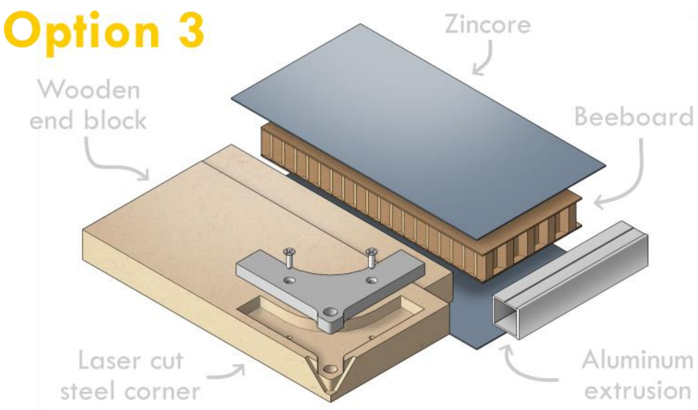


PROS	CONS
Simplifies the existing parts.	Investment in tooling and new machinery.

Figure 51: Design recommendation option 2.

4.7.4 Option 3 (most disruptive)

A hybrid of the Regular Slim and Slim Flex, similar to the prototype, would combine the strength of the Regular sandwich with the ease of assembly of the slim Flex (**Fig. 52**). Although there are no new parts introduced with this construction, it is still the most disruptive option to the current process. In the ideal order of operations the sandwich is first assembled and edge banded, to then mill the cavity for the flex plate with the corner details. This may require a small adjustment to the Flex plate to prevent the wood from chipping off in the corners. Alterations to this construction could be to precut details in the wooden panels before assembly and the aluminum extrusion could have a slot milled at the ends to fit over the wooden blocks, similar to the prototype. Although the constructions of the Regular Slim and Sim Flex have separately proven to work, the main concern with this construction is the difference in how wood expands due to environmental conditions compared to the metal.



PROS	CONS
Removes human error in details.	More disruptive and less certainty.

Figure 52: : Design recommendation option 3.

5 Discussion

5.1 RESULTS DISCUSSION

The factory research and the re-design both had their own results, and they have already been discussed in their own chapters. However, even though there was no final design, both still had useful results.

5.1.1 Factory research

The Gigamap was both part of the process as well as the main result of the factory research. It gave a detailed overview of the production process of the Slim, including: an overview of the production steps , how they relate to each other, material cost, time spend at each department, movement through the factory and the historical development of the Slim. The Gigamapping process included multiple iteration. The final version was created after the Re-design phase. Therefore, the gigamp had a better comprehension of what information was important compared to the proviso version. The Gigamapping process helped develop an understanding of the production process and the final Gigamap was consulted whenever there was uncertainty during further developed of a solution for the process.

The factory research itself did not uncover as many problems for the factory workers as was expected. However, the research may have been influenced by the main assignment from the factory to improve the product. The analysis was therefore more focused on understanding the process itself and less on how it was experienced. Nevertheless, the basis of the factory research has been laid with the Gigamap. Future research could continue from there with more focus on analyzing and improving the experience of the production process by the factory workers.

5.1.2 History of the Slim

A notable type of information in the Gigamap is the history of the Slim that was uncovered during the factory research. The Slim has been in production for over 20 years and throughout its life various changes have been made to the design and production process. However, with the original design team having been completely replaced since and incomplete documentation, the full extent of changes was unclear. The information was not lost as there were still plenty of factory workers that have been with Arco since the introduction of the Slim. The information on the history was useful during the development of new solutions. Knowing what alterations to the process have been made or tried helped to understand the possibilities and prevented repeating past mistakes.

5.1.3 Re-design

The re-design process was supposed to deliver a final design or modification to improve the Slim production process. However, the prototype showed that the final design was not a successful alternative, and there was no time left for new iterations. Instead of one solution, there are therefore three recommendations for further development. Nevertheless, the re-design process still gave valuable insight into the production process as well as into the construction of the Slim itself. By designing alternatives, previously unknown requirements were uncovered, and existing requirements were better understood.

The detailed understanding of the production process from the Gigamapping helped in envisioning what the impact would be of any change of the production process or of a new part would fit within the production process. Ideas and concepts could therefore be adjusted to the factory during te development and the final design could even be produced with little investment cost. However, this has also limited the development new ideas, as new production methods were not always considered during re-design process. There may therefore still be room for further development of the Slim design and the design recommendation can be the first starting point for a new re-design process.

5.1.4 Decisions

Changes in the production process should always be evaluated based on their effects across the production process. The Gigamap has shown how steps are interconnected, where the redlines in the diagram show how steps are affected by the procedures in other steps. The connection of the legs requires high tolerances to fit properly. Those tolerances are determined by both the mechanical and design requirements of the table. However, the design requirements are based on decisions, and re-evaluating them could help simplify the production process. This is a theme throughout the production process, where deliberate decisions in favor of one step directly or indirectly affect other steps. Arco has a high-quality standard to uphold and this sometimes means that they cannot take the most cost-effective direction.

5.1.5 Limited improvement

The Slim table has already been in production for 20 years and has been in constant development. The fact that the factory research and redesign did not result in a clear solution was in part due to the process already being difficult to improve. Even when the redesign deliberately deviated from the current design, it remained difficult to find a better alternative. This is even true for the human side of the production process as Arco has always valued its factory workers. Their approach to manufacturing is still fairly traditional, and the processes are already designed with humans in mind. Although finding significant improvement was difficult, it did make the execution of the HCD research easier. As the roles of humans in the factory are already clearly recognized by the factory. Still, there will always be room for improvement, which is true for both the production process and the research method.

5.2 METHOD DISCUSSION

Although the assignment of this thesis was to find improvement in the production process, a large part of the research revolved around the implementation human-centered design in manufacturing. What have we learned from it?

5.2.1 Human Centered Design the factory

This thesis began with the idea to analyze the production process of the Slim table by interacting with its factory workers. This idea was supported by the fact that, while previous industrial innovations have often been presented as replacements for humans, the current revolution, Industry 4.0, acknowledges the value of factory workers in the production process. Development towards Industry 5.0 is taking it even further by making humans a central value in its future industrial vision. The field of Human-Centered Design (HCD) already focuses on including the human experience in the design process and was therefore selected as the approach in this thesis.

This thesis serves as a case study for how HCD can be applied to examine a production process. The factory research and re-design process each yielded useful insights. However, they do not provide a clear answer on the effectiveness of empathic design. To find that answer, the types of data that were collected need to be evaluated and the role of the Design thinking frame, Empathic design and the Gigamap in the research need to be discussed.

5.2.2 The Design thinking Frame

Having decided to use HCD, the next step was figuring out how it could be applied in the factory environment. Luckily, Design thinking has already explored the application of design in other fields and has identified frame creation as the core practice. Therefore, to translate HCD to the factory environment, a frame was proposed in which the factory workers were seen as the user and the factory as a product. The production process could then be studied as the interaction between worker and factory. The frame opened the way for the application of HCD in the factory environment, however, selecting the right method remained complicated.

In the selection process for a HCD method, the application of each method and its tools had to be considered in the context of the factory. The company had also requested that research should not interfere with the factor's daily activities. Empathic design was therefore selected as the method for analyzing the production process, because it utilizes observational tools and fosters engagement by joining the activity in the factory, which limits disruption of the process. The frame further helped to compare the various HCD methods for the application in the factory. In the end, however, the selection mainly came down to the tools which Empathic design offered and how they would fulfill the requirements set by the company. Nevertheless can the frame still be considered a useful selection tool for HCD methods for other factories that could have different research requirements. As it did provided an initial overview of how various HCD methods could fit the factory context

Although the selection of Empathic design was mainly based on external requirements, the frame was still an important factor for further translation of the method and in developing the strategy for the factory research. It did however have one flaw. Through the frame, the production process was investigated as an interaction between users and a product. However, because Empathic design emphasizes (the experience of) an interaction, the main focus of the factory research became the production process of the Slim table. Therefore, the end result of the factory research lacked insight into the Slim table itself, i.e. the product. Although this was eventually resolved by further examination of the Slim table in the exploration phase of the Re-design process, this should be kept in mind for application in future factory research projects.

In the current application of the frame, the product that is produced is omitted from analysis by the research method. However, the optimization of a production process may also include alterations to the product. This is a result of the interpretation of the frame. This does not imply that the frame is useless however, it has more to do with the interpretation of the interaction between factory worker and the factory. Interaction could be seen as the result of users using a product to accomplish a desired goal. It is the designers' responsibility to make that interaction as pleasant as possible and not to challenge the users' motives for the intended goal. Within the frame, the goal is then the product that is being produced. However, unlike regular user interaction studies where the goal is defined by the user, the product that is produced is defined by the company, which is outside of the frame. Therefore, evaluating the product (as the goal) would not conflict with the factory workers' motives (as users) and the product could and should be included in the analysis. Future research should therefore also incorporate methods to assess the product that is produced. This could be done by using the same method or by including additional research methods specific to the product.

5.2.3 Empathic design research

The Empathic design method offers a way for designers to learn more about product experience directly from its users. Within the factory research, it offered a way to learn directly from the factory workers. For guidance in the application of Empathic design, the method offers a framework consisting of four steps: Discovery, Immersion, Connection and Detachment. There are various tools from empathic design for each step in the framework. Throughout the factory research information was gathered on the individual steps of the production process and the relationships between them, to create an overview of the production process. The Empathic design tools resulted in qualitative data directly from the factory workers, while quantitative data, such as costs, was gathered from existing documentation. Some data may not have required an empathic approach to be uncovered. However, the difference that the Empathic design method made was that it included the factory workers’ perspective. This added value to information, such as on the procedures, based on how it was experienced by the factory workers

There was one particular type of information that was uncovered through the engagement with the factory workers. Before the research began, the history of the Slim table was only partially known. However, the experience of each factory worker has given them detailed knowledge of their activities in the factory, especially for those that have been working within the factory for more than a decade. The knowledge on the Slim’s history was therefore still present. It is however distributed among the factory workers. By engaging with the factory workers, the full story could be uncovered, with each conversation adding more detail of the story. Uncovering the history of the Slim table then helped understand the past developments in the construction. However, for other products, uncovering its history may not be as relevant. It did however show that the factory workers can have valuable knowledge from both the current and past experiences. Wich can be uncovered through closely engaging with the factory workers, via HCD or otherwise.

The purpose of empathic design is to establish an empathic connection with users, which in the case of this thesis, are the factory workers. At first the information and experiences gathered during the Immersion in the production process was thought to have been enough to form an empathic connection with the factory workers. However, after building the prototype it became clear that this was not the case, as it was the prototyping that eventually established the connection. When building the prototype, I was focused on the end result of the process, instead of on analyzing the individual steps in the process. It helped understand the struggles of the production process, as they were now in the way of my goal and not part of my goal. Only after I was truly invested in having the best end result did I understand what it was like to work on the product, because my goals at that time aligned with those of the factory workers.

The prototyping experience may suggest that a true empathic connection can only be achieved when the designer or researcher are truly invested in reaching the same goal as the factory worker. This research was limited to how much could be done in the factory, both in time and in the operations that could be performed. Not spending enough time with the users was already described as a pitfall for design research in the literature. However, understanding the production process of a factory does not require as much time as an interaction study, because multiple cycles of the production process can happen in a short amount of time. The extra time should however be spent on joining factory workers also after the production process has become clear, to align the goals with the factory workers. Preferably, a researcher should be involved with the production of a single product from start te finish to enhance the attachment to the process.

5.2.4 The Re-design process

The assignment for this thesis was to analyze the production process for improvements. As a result, the research leaned more toward finding technical solutions for the product and process. This was especially true for the redesign process that focused more on solving the technical problems that were uncovered in the factory research. This could still be considered in line with the fourth step of Empathic design method, detachment. Even though the redesign process may not have employed HCD methods, the data that informed the redesign was still collected through empathic methods. It is therefore debatable whether the design process itself needs to be empathic as well

The factory research did not uncover as many direct improvement opportunities for the factory workers as hoped. This was in part due to the technical focus for the assignment. However, understanding their experiences did help to make sure that any proposed changes would not negatively affect their experience either. Nevertheless, the human value in the production process was not always as well included as it could have been. If there was more emphasis on the experience in the factory research, the redesign could also have focused more on improving the experience for the factory workers.

5.2.5 Gigamapping

The factory research involved multiple visits that generated rich and detailed data, which required processing before the next visit. However, the relevance of the data for the analysis of the production process was often not immediately evident. The Gigamap was therefore helpful in this process as it allowed for rough integration of data before focusing on order an readability. The Gigamap could accommodate every little detail, and through iterations the data became more structured. Through the Gigamapping process the data was analyzed and connected to each other. At the end the most important data could be identified based on their position and connections in the Gigamap.

Using the gigamp in the research process allowed for fast processing of the data. However, the empathic design research data was not as well documented as it could have been. The purpose of a Gigamap is to make sense of complex situations by combining different types of often pre-existing data. By integrating Gigamapping in the research process, it essentially skipped the step of organizing the collected data and proceeded directly to the analysis of the data. The ordering occurred later in the Gigamapping process. However, by then all the data had already been combined. Making it difficult to track the sources of some data. Although this did not detract from the quality of the resulting Gigamap, it does make repeatability from an academic perspective more difficult.

The Gigamap is a flexible tool that can be adapted to different purposes and contexts. In this thesis the Gigamap was developed into a technical representation of the production process, reflecting the initial goal to find improvements in the production process. However, this made it difficult to also capture the subjective experience of the factory workers in the Gigamap. Nonetheless, was empathic data still part of the research results and the subsequent re-design process. Because, as the researcher the data in the gigamp still had an underlying unwritten empathic meaning. To better convey the empathic aspects of the research in the future requires a different Gigamap design. One of the examples in the literature review (Caring for Caregivers) showed that subjective information can be included in to a Gigamap. To properly include the subjective empathic data in the Gigamap, it needs to be part of the research goal and the Gigamapping process from the beginning.

6 Conclusion

6.1 RESEARCH CONCLUSION

This thesis was based on the idea that factory workers should be involved when improving a production process, as they are the main practitioners of the production process and therefore the most experienced. The research demonstrated that designers and researchers can learn from the factory workers through existing human-centered design methods. Given the increased emphasis on the human aspect in manufacturing, HCD as a research method for production processes should be regarded as a valuable practice.

The main question that guided the research was:
"How can a human centered design approach help improve craftmanship driven production processes?".

A review of the literature on industrial development has shown why this question is relevant in the first place. Although past developments may have reduced the involvement of humans in the factory, more recent developments have started to acknowledge the value of humans within a factory. Through the creation of a design thinking frame, the factory workers and the factory itself were considered as users and product, respectively and Empathic design was selected as a HCD method to analyze the production process as if it were an interaction. Empathic design tools enabled direct learning from the factory workers, who shared their expertise and experiences. The visits to the factory also revealed the distributed knowledge amongst the factory workers on historic development of the slim table. Altogether, this resulted in a comprehensive overview of the production process. The re-design process for the Slim table that followed was informed by the insights gained from the factory research. The empathic insights helped to envision how any of the concepts would be produced in the factory and what it would be like for the factory workers actually produce them. The generated concepts therefore that matched the current capabilities of the factory and the factory workers. The final design also reused existing parts from the factory, which reduced uncertainty on the feasibility and it meant that factory workers would already be familiar with the components. Wich limited the impact on the factory and reduced the investment cost required for implementation.

An additional finding that was not anticipated for, was the benefits of using Gigamapping. What was originally selected as a tool to visually document research findings turned out to be an excellent combination with empathic design. Interaction studies, such as empathic design, result in rich and detailed data from the studied users. Combing through the data to find what is important is always difficult. However, the Gigamapping processes helped to structure the data and determine its importance through the connections that were made within the data.

The literature has shown that humans will continue to play an important role in the future of manufacturing, especially for craftmanship driven production processes, where it is the human interventions within the process is that makes products show craftsmanship. The results of the factory research confirmed that Human-centered design can be applied in the manufacturing process for optimization, by framing the manufacturing process as an interaction between user and product. The results of the Human-centered design research also aided the design process by providing information directly from the factory and its workforce, which allowed for the development of solution that were tailored to the factory and factory workers.

6.2 RESEARCH RECOMENDATIONS

This research has demonstrated how Empathic Design can be applied to analyze a production process. However, it only explored the potential of Human-centered design for manufacturing. HCD was suggested as a possible way to engage factory workers in the development of the manufacturing processes, similar to how users are increasingly involved in the optimization of product interactions. Future research in process optimization should also use HCD to include the Factory workers in the process. This Thesis chose Empathic design as its main research method. However, other HCD methods might be more suitable depending on the factory settings and the research objectives. The Design thinking framework that was proposed in this thesis should help in adapting HCD methods to a factory context. However, the application of the framework will need further refinement to also consider the product/goal in the analysis of production process.

This thesis also used Gigamapping in combination with the empathic approach to the production process. The main advantage of the Gigamap was its ability to handle complex data. The Gigamap should therefore be regarded as a useful tool in Empathic design, as well as for other HCD methods. The literature review already includes a Gigamap example where people's personal experiences are recorded. The Gigamapping will help interaction studies place rich and detailed subjective data from interaction studies in a larger context and link it to other objective data.

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8 Appendices

A LARGE SIZE GIGAMAPS

A.1. Paper Gigamap

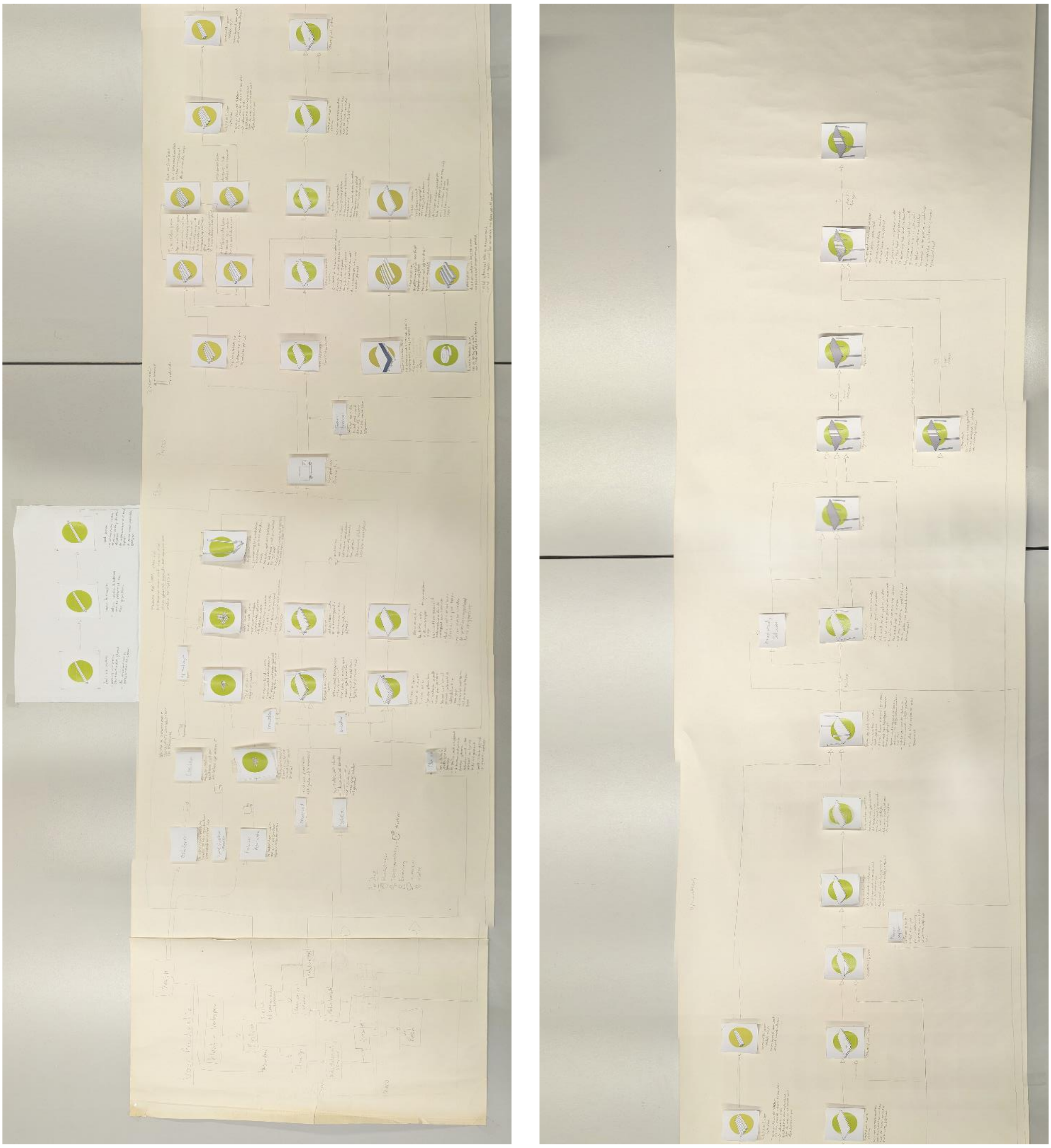


Figure A: Large image of Paper Gigamap in two parts.

A.2. Gigamap v1

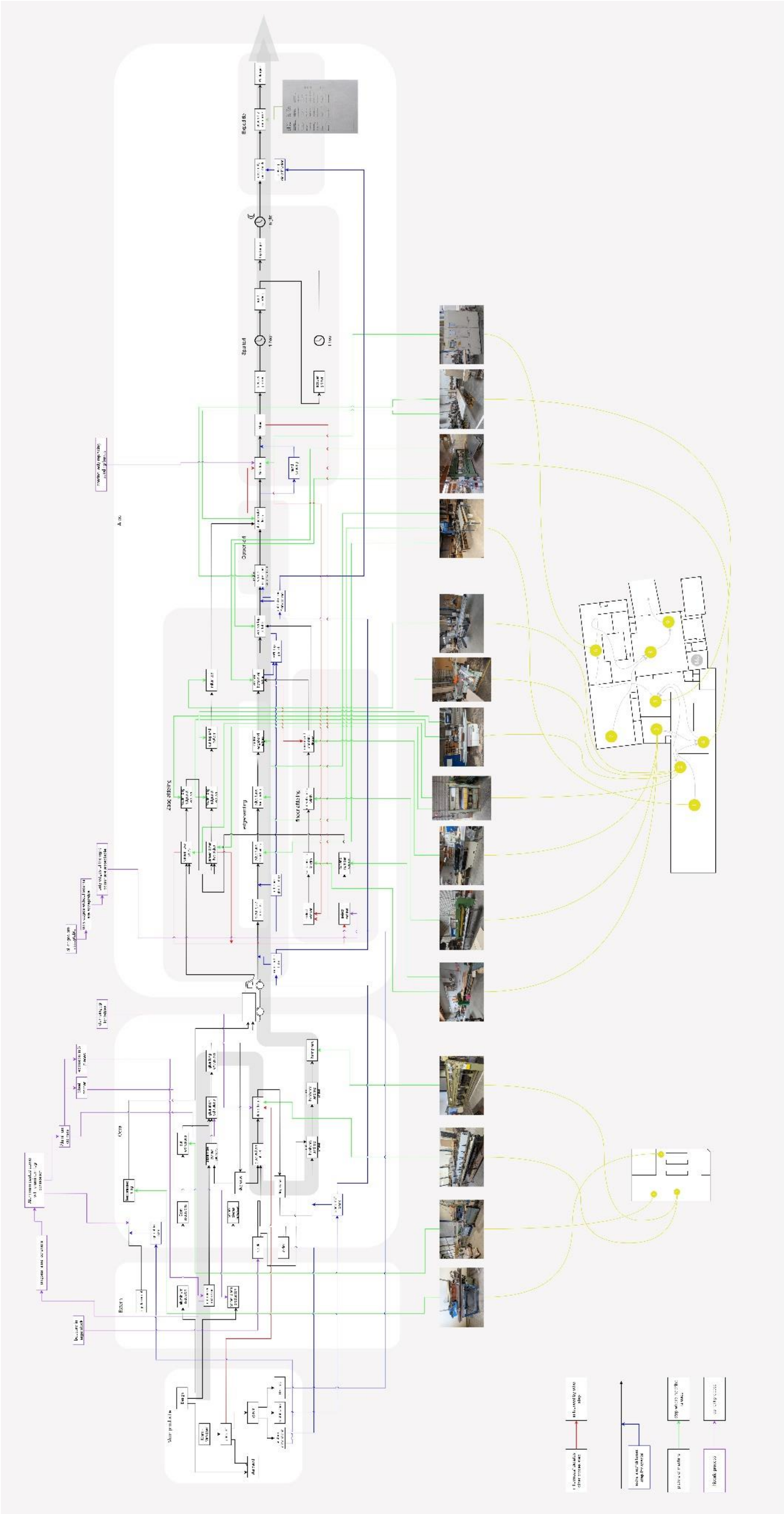


Figure B: Large image of Gigamap v1

A.3. Gigamap v2

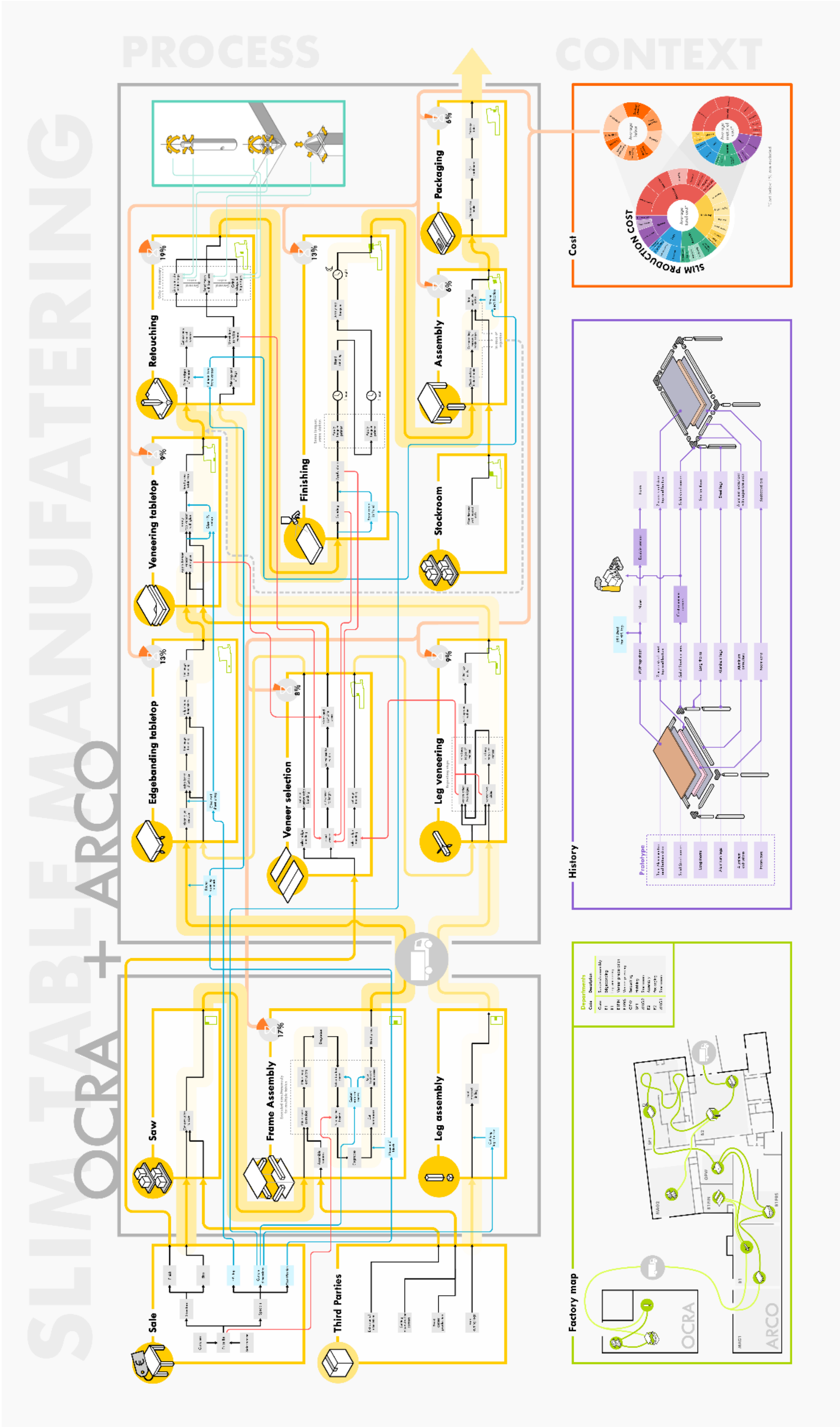


Figure C: Large image of Gigamap v2.

B DATA FROM BILL OF MATERIALS

(only in printed version)

The data from Bill of materials of four Slim tables (The Regular Slim in 160x90cm and 80x90cm, the Slim Plus in 240x105cm and 360x105cm, all with 75cm legs) was combined and restructured to be clearer to understand for analyzing the cost and labor. Only included in printed version.

C ROOT CAUSE ANALYSIS

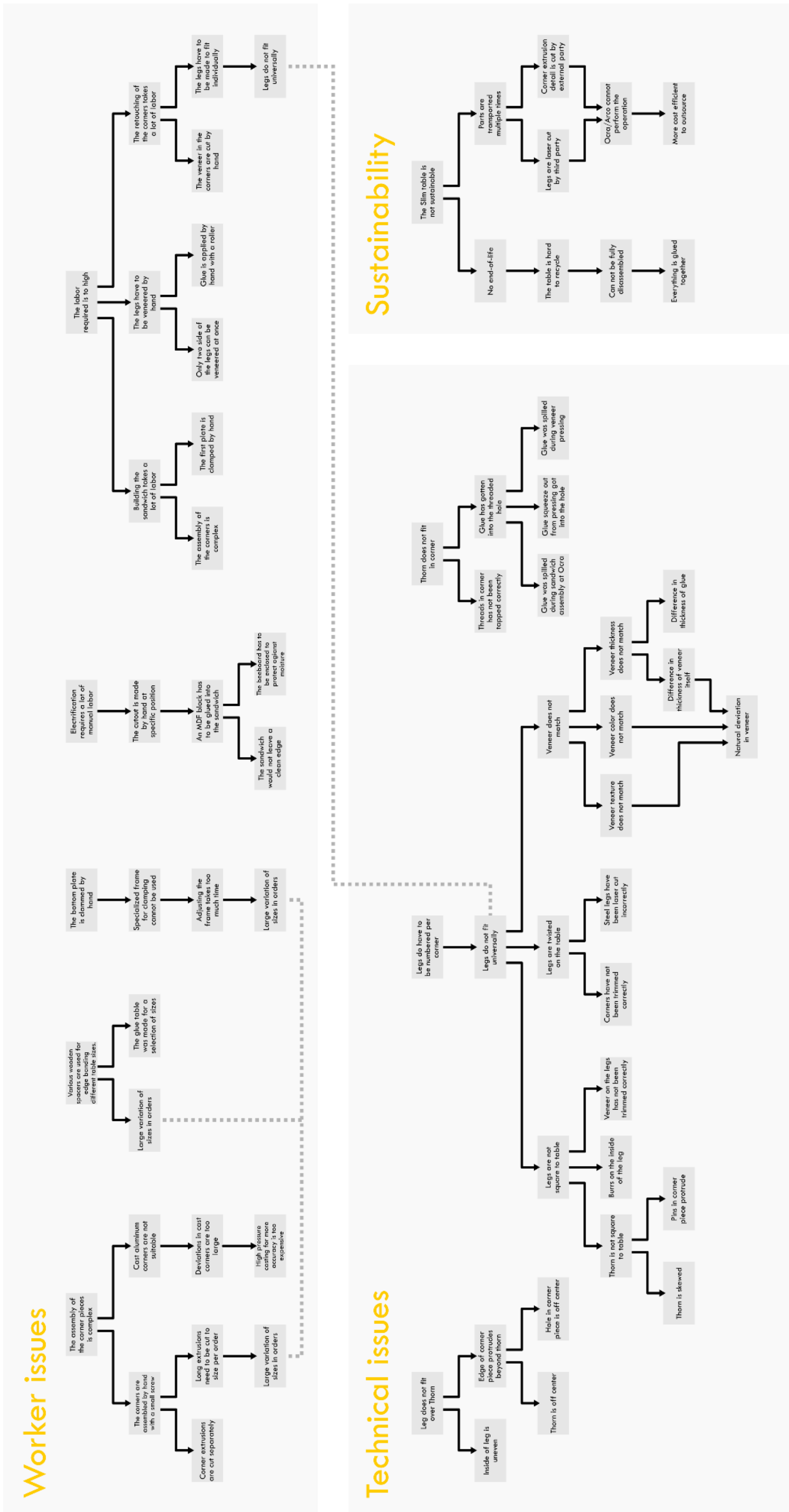


Figure D: Large version of the root cause analysis tree diagrams.

D STAKEHOLDER DISCUSSIONS

Various stakeholders in the factory process were approached to discuss the possibilities for changes in the process. Stakeholders included the two foremen from the factory floor, the head of purchasing, the head of product development and the financial director. Additionally, the discussion with the stakeholders helped to verify if the understanding of the production process was correct and if parts were missing. Below are all discussions summarized. Statements are heavily paraphrased, the stakeholder can therefore not be held responsible for the statements.

BERNIE 20-4-2022

(Former) Purchasing manager

Bernie had worked for several years at Arco and was about to retire. As he already worked at arco when the Slim was introduced could share some insight on the development throughout the years. For instance the frame of the sandwich used to be partially produced externally and the beeboard and the top zincore sheet was glued in at Arco. He was also closely involved in the development of cast the cast aluminum corners. The aluminum corners costed less than their steel counterparts (He said that the steel corners used to cost €28 a piece while the aluminum corners only costed €8 a piece, later however, that latter costed €10). Although the first series of aluminum corners was not as good as they would have liked, the second series was already a lot better. After about 10 years, however, they reverted back to the steel corners. Surprisingly het told that as part of a licensing deal, the slim tables are also produced in the USA, where they still regularly order the aluminum corners from Arco.

Bernie also noted that outsourcing is often difficult for Arco. As the quantities for Arco are often relatively low for industry standards, while the quality requirements are fairly high. This makes the cost per part to

HAYCO 20-4-2022

Foreman, overseeing: finishing, assembly and packaging

When discussing the production process with Hayco het pointed out that he did not understand why the retouching department kept using a hammer to straighten the thorn when fitting the legs. While at that stage they would tighten the thorn as far as possible, it was not given that during the test assembly or by the customer the thorn would be tightened as far. Therefore, hitting it with a hammer would not help, because when the thorn is a few degrees les tightened the correction also a few degrees of he explained. He wouldn't want to go back to the aluminum corners either, they would to often give problems with the fitting, it was often to loose. And even if the legs would fit universal you would still need to match each leg to the veneer on the table. There is just naturally a lot of variation in veneer color and pattern. He did admit that the process would be easier is the fitting was at least universal. There is almost never complete rejection, the table can always be saved, the most common point of failure is difference between edge banding on the table and the legs. In those cases new legs have to be fitted. Lastly when it came to the End-of-life he did not see any problem with how things are now. The tables are so durably that they should last the owners a lifetime.

NICK 21-4-2022

Foreman, overseeing: machine shop, veneer preparation and retouching

Nick oversees the largest part of the slim production, there was therefore a lot to discuss. We went through the production process and discussed where thought that there was room for improvement. He confirmed the statement by Hayco that universal fitting legs will still differ in color. Differences in the veneer are already present in the material when it arrives at the factory. Numbering the legs may also not be necessary, however for quality assurance it is important to know what leg was fitted to what corner. They are always working on improving the process, if there was anything to gain it would be around the corners. Still, he was skeptical about improving corner pieces. Traditionally you would contour mill the whole table and then drill the mounting holes later to accurately place them at the corners. With the slim table that is not possible. It would help if you could drill or tap the holes after veneering, however that is also difficult with the current construction. There is still a lot of inaccuracy in the process, such as variation the corner pieces, how much force is used to tighten the thorns, how accurately is the thorn is produced or the position of the leg in relation to the table. Especially last one he would like see improved.

When it comes to the veneering process he sees little room for improvement. Deviations in the veneer are not the problem, that is simply part of the production of furniture. There has already been years research into what the ideal veneering process is, even before the Slim. And the veneer preparation is simply necessary to achieve Arco's required quality. Whit edge banding there is also little to gain time, as the glue has a certain set time. The current procedures take this in to account and use the time for other tasks, such trimming the previous table and preparing the next. The procedure for edge banding different sizes were also discussed, as they use various wooden blocks for clamping different tables. He answered that you won't gain hours with improving that stage. The majority of tables are still standard sizes, so those blocks are not switched that often. Additionally, manual clamping is almost necessary to correct the edge banding if it starts shifting. Even pressure is also important for proper glue adhesion.

Nick would prefer it if the sandwiches were already cleaned and the electrification was cut also at Ocra. Those are two things that take up a lot of time at Arco and that there is no dedicated space for the cutting the electrification cavity. Something that may be possible at Ocra. Nick also emphasized, and it may be the most important conclusion from the discussion, that whatever the solution may be, it would be hard to find any support within the factory if it would take longer to do than current procedures.

OCRA (excluded)

One stakeholder discussion that is missing is that of Ocra's foreman. The previous foremen had recently stopped and the current one had only just started. The foremen could therefore not help beyond what the factory workers at Ocra had already told me.

GERBEN 21-4-2022

Head of product development

Gerben is also my supervisor and was therefore already well informed on the research. There weren't as many questions as for other stakeholder as the subject had already extensively been discussed. However in this discussion it was about his views and insight as head of product development. His overall thought on the current stat of the Slim production process is that it requires too much manual labor. Although Gerben is generally less satisfied with the current efficiency of the factory, within the factory they are fairly satisfied with their current efficiency. Probably because they only focuses on how they can perform the current procedures as affective as possible. He stated that the factory workers are often overly focused on their current way of working and tend to resist any changes. With every adjustment process there is always a distorted picture of what the situation was beforehand. The previous complaints are then often forgotten and only that what was nicer is discussed.

JAN + GERBEN 26-4-2022

Financial director *Head of product development*

With the factory research concluded, the continuation of the assignment had to be discussed to determine what direction for the assignment would benefit Arco the most (plan A or B from the approach). A meeting was therefore scheduled with the Financial director and Head of product development. The meeting started off with a presentation including the insights from the Gigamap, the cost analysis, and the first ideas for improving the slim production and ideas for an extendable slim. The impression was that Jan would like to see an extendable slim table included in across portfolio, while Gerben was more focused on the improving the current production process. However the discussion concluded that there was more to gain and less uncertainty in process optimization compared to developing a new extendable Slim table. We were not yet able to identify a final solution for improving the production process, as there were still some gabs in the knowledge surrounding the Slim and its production process. An idea was therefore discussed to take a different approach to improving the process and to fill the gabs. Three subjects where identified that would require further investigation: automation, tolerance reduction, reconstruction (these would later become the 3 themes in the exploration). Automations would address the reduction of labor by focusing on of the process. Tolerance reduction would address the accuracy by focusing on the deviations. While reconstruction of the table would investigate how changes in the design of the table could better accommodate improvements in automation or accuracy.

There were a few details of the production process that stood out in the discussion. Such as decreasing the cost of the edge banding of the legs by focusing on automation or other ways to improve the current process. the impression was that the cost and time of the process were relative high compared to the rest of the process. A different topic were the cast aluminum corner. The factory research shows that current problems could be solved by the cast corners, however from within the factory the cast corners were deemed unsuccessful. While an USA based manufacturer that produces Slim tables overseas as part of a licensing deal still uses the cast aluminum corners. The consideration was made to plan a meeting with the factory to discuss their experience with the slim table and determine how they handle the cast aluminum corners. However, in doing so there was a risk of making the impressions that we question their abilities. As Arco was happy with the current relation with the US manufacturer they decided to not contact them as to not cause any trouble.

CARLO 12-7-2022

Former Head of product development

An unexpected conversation happened when an the former head of product development was present in the factory. Although retired from his work at Arco, he regularly helped with factory tour for important clients. What was a chance encounter ended up being quit an informative conversation. Carlo was involved with the Slim table from start. Although research and conversations with various workers that have been around since the first Slim tables gave an idea of the history, It was talking with Carlo that brought everything together into a coherent story.

E SIMPLIFIED GIGAMAP

In exploring the three theme we need to look back at the construction process and make notes about the process. A simplified production process diagram was made to keep and overview of those notes (**Fig. E**). If we would directly write them in to the Gigamap the information would become overshadowed by the other data. The simplified diagram only includes the main process departments. This has simplified both the exploration of the process as well as the documentation of that exploration. It has to be noted however, that the diagram is not a full replacement of the main Gigamap. The simplified diagram and the main Gigamap were used side by side, with the simplified diagram denoting what part of the Gigamap is being discussed. You are therefore encouraged to look back at the Gigamap for further details.

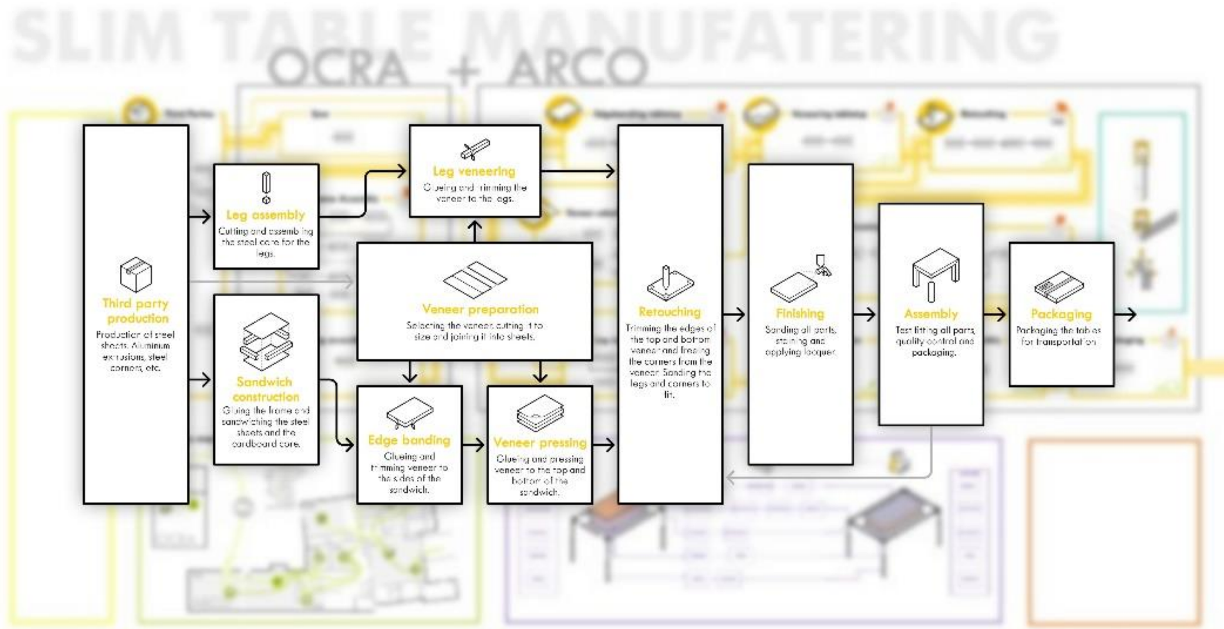


Figure E: Simplified Gigamap for adding annotations to the process.

F THEME 1: AUTOMATED

The production process takes a lot of manual labor. However, what if we could completely eliminate all labor from the process and automate everything. How would the production process look?

F.1. Designing automation

This theme focusses on fully automating the production process. At first sight, automation may seem to go against the human centered goals of this research. However, the developments of industry 4.0 (chapter x) showed that increased use of technology can and should complement factory workers. Any implementation of automation in the future will likely still involve manual operations. Developing a fully specified automated production process would be inefficient, as it is already clear that some if not most of the automation that will be developed in this stage will be discarded. A more open designerly approach is therefore taken to explore new automations first. Where, Instead of using specification of machines to determine operations, photos and videos are used to inspire new ways of production. A fully automated production process will still be conceptualized to break free from preconceptions and limitations in the current process. However, at the end of this theme the concept is evaluated to determine what automations would be beneficial for the production process.

F.2. Could be automated

The first step in automating a manual process, will be to consider what aspects of the process can actually be automated. In doing so it is important to focus on the goals of each procedure rather than the steps, as the manual process may have a different order of operation than an automated one. The Gigamap is a useful tool in this case to provide an overview of the goals and the roles of different departments in the process. Ideally we would make notes on top of the Gigamap, however to keep the exploration clear and focused a simplified Gigamap is used to add notes to the process.

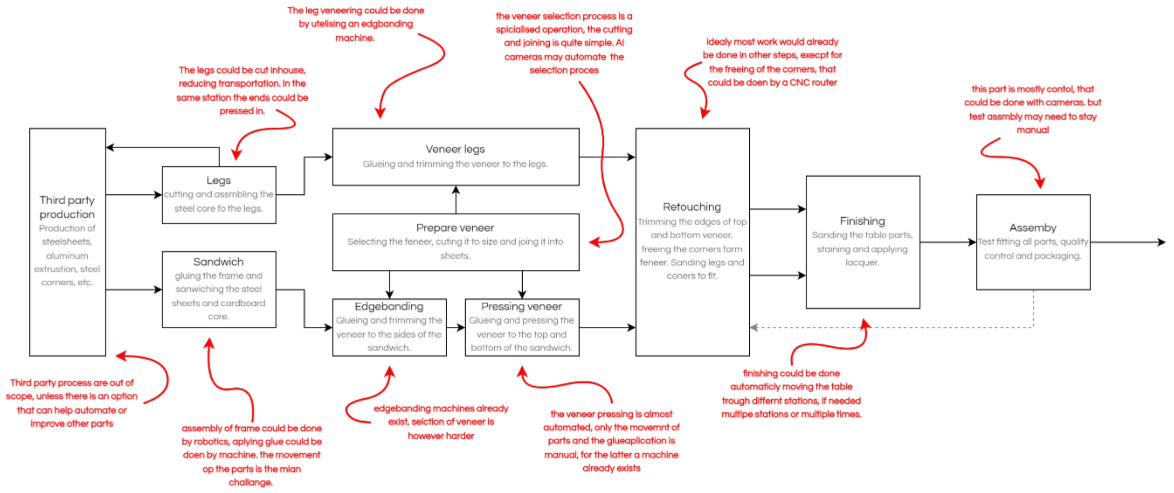


Figure F: The simplified Gigamap with annotations on what could be automated in the process.

When assessing the different departments for automations the annotations (**Fig. G**) only focus on one half of the process. Because, what happens in the factory can be divided in to two types of activities, 'Modification', which involves manipulating materials, while 'transportation' involves moving materials around the factory. However, the feasibility of an automated transportation system depends on the available space and production setup in the factory. There are, however, too many variables to already for designing a transport system, the automation will therefore only focus on the 'modification' activities of the process. The annotations have focused on the goals of each step to identify what part of the process could be automated. While new techniques are required to automate some processes, others are already mostly automated except for material handling.

F.3. Inspiration

For the automation of the production process, various manufacturing techniques were considered. These techniques could be grouped into two categories: 'traditional manufacturing', which involves methods that are derived from older manual practices, and 'modern manufacturing', which includes newer and more advanced methods, even if some of them have been in use for several years. Below are several examples for each category that were considered for the automation.

- <u>Traditional manufacturing:</u>
  Casting, machining, welding, glueing, Bending, etc.
- <u>Modern manufacturing:</u>
  3D printing, laser cutting, CNC milling, robotics, AI/Machine Learning, etc.

The traditional and modern manufacturing techniques form the basis for assessing and redesigning the process. With these techniques in mind, online research was conducted for implementations related to the production process of the Slim table. Visual materials such as photos and video were gathered and their addition to the automation is described in (**Fig. H**). Examples of use cases served as main inspiration for automating the production process by showing practical examples of how the techniques could be implemented.

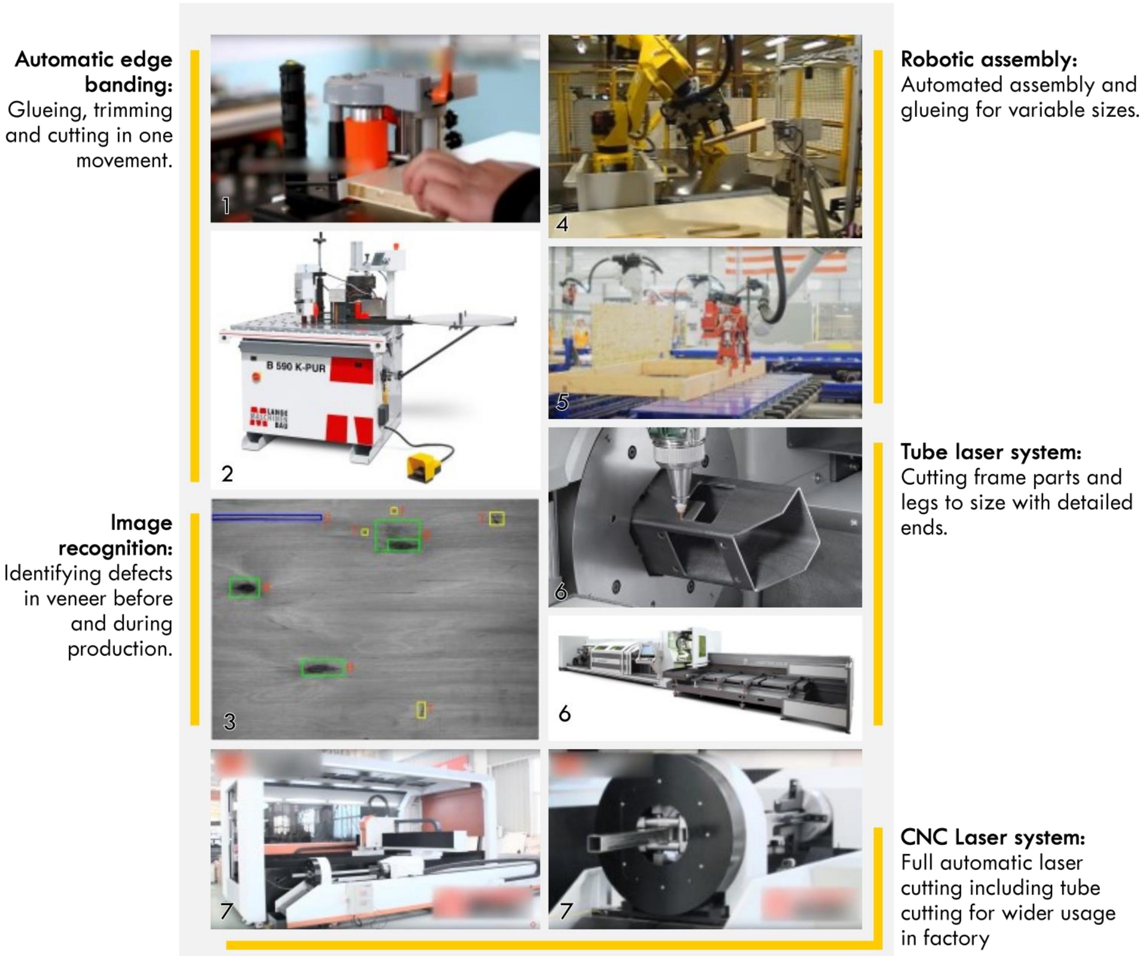


Figure G: Images and screenshots of videos that served as inspiration for the automated process concept.

1. (Osetmac woodworking machine, 2020); 2. (lange maschinenbau GmbH & Co. KG, n.d.); 3. (Urbonas et al., 2019); 4. (JR Automation, 2021); 5. (House of Design Robotics, 2021); 6. (BLM Group, n.d.); 7. (Golden Laser, 2017)

F.4. Expo

The Techni show, an expo for manufacturing technologies that took place at the end of August, provided additional inspiration for the exploration. The expo showcased many examples and demonstrations of metal working and smaller products (**Fig. I**), which gave an idea of the size and capabilities of various machines. Even though, the lineup of companies were mainly focused toward metal working and smaller plastic or electronics products, the experience still helped to contextualize the existing findings and to get a feeling for scale. There weren’t many specific examples at the expo that could contribute directly to the Slim process, some did inspire new ideas.

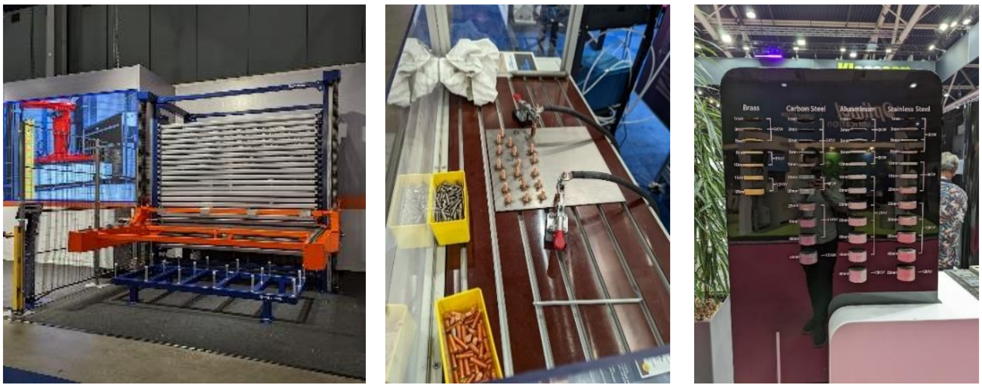


Figure H: Three examples from the TechniShow, (left) a storage picker for sheet material, (middle) Spot welding threaded ends and (right) laser cut samples of several metals at different at thicknesses.

F.5. Automated production concept

A fully automated production process was conceptualized as a sketch (**Fig. J**). Visualization of the process helped to fully develop the automated process. Sketching each station helped keep track of what steps were already conceptualized and in what order they would follow, without going into too much detail. Although the sketches of each step are simple, together they form a representation of what a fully automated Slim production could look like. Which is sufficient as the concept mainly exists to identify what technology each step could benefit from.

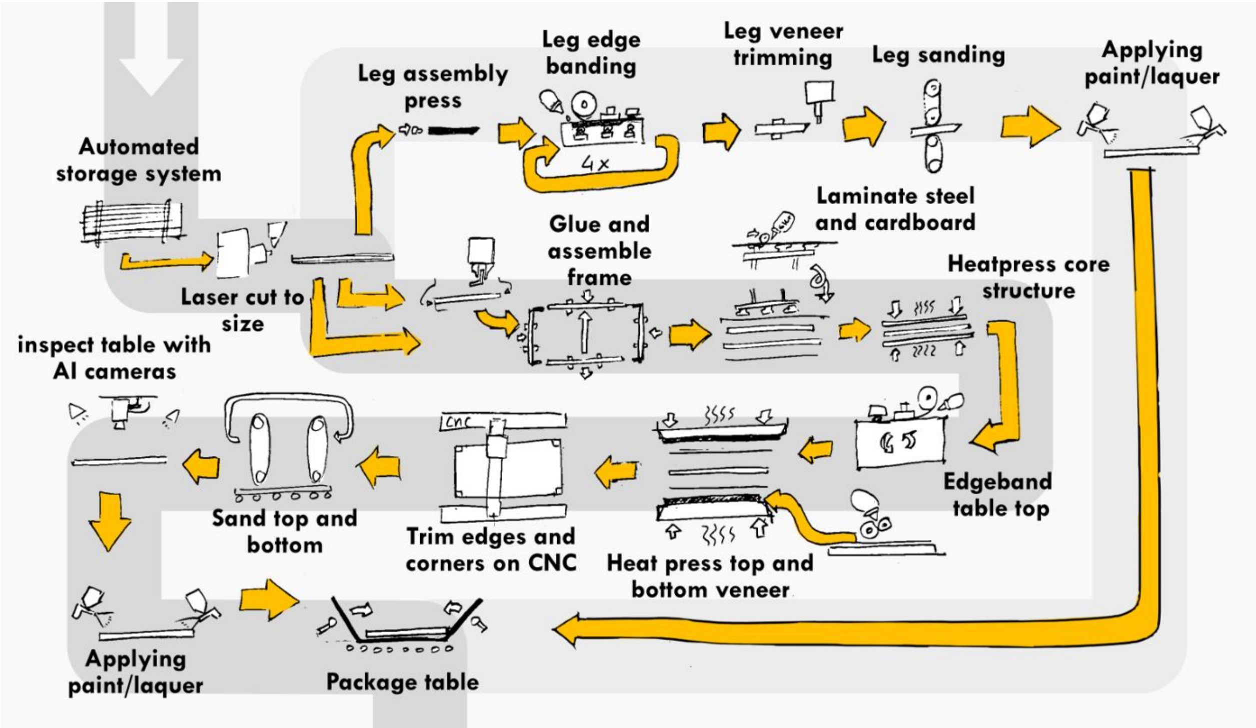


Figure I: Concept of a fully automated Slim production process.

The process is divided in stations for different steps in the process. Once again the process splits into two, with one branch focusing on the tabletop and the other on the legs. The yellow arrows between each station represent 'transportation' through the factory from one station to the next. At the start, aluminum and steel parts are automatically cut to length for each order, including the corner details. The frame is assembled by a robotic arm and adjustable clamping table. To complete the sandwich, glue is applied on each layer and they are heat pressed together. Legs are veneered by going four times through an edge banding machine. While the table goes through a similar machine for edge banding by using a turn table. Glue is applied on veneer sheets using rollers and they are stacked with the sandwich in a heat press. Before sanding both the ends of the legs and the edged and corners of the tabletop are trimmed by a CNC mills. before finishing with lacquer or paint, a camera setup with image recognition is used to check te tables surface quality. If everything in the process in tightly controlled the legs and the tabletop should always fit and only come together at the last step for packaging.

F.6. Should be automated

Developing a fully automated production concept was a creative exercise to find solutions without being bound by the restrictions. It is, however, not a realistic scenario. A consideration should be made for each stage in the production process for what should and should not be automated. Arco does not only produce the Slim tables, some parts of the production are universal for all tables. Several departments therefore need to be able to handle tables of varying sizes and shapes. These departments include: veneer pressing, sanding, finishing, and assembly/control. It is not unexpected that some parts are better left to manual labor. Flexibility was already identified as one of the main advantages of manual labor (see chapter 2.1.5). The balance between manual labor for automation therefore has to be considered in service of flexibility and quality.

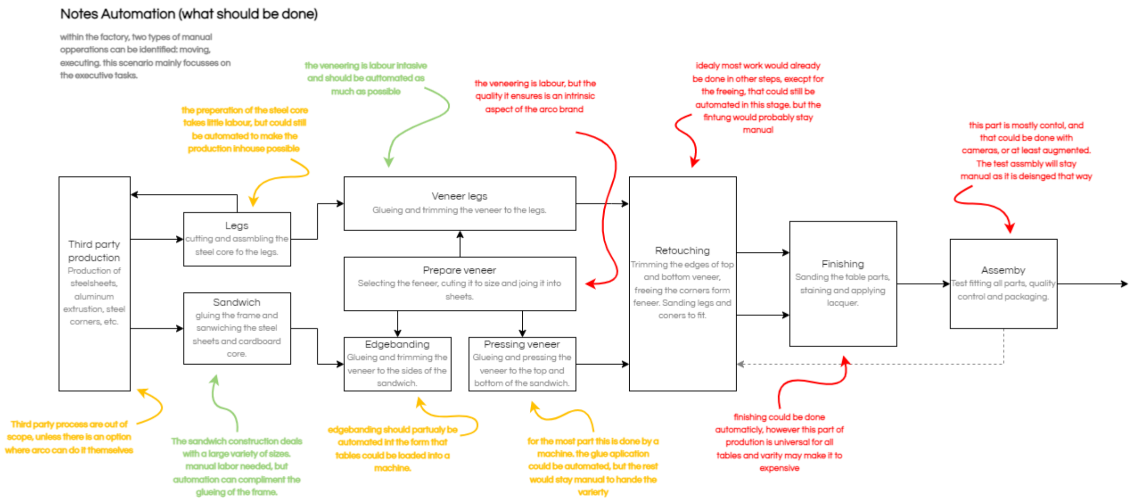


Figure J: Simplified process diagram with annotations on automation (green should be automated, yellow would benefit from partial automation, red should not be automated).

Once aging the simplified process diagram was used, however this time to consider what should be automated instead what could be automated. Annotations (**Fig. K**) came in three varieties: green should be automated, yellow would benefit from partial automation, red should not be automated. The main findings were as follows:

- Movement of materials: keeping this manual is recommended, as it allows for more flexibility and control over the materials. Automation would also require a complex and costly conveyor system that might not be compatible with all types of tables. Although this was explicitly excluded from the automation design process it was still clear based on the concept and current factory layout.
- Sandwich assembly: Automation could increase the efficiency and consistency of the assembly process. The sandwich assembly consist of multiple steps and not all steps may benefit equally. The manual process could also be aided by automation, for example by using a automatically adjusting clamping system.
- Leg veneering: The legs are veneered by using the edge banding strips and automated systems do exist for edge banding. For the Slim legs, however, wood directly applied on top of metal. This requires a different type of glue as the standard machines and it is unknown if this is possible on existing machines. If it were possible the retouching stage would also benefit from it, as it could increase consistency.
- Veneer selection: We recommend keeping this department manual, as it is a crucial part of showing craftsmanship and quality. Automation would not be able to offer the quality control necessary.
- Retouching: This stage in inherently a manual process as its purpose to fix defects. This stage would therefore benefits the most from automaton when the consistency in other steps is increased

instead. However, part of retouching is also to clears the corners. This step would benefit the most from automation and could instead be separated from retouching.

- Finishing: This process is almost universal for all Arco's tables, automation would require a uniform and standardized machine that might not be able to handle different colors and finishes for each table.
- Assembly/control: The Slim table is not shipped fully assembled, instead it is hassled when it arrives on location. The assembly is designed as a manual process and should therefore also by checked manually. Additional assembly, such as electrification, is too incidental to justify automation.

Just as the steps that have already been discussed, the automation of the remaining parts of the process depends on the consideration of cost and efficiency. The execution of automations depends on the investment costs of machines in comparison to the current labor costs and increase of efficiency.

F.7. Conclusion on automation

The Slim table requires a lot of manual labor in its production process. Although this is applicable across the production process, a large contributor is the retouching stage. There each leg has to be fitted to a specific corner of the table. which means that the legs of the table are not interchangeable. Automation could reduce manual labor in the production process by increasing the consistency and efficiency. However, manual labor also has some advantages, such as showing craftsmanship and giving flexibility needed for producing the variety of tables.

Automation does not have to mean full elimination of human labor. On the contrary, developing a hybrid system by aiding the manual labor with automation is better and probably cheaper. Keeping most of the production process of the slim table manual is recommended, as it shows craftsmanship, which are important values for the product, and offers flexibility, which is necessary due to the variety of sizes. However, certain parts of the process would benefit from partial automation to improve the efficiency and consistency of the production process. The parts that would benefit the most from automations are those that are exclusive for the Slim table. By finding a balance between manual labor and automation, the production process of the slim table can become more efficient.

G THEME 2: TOLERANCE FREE

From the factory research it was already clear what the procedures were to make all the parts of the table fit together. However, what we need to know as well is why exactly those steps are taken.

G.1. Investigating tolerances

The Slim table is a product that requires high precision and quality in its production process. Deviations occur throughout the process, however they do not always have the same effect. Some deviations are negligible, while others are critical. It is therefore important to understand what the tolerances are in production and how deviations may add up. Aside from its strength, the Slim table also has a visual quality to upheld. Due to the simplicity of the Slim tables design the corners play a large role in the overall appearance. The most critical part is therefore the connection between the tabletop and the legs at the corners. The ideal goal of this theme would be to device a procedure that would eliminate deviations to such a degree that all legs are interchangeable. Tolerance in the final product would still be allowed as long as it doesn't affect the design.

G.2. Structural and aesthetic

The factory research has provided insight into the production process and the various procedures, it has however not focused on the design of the table itself. Besides all the parts needing to fit together, the table also has aesthetic requirements. At the retouching stage a document is posted on the wall (**Fig. L**) that serves at the main guideline for the design detail of the table corner. The document defines visual tolerances instead of just mechanical tolerances. By looking from the perspective of the design of the table instead of the production, two critical properties can be identified that require tight tolerances: structural and aesthetic.

- Structural properties: The stability of the table depends on the perpendicular connection between the tabletop and the legs. Any deviation in this alignment can result in a loose or skewed connection, which can compromise the strength and stability of the table.
- Aesthetic properties: The appearance of the table is influenced by the alignment of the veneer on the tabletop and the legs. The veneer has to match at the corners, creating a smooth transition. Any deviation in this alignment can result in gaps, which can detract from the design and quality of the table.

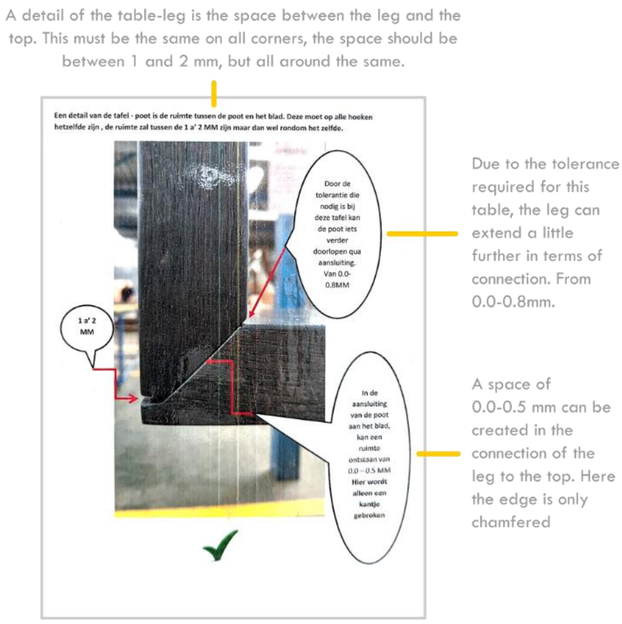


Figure K: Document from the factory with aesthetic guidelines for the table corner.

The aim of this theme is to investigate the tolerances in the production process in relation to the design of the table. Based on the structural and aesthetic properties the production process has to be re-analyzed to better understand how they are affected by deviations. The factory research notes are re-evaluated and the factory itself is revisited to help clarify the details of the procedures in regards to the tolerances and deviations. This theme will focus on the effects of deviation on the structural and aesthetic properties. The first step, however, is to identify where deviations occur in the production process.

G.3. Deviation accumulation

The Slim table is made of aluminum, steel and wood, each material has its own deviations and tolerances. For metals, it is important to minimize deviation from the start, as they are difficult to adjust later. For wood, it is more flexible and adaptable, as it can be trimmed to size after assembly. Wood is also a natural material that can change shape and size due to humidity and temperature. To address the deviations we need to understand when they are introduced and how they develop throughout the production process as some deviations may accumulate across multiple steps. By using the Gigamap as a reference the possible sources of deviations can be identified.

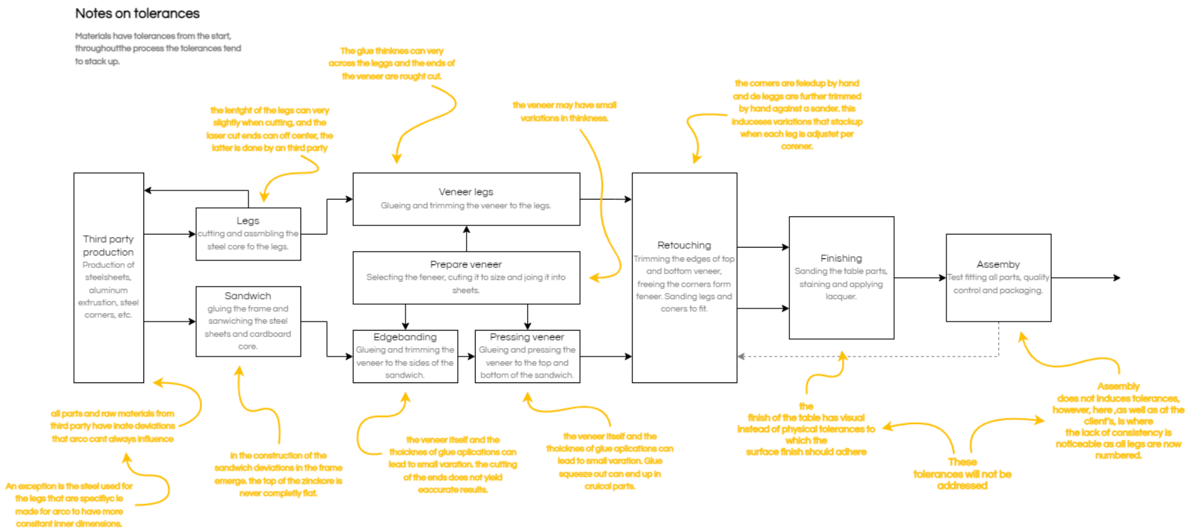


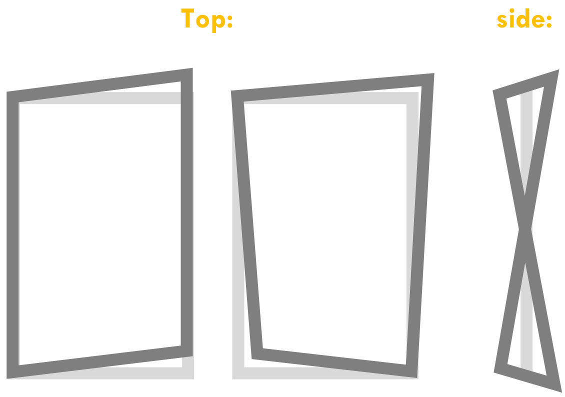
Figure L: The simplified Gigamap with annotations on tolerances across the process.

The production process of the Slim table consists of several steps that affect structural and aesthetic properties of the final product. Each step of the production process was evaluated and notes were added (**Fig. M**) on where deviations were introduced. Some deviations are predefined by third party ministering. As part of the sandwich the core of the corners may be affected by the assembly of the frame. Although retouching is meant to fix defects, for the Slim the retouching stage itself also introduces deviations. As at that stage the corners are cut and the legs are trimmed by hand. The finishing stage that comes after retouching mostly affect the aesthetic properties of the tables surface, and does not pose as much of a problem. Deviations accumulate throughout the process, however, they manifest themselves at the retouching stage, as that is where adjustments are made to ensure the correct fitting. The challenge with deviations in the production process is to ensure the consistency of the corner connection, which is a key element of the entire table. Therefore, any changes to the process should not only be evaluated based on the retouching stage, in addition to on their impact on the table in general.

G.4. The frame

The core of the Slim table is the sandwich construction consisting of a core, outer sheets and a frame. This frame is assembled by hand from various parts and is therefore prone to deviation. In theory the a small variant in lengths or angle during the cutting and assembly of the frame could lead to a deformed frame (**Fig. N**). in practice however, these variations are easily adjusted, by for example measuring both diagonals or clamping it to a flat surface. Any twist in the frame is also fixed by the heat press that is used in the final glue-up of the sandwich. Small deviations in the shape of the table are also not as noticeable on a larger scale. The corners however are different.

The legs of the Slim are mounted to solid steel corners in the frame. Those corners are pre-maid and already square regardless of the frame assembly. As part of the design detail however, the ends of the aluminum extrusions of the frame are milled as separate shorter pieces to make cutting longer extrusions to length easier. Small misalignments are cut away during the retouching stage. Misalignment may however also affect the thickness, which would require extra sanding of the corner veneer. Overall the assembly of the frame does not impact the final result of the table as much as expected. Most deviations that do matter result from the materials themselves. These will, however, later be discussed as part of the assembly of the comers.



Exaggerated deviation from square frame

Exaggerated deviation from flat frame, with legs

Figure M: Exagurated visualisation of the how deviation may affact the frame of the Slim.

G.5. Cutting corners

As part of the procedures of the retouching stage the corners of the table need to be cut. During production the corners become entirely covered by veneer, first by edge banding and later by the top and bottom veneer. At the retouching stage a special jig is attached over the corners and trim router used to cut through the veneer. This operation will, however, also introduce deviations and not only in the veneer. Each of the three materials that make up the corner (**Fig. P**) are affected differently.

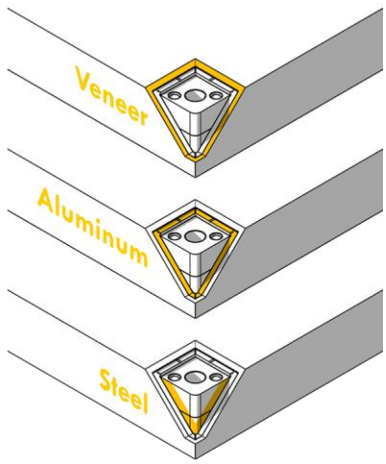


Figure N: The areas of each material that is cut by the trim router.

Veneer
The veneer does not have a structural purpose as it is relatively soft. Deviations in the trimming of the veneer therefore have little effect on the structural quality of the corner. However, deviations do matter in achieving the correct aesthetic of the table. The cut could be asymmetrical or the wood veneer may chip of or split.

Aluminum
Although the aluminum corners already have the right shape, cutting into them during this operation is actually desirable. The aluminum milled (**Fig. O**) by an external party and this leaves a concave edge on the miter in the vertical wall. With the cutting operation at retouching this edge is flattened. The edge forms an important interface surface for the steel tube of the legs. Any deviations may lead to a twist along the vertical axis in the legs.

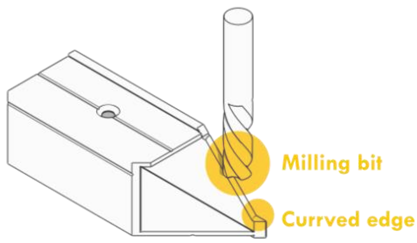


Figure O: The milling operation on the corner extractions.

Steel
Although not necessary, the trim bit can sometimes go through the steel corner pieces. this can occur when the edge banding has a lower thickness than usual. Although cutting in the steel does not affect visual quality, it can affect stability of the legs. The interface surface between the corner and inner sides of the legs is reduced which can make it harder to adjust the fitting.

G.6. Assembly

At the retouching stage the Slim tables are pre-assembled and adjustments are made to ensure the correct fitting. The exact procedure is depended on three parts: the corner of the tabletop, the thorn and the leg. These parts have accumulated deviations from third party production and during the different production stages at Ocra or Arco. However, not all deviations affect the fitting equally. Adjustment are only made when the deviations cause the legs to not fit over the corners or prevent the legs from being perpendicular to the table. Based on their effect on these two constraints the possible deviations for each of the three parts (**Fig. Q**) are discussed below.

Thorn (Doorn) (or mandrel)
The tolerances of the outer diameter of the Thorn are already well adjusted to always fit inside the legs. Deviations in the threaded hole on the bottom of the thorn have almost no impact, as the length of the rod to attach the legs can already with can accommodate for it. The threaded top, on the other end, can still pose a problem.

If the thread is off-axis (1) the thorn would not be perpendicular to the corner, even when fully tightened, which would translate to the legs also not being perpendicular. While the thread being off-center (2) can stop the legs from fitting altogether. When attached to the table the edges of the steel corners should be tangent to the thorn. If the edges of the corner protrude beyond the thorn they can block the legs from sliding over the corner. This can only be fixed by grinding the inside of the legs. If the thread is off center, the alignment would also depend on how far the thorn was tightened, which is an undesirable variable in itself.

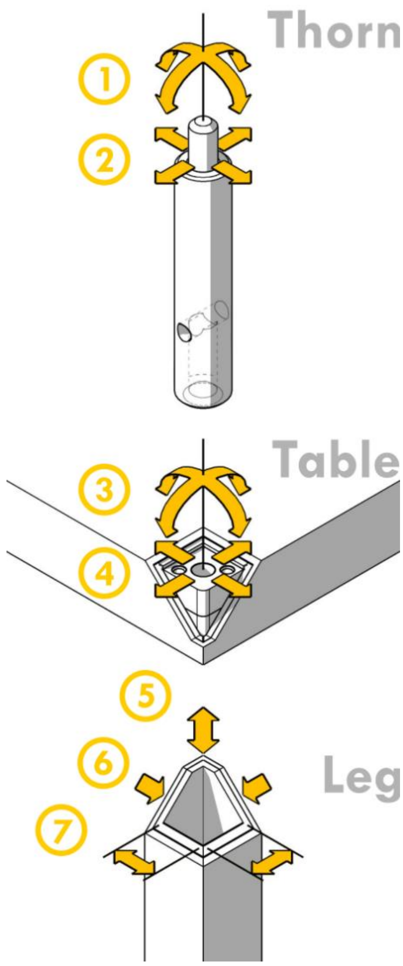


Figure P: Dimensions that are important for a correct fitting of the legs.

Corner piece (Hoekstuk)
If the threaded hole in the corner is not perpendicular (3), the thorn would not be either. There are also other possible defects that affect the thorn. The pins that hold the two parts of the corner together can protrude, glue residue can end up in the threaded hole and in the past it even occurred that the holes were not fully tabbed at all. These defects would prevent the Thorn from being fully tightened and perpendicular. In those cases the pins need to be hammered or grinded down and tholes retaped. However, the most important dimension of the corner piece is the relative position of the threaded hole from the side(4). If distancing to one of the outer edge is too large the edges would protrude and block the legs, like described with the thorn. If the distance is too small, the outside faces of the leg may no longer align with the table's faces.

Leg (Poot)
The production process of the steel core in the legs references the outside of the legs and leaves a weld seam on the inside. Although the seam is grinded down by a third party manufacturer, it is not always consistent. Deviations in the steel core itself therefore mainly occur on the inside (7) and sometimes require additional grinding to fit over the thorn and corner. The Mitered ends of the legs are laser cut by a third party. At Arco the wood veneer is applied and trimmed down manually on a disc sander. Although a special jig gives guidance, deviations cannot prevented, mainly on the top and diagonal edges (5 & 6).

Legs are handpicked from the stockpile to match both the color and thickness of the veneer on the legs to that of the table. If the difference in thickness is small enough it may even be resolved by sanding. When the legs are attached to the table the sides of the legs need to be parallel to the sides of the table. If the diagonal edges do not align with the table, the legs may end up twisted. Adjustments are therefore made by slightly griding the diagonal edges again with the disk sander, until they fit. Then, when everything is corrected the connection should be symmetrical and the distinct gap between the legs and tabletop should be between 1 to 2 mm (**Fig. R**).

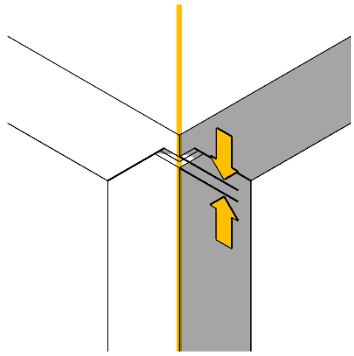


Figure Q: The distance between the legs and table that should be 1 to 2 mm.

G.7. Slim Flex (existing alternative)

A recent addition to the Slim family is the Slim Flex. A smaller table that could be used as extension to the regular slim tables. However, due to the smaller size, the regular construction of the sandwich would become too expensive. Fortunately, the small size allows for the table top to be made from a single sheet of plywood. A new mounting plate had to be developed that would result in an equally strong corner connection while looking the same as the regular Slim. While also keeping the mounting of the legs identical to the regular slim tables. This mounting plate will be referred to as the Flex plate.

Flex plate
The Flex plate is laser cut from 10mm thick steel with a threaded hole. The laser cutting process leaves a slanted edge because of the laser beam's conical shape due to focusing. Flex plate therefore has a top and a bottom side, however in the production process this distinction is not made. The Flex plates are glued into CNC milled recesses on the bottom of the table top (**Fig. S**). While the glue set the table top is clamped in a small veneer press that ensures the surface of the tabletop and the four corner plates are parallel. However, the flex plates can still have a small planar shift, as the recesses are slightly bigger.

Figure R: A Slim Flex plate in milled recess without glue.

G.8. Ideas

The aim of this theme was to develop a new method that could guarantee a perfect fit for every leg. However, the reality turned out to be too complex for such a simple solution. The relations between deviations are so intertwined that any attempt to correct one would inevitably affect others. Therefore, no single procedure could account for all the possible deviations. Nevertheless, the investigation did provide some valuable insights and ideas about the deviations, as well as the limitations of current procedures.

- Before any adjustments are made at the retouching stage, deviations are instead introduced when the veneer on the legs and corners is trimmed. During the fitting of the legs it are the edges of the legs that are often sanded. Even if the table's dimensions were to be off, the legs would still be the ones that to be adjusted. It seems inefficient for the retouching stage to first introduce deviations before trying to fix them, instead of avoiding them in the first place.
- There has to be some play between the thorn and inside of the legs to account for the deviations. However, if the process could be adjusted in such a way that the thorn would always fit perfectly in the legs. As long as the thorn would be perpendicular to the table the legs would also be. The legs would then be straight from the start.
- If the tolerances for the allowed distance between the mitered edge of the leg and the table would be decreased, it would make adjusting for the visual properties easier as well. A build in adjustment system could be created in the corners, if the legs could not be made to fit right straight away. That should, however, not be something that needs to be done by the end users. Instead it has to be something that is adjusted once in the factory or possibly when refurbishing a table.

In the end, if the thorn would fit perfectly in the leg most of the deviations would not matter for the structural property of the table. Deviations would only affect the design detail of the corners. There are several solutions, however they do more exist as an hypothetical scenarios.

Moreover, analysis the deviations and tolerances has also raised a new question that may requires further investigation. It seems that there is currently a small gap between flat side of the leg and the underside of the table. The table seems rest on the mitered edges of the table. This is even pointed out by the retouching guidelines (**Fig. L**). This particular edge is laser cur perpendicular on the legs and is also the least affected by the trimming of the veneer. It seems that this would be an ideal reference surface for establishing a perpendicular connection between the leg and the table. This has however only be observed in a small number of tables, at this point it is not clear if this is the case for all tables. Nevertheless is refocusing the retouching activities to using this edge as the reference may help increase consistency.

G.9. Conclusion on tolerances

Investigating the tolerances has not lead to a single solution or idea. Nevertheless, it has still identified a goal for the improvement of the production process. In making everything fit together the focus is on making the legs fit on the table. Each leg therefore ends up being unique, as they each have been slightly adjusted separately. production should therefore shift its focus to making the legs as similar as possible and adjust the corners of the table to the legs instead. However, with the current order of operations it is difficult to adjust the corners without damaging the outer veneer. Shifting the focus of the table would therefore also mean that the order of operations have to change. It is suggested to use a precise cutting machine to trim the veneer in the corners and on at edges the legs to ensure consistency. This would in turn, however, require more consistency in the corners or different materials to not wear out the cutting tool with every operation. The flex plate already offers an alternative corner construction and other alternative should be explored as well to improve the consistency of the production process.

H THEME 3: RE-CONSTRUCTED

Changing parts of the process may not always be possible without changing parts of the product. The construction of the table may therefore also have to change to improve the production process. What alternative constructions possible for the Slim table?

H.1. Re-constringing process

The other two themes have focused on the production process to find improvements. The production process has already been tailored to the current construction of the slim table and vis versa. Changing the production process may therefore also require changes to the Slim table. This theme therefore focusing on finding construction of the Slim table, by looking for new materials and methods to re-construct the slim table from the ground up. The design process for re-constructing the Slim table required a better understanding of the Slim design and the possibilities. This started with analyzing the current construction to better understand it strengths and weaknesses. Inspiration for new constructions is drawn from various products with similar features or functions, and by looking for alternative materials. Ideas were developed by experimenting with samples and they were sketched out or 3d modeled to visualize them. By understanding what changes to the slim construction are possible, ideas from the other two themes that may not be possible with the current construction will therefore not be dismissed.

H.2. Glue test

A parallel development to this research helped gain insight in the strength of the table's inner construction. In the past the aluminum extrusions have always been treated with a chrome based coating to prevent oxidation and increase glue adhesion. Due to recent concerns surround chrome based coatings (RIVM, 2023) suppliers are starting to cease usage of chrome. Arco therefore had to look for both an alternative surface treatment of the aluminum extrusions, as well as a compatible glue. Several test were caried out with different combinations of surface treatment and glues where the tables were testes to their limit. The maximum weight was based on previous test from a test institution, while the current tests were excecated by Arco. It was seeing how each table would slowly fail that gave insight in how load was distributed in the construction.

Figure S: Glue test under continuous load, from left to right is setup 1, 2 and 3.

<u>Setup 1: 8-4-2022</u>
Slim table with anodized aluminum, one side sealed, one side unsealed. Sandwich glued with two component glue (LOCTITE AA3298 + activator LOCTITE SF737) and veneered according to standard process.

<u>Setup 2: 22-4-2022</u>
Slim table with anodized aluminum profiles, The sandwich is glued the current way with 2-component glue (LOCTITE AA3298 + activator LOCTITE SF737) on the bottom and effervescent Glue (ICEMA 145/12) on the top and not veneered.

<u>Setup 3: 4-6-2022</u>
Slim table with anodized aluminum profiles. The sandwich is glued with effervescent Glue (ICEMA 145/12) on the top and not veneered.

H.3. Strength analysis

The slim table is named for after its thin appearance, nevertheless is it still strong enough to hold a person. A redesign should at least be equally as strong. Suggesting any to change to the table will therefore require a clear understanding of why the current construction is so effective in first place. This starts with how forces are distributed sandwich construction. A cross-section of the Slim table (**Fig. U**) shows the six layers of three different materials (veneer, Zincor and Beeboard) that make up the sandwich. When a load is applied on top of the table different forces act on the construction.

- Compression along top sheet of Zincor (green)
- Tension along bottom sheet of Zincor (blue)
- Compression across beeboard when loaded (red)
- Tension on inside beeboard when unloaded (orange)

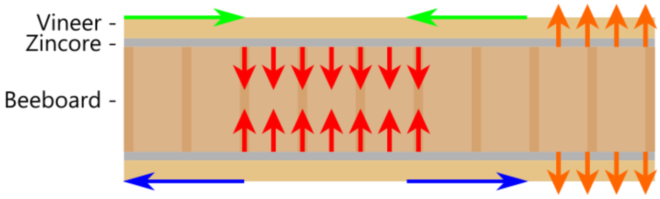


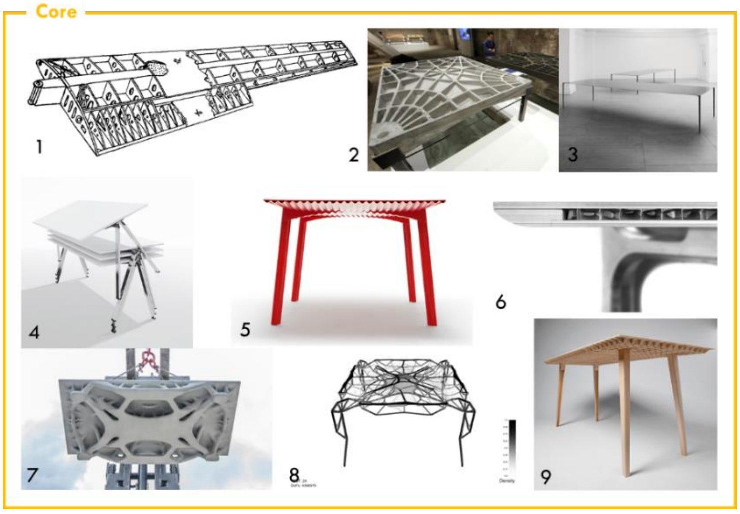
Figure T: Schematic cross section of the Slim table with internal forces.

Ideally a full mechanical strength analysis would be conducted on the table. Unfortunately, after multiple failed attempts it was deemed out of scope. Assumptions therefore had to be made based on that what was already known and what could be observing in the load tests. Before fully collapsing, the sheets of zincore would start to detach and the table would start to sag. Although it was never observed in person, based on the observations it was deduced the table would collapse when the aluminum frame started to buckle instead of bend. The assumption therefore was that the zincore and beeboard were distributing the load evenly to the aluminum frame, which bore most of the weight.

Unfortunately, the assumption about the aluminum frame proved to be faulty. This was only discovered after building the prototype. Up until then it was assumed to be plausible and it has therefore affected the re-design process. The full implications will be further discuss in a later chapter with the prototype.

H.4. Inspiration

After being fully embedded in the current production process of the slim it is hard to think of ways it could be any different. The Slim table was developed to be thin, lightweight and strong table. Looking for other products that have been designed with simar goals in mind can inspire new ideas. Especially other tables that advertises these features just like the slim. Several examples were gathers (**Fig. V**), each used different techniques or material to achieve strength while staying thin or light. While some examples are more literal, as they are either an existing table on the market or a prototypes, other examples are more abstract. There are a few that used topology optimization for generating a structure. Those are not only an inspiration for using that technology, they by themselves also show how loads distribute trough a shape similar to the a table top. The examples each show a different methods to reach se same goal of creating a lightweight stronger structure that can inspire an new way of constructing the slim table. There is, however, one table that has purposefully been excluded from the inspirations, the LIM from MDF Italia. The table is a direct competitor of the Slim and the similarities have led to a dispute in the past. The table was therefore left out to stay away from new conflicts



1. Aircraft construction
2. ETH Zurich's concrete floor
3. Carbon fiber
4. Stackable Lisocore table
5. Corrugated wood
6. Aluminum honeycomb
7. Topologically Optimized Concrete
8. Topology optimization
9. Wooden grid

Figure U: Table construction inspiration

H.5. Material alternatives

The Slim table was innovative for its use of materials, since then however, new materials have been developed. A further look at wat is currently on the market could inspire a new construction for the Slim. At first the focus was on finding alternatives for the inner core of the Slim. However, the search later also extended towards alternatives for the veneer. Mainly in an effort to decrease the labor intensity for the veneering of the legs The corners were not included as their strength was considered to be defined by the geometry, not from its material properties. Alternative geometry of the corner was later explored. Even if a new material does not chance the strength or weight of the table, premade material can still simplify the production process. In addition, reducing the variety of materials can increase tits sustainably, as it is the combination materials make the Slim table currently hard to recycle.

1. Aero wood
2. Corelam
3. Greenpanel
4. Neucorpanels
5. Alfa G3
6. Lisocore

7. Decoflex
8. Paperbacked veneer
9. Wigger automated veneering sample

Figure V: Sandwich and veneer material for inspiration.

Various examples of wood panels and flexible veneers were found while searching for alternative materials (**Fig. W**). The various panels could potentially replace parts of the current Slim sandwich. The Further development is needed determine if the use would result in a sufficiently strong product. For the veneer, however, it became clear in later discussions that the flexible products would not be sufficient. The current method uses the same edge banding for the legs as it used on the sides. Switching veneers may require a redesign of the corners to compensate for the difference of thickness. But most of all, the thickness of the veneer is actually an important feature that helps absorb bumps to the table.

H.6. Samples

Working with materials directly stimulates creativity. During the factory research, samples of the Slim table helped to explore and understand the existing design and its components. Some material samples were also available at arco, which allowed for experimenting with new design possibilities. This helped in getting a better sense of the size and strength of different materials, and also inspired new ideas (**Fig. X**). Thicker flexible veneer could be wrapped around the legs, simplifying the veneering process. however it may not be possible to get sharp edges. Some of the core material had cavities that could be used for structural support inside the material, such as a treaded rod. These ideas together with the rest of the re-construction themes gave alternatives for the Slim construction an producing, hover further developed is still required.

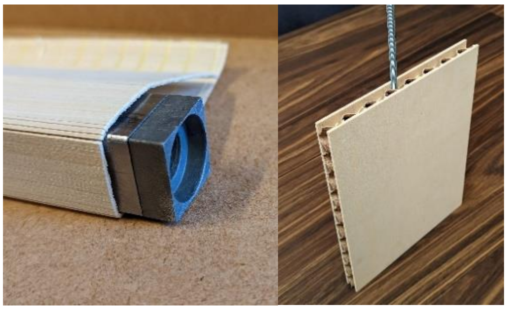


Figure W: Experiments with samples of flexible veneer (left) and Lisocore (right).

H.7. Construction ideas

Parts of the Slim table cannot just be replaced. The tables constructing therefor has to be redesigned to utilize new materials. This includes ways to add a frame for strength an rigidity. However an important that makes the design of the slim work is the mounting of that legs. there other ways of connecting the legs of the Slim? However, coming up with new methods is not an easy task as the corners of the Slim already have a predefined geometry. The sketches show various ideas that rethink how legs could be connected to the table in combination with a frame that would work with premade sandwich material. The 3D models explored what alternative corner geometry would still fit with the design of the Slim tables.

The Slim well designed and engineered table. Parts of the Slim table cannot just be replaced. The whole structure of the table needs to be redesigned to utilize new materials. One of the challenges is to find a way to add a frame to the table to increase its strength and rigidity. Another challenge is to maintain the distinctive corner detail of the Slim table. The corners have a fixed geometry that limits the options for alternative attachment methods of the leg. The sketches and 3D models presented here explore some possible solutions for these challenges (**Fig. Y**). The sketches show different ways of connecting the legs to the table and adding a frame that would work with premade sandwich materials. While the 3D models show what geometry could be used attach the legs, while still preserving the design of the Slim table.

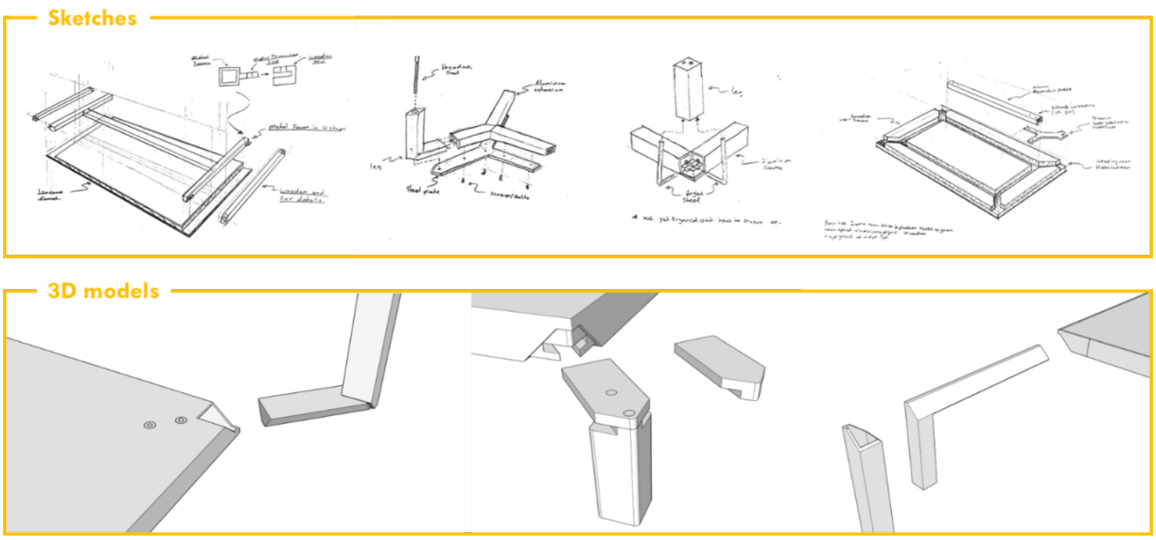


Figure X: Sketches and 3D model of re-construction ideas.

H.8. Conclusion on construction

New methods and materials were research for re-constructing the Slim table. For the legs the veneering and connecting to the table were explored. From a material point of view veneering the legs reached a dead end. There is too much uncertainty if materials could deliver the desired quality and properties. For the mounting of the legs however there is enough potential for further development. The final design of the connection, however dependents on the rest of the tables construction.

The core of the slim table is essentially a composite material made of Zincore and Beeboard. During the conception of the slim table there may not have existed many alternatives. However, new material have become available and there is a now larger incentive to develop more sustainable alternative to existing materials. A new core material for the Slim can reduce the complexity of production by utilizing premade composites, as well as increase recyclability by reducing material variety.

There are multiple options for premade composite panels that could be used in the construction of the Slim. However the requirements for replacing the core material are still uncertain. It is therefore impossible to immediately make the right selection a core material. However most composite panels are all essentially the same, a core material between to sheets. The redesign of the Slim construction should therefore continue without focusing on a singular material. In doing so, the uses of a premade panels can still be explored without limiting creativity by the restrictions of one material. The redesign would then have to determine the requirements and a selection can be made afterwards.

I PLANNING FEEDBACK SESSION PO

The feedback session will take place on **Thursday 7th of July from 15:00u to 17:00u** with the product development team. Although they are already familiar with designing and problem solving some structure in the session is still desired. Both for stimulating the ideas, as well as helping in documenting the session. For this, inspiration comes from codesign sessions. The session will be divide in three stages: presenting research results,

I.1. Presentation

The PO team is already familiar with the factory. They may not know all details of the Slim productions but that would be unnecessary to explain beforehand. Details will only be further discussed when needed. What will be presented:

- The simplified process diagram to help aid the discussions later.
- the problem and cost analysis so they understand the goal.
- the conclusions of each theme to set the focus
- If I have missed anything then it will be added.
- the ideas and inspiration of each 3 themes to discuss

I.2. Ideas per theme

For each theme a piece of A3 paper is placed on the table. Everyone is encouraged to write down or draw ideas on post-its and place them om the sheet where it is most suiting. And discuss what an why they have placed it. Ideas can be functions, production methods. The expertise of the factory can also yield general requirements or statements that are important to include, these can be placed above the sheets, as overarching values. To help visualizing the use of this format example post-its will be placed beforehand.

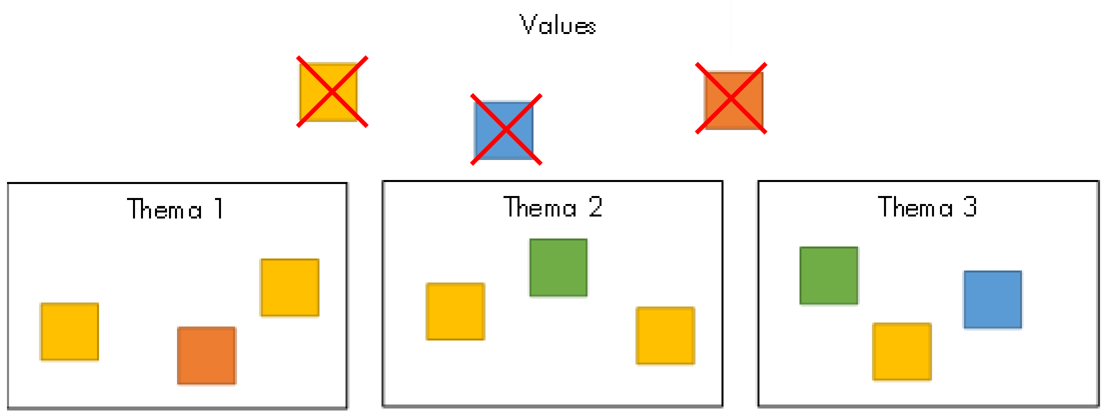


Figure Y: Visualization of how post its should be used in the feedback session.

I.3. concepts

After a discussion on the themes, we will discuss what should/could be realized. Taking the corresponding ideas and placing them on other sheets that represent the three or more concepts. Beforehand all ideas are numbered to allow ideas to be included in multiple concepts by simply adding a post-it with just a number.

J CALCULATIONS FOR CARBON FIBER TABLE

(only in printed version)

If Arco were to use carbon fiber sheets, they would not laminate them themselves. The cost of premade carbon fiber sheets was therefore compared to cost of Slim tables. BOM that were already available were used for the Slim cost. Because the dimensions between the carbon fiber sheet and the slim tables were not equal the cost per square meter were calculated.

[redacted]

Figure Z: Calculations for comparing the cost of the Slim table to carbon fiber sheets.

The cost change depending on the size. However, the cost for carbon fiber sheets start higher and then decrease. While the cost for the Slim start low and increase with size. When plotting the cost to size ration, the breakeven point occurs around 1,75 m^2. However this is a comparison of the total cost of the Slim to just the sheets of carbon fiber.

[redacted]

Figure AA: Graph of cost development of the Slim table and carbon fiber sheets based on surface area, assuming they develop linearly.