PRODUCT DEVELOPMENT USING DESIGN THINKING APPROACH

Lappeenranta–Lahti University of Technology LUT

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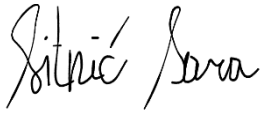

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ABSTRACT

Lappeenranta–Lahti University of Technology LUT

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Product development using Design thinking approach

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Design thinking is a relatively recent, very efficient, team-based approach to innovations. This methodology motivates entrepreneurs to focus on costumer's needs, resulting in inventive ideas. It is divided into five stages. Innovators engage with consumers, collect various ideas to meet their needs, then choose only one or two successful ideas to test in the final step of Design thinking.

The subject of this study is the application of Design thinking methodology to the problem of excessive amounts of wood residues in the lumber industry in Bosnia and Herzegovina. Wood processing or lumber industry encounters the problem of large amounts of wood residues remaining after production. Through five steps of Design thinking, this study examines the development of numerous concepts suitable for solving the problem of sawdust residues that in large quantities remain unused in companies within the wood industry. The idea of mycelium eco-packaging as a substitute for Styrofoam in transportation matters is one that has stuck to the end of the research. Besides the environmental benefits of mycelium eco-packaging over Styrofoam the cost-benefit analysis demonstrated the financial benefits.

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“Some people think design means how it looks. But of course, if you dig deeper, it is really how it works”

Steve Jobs, Apple

1. INTRODUCTION

1.1. Introduction to innovations

In order to achieve success in the contemporary state of the world, one needs to develop and acquire a variety of skills that were not necessary prior to Industry 4.0 (Shute & Becker, 2010). Companies are rapidly researching and developing new tools, services and methods to remain relevant on the market and remain competitive. Most often, they choose to introduce groundbreaking and innovative services to their customers to gain an advantage on the market (Noorani, 2014). Innovation, however, can entail many things and can be defined in multiple ways. Fichman (2001) defines innovation as a creative development process or the implementation of a new idea with a focus on enlarging features of the product to offer better service to customers. By this definition, the techno-centric idea of innovation has been replaced with new approaches to innovation that can be applied across all aspects of business and society, all to develop products that sufficiently fulfil the needs of customers (Brown & Katz, 2009). In the past decade, especially so the last five years, companies are employing the ideas of the Design thinking approach, which is gradually becoming the go-to method for innovating and reaching customers. Companies around the globe have started implementing this approach in their business models to achieve solutions to their most complex problems (Albay & Eisima 2021).

1.2. Definition of Design thinking approach

Since the Design thinking approach is a relatively new concept, only recently starting to gain attention in the business world, it can be difficult to place a strict definition on what exactly it is (Dunne & Marting, 2006). According to more recent definitions, Design thinking is a multidisciplinary, human-centred approach to innovation that combines technological, business and human elements in solving a problem (Plattner et al., 2010). The concept of Design thinking is based on the idea that designers should use the skills and resources that are technically feasible and economically viable. It has developed over the years and now it is teaching every individual that anyone and everyone can be creative (Brown & Katz, 2009).

1.3. Motivation

The motivation to write about Design thinking comes from various sources. The main being that, this approach is fairly new and has a huge potential which strikes as something very intriguing. The popularity of Design thinking is bound to increase over the years to come and as such should be studied and applied in local industries in Bosnia and Herzegovina, and all around the globe.

A good example of this comes from the lumber industry and forestry in Bosnia and Herzegovina, which has a long tradition, an abundance of resources, exemplary potential, as well as fantastic yearly growth. According to the UNDP (2017), annual tree felling comes down to 4.5 million m^3 and about 15% of the waste is left unused. Bosnia and Herzegovina also has a wide range of products, mainly based around exporting raw materials such as beech, fir, spruce, pine, and to a much lesser extent, walnut and oak. The main strategic advantage of the lumber industry in Bosnia and Herzegovina, however, is the highest possible level of finalization and the highest possible export of finalized wood products. However, a significant share in production consists of lower degree processing, such as various materials, pellets, pallets, briquettes, and the like (Wood Industry and Forestry Association, 2020). Environmentally friendly, this industry has an export potential with a market share of over 60% (Chamber of Commerce of the Federation of Bosnia and Herzegovina, 2018) and it is an industry with a high surplus. In 2021, the wood processing industry in Bosnia and Herzegovina exported wood products worth approximately 625 million BAM (Chamber of Commerce of the Federation of Bosnia and Herzegovina, 2018). In 2020, despite the pandemic, according to the data of the Foreign Trade Chamber of Bosnia and Herzegovina, the value of lumber industry exports amounts up to a 1B BAM (BHRT, 2021). From this, it can be concluded that the lumber industry in Bosnia and Herzegovina is seeing high annual growth, and with that would significantly benefit from applying the Design thinking approach.

One of the major problems within the lumber industry, as in many others, is the amount of waste obtained during processing. This waste, also called „scrap“ cannot be used in the final product, and as such is often used as an energy medium, in the production of fuel in the form of pellets and briquettes for export (Chamber of Commerce of the Federation of Bosnia and Herzegovina, 2018). If the Design thinking method had been used to solve this challenge, a useful product built from the excess "scrap" would have been discovered or designed.

2. LITERATURE OVERVIEW

The Design thinking approach is still in its early phase of development, and few studies touch upon the reasons as to why this approach should be implemented in more projects and companies. However, research that has been conducted shows that project management with a focus on financial stability, time and quality is not showing the best results in terms of fulfilling the needs and requirements of customers. The main reason for that being the lack of understanding of the customers' actual needs. That being the case, it's easy to conclude that project management should be shifting to a more user-friendly approach – Design thinking (DT).

2.1. History of Design thinking

The origin of the Design thinking approach roots from the mid-20th Century, when it was first mentioned by John E. Arnold in his book "Creative Engineering". In his book, John E. Arnold segregates DT into four segments: novel functionality, higher performance level of solution, lower costs of production and increased salability (Arnold, 2016). A few years later, L. Bruce Archer (1965) connected the approach of Design thinking to management strategies and describes his prediction that, in the future, design and management will be inseparable concepts. This led to many authors attempting to tackle the idea of Design thinking, such as Herbert A. Simon in "The Sciences of the Artificial, Bryan Lawson in "How Designers Think" and finally, Peter Rowe in the year 1987 in his book dubbed "Design thinking" referring to the approach from a more architectural point of view. The Design thinking approach was, however, firstly introduced as a business model by David M. Kelley, the founder of design consultancy IDEO. (Brown & Katz, 2009).

At the start of the 21st Century, the Design thinking approach has shown great potential, with more literature and studies about this approach being written each passing yea (Dunne & Martin, 2006, Brown & Katz, 2009).

2.2. Applications of Design thinking

Today, the Design Thinking approach is mainly being used as a tool for business strategy improvement and transformation. Large industry giants such as Nike, Starbucks, the Bank of America and GE Healthcare have recognized the potential of this approach and have already

benefited from applying this method to their problem-solving solutions (Namdarian, 2021). Inspired by the success of the product development and decision-making fields of the industry, Design thinking has started to accumulate a lot of attention within its field of study. As such, the Design thinking approach is finding its way into other, non-business fields, such as education and much more.

2.2.1. Design thinking applications in companies

Bank of America's so-called "Keep the Change" program is one very good example of how Design thinking can be applied to benefit customers (Brown, 2010). This program aimed to investigate the ways to increase the number of savings accounts within their customer base. IDEO, a global design and innovation company that was given this challenge, used their ethnographic-centred approach to design to discover the ways to increase savings account openings. They conducted research and discovered that their customers had a habit of rounding up the amount of money they would pay with when making a transaction. This led to the development of the innovative idea that brought 10 million new customers to the Bank of America. Namely, customers had two accounts: debit and savings account. The amount paid with a debit card would be rounded up and the overage transferred to the savings account (Schmieden, 2018). Additionally, they discovered that the customers liked the idea of saving more than the actual amount they save (Namdarian, 2021). What customers needed, is to "keep the change" after transactions. The results of this creation were astonishing – 10 million new customers and 1.8 billion dollars saved by them (Brown, 2010).

According to Kelley & Kelley (2013), Dough Dietz, a veteran of General Electrics, helped GE Healthcare to develop a high-tech medical imaging system using the approach of Design thinking. He led the project to create an MRI scanner worth multimillion dollars and did not hide his amazement when it was set up for use. His amazement was blown away however, when his first patient, a little girl, stepped into the room for an MRI scan screaming with tears streaming down her face. Having had felt the despair of her parents being unable to make the whole experience easier for her, Dough decided to take things into his hands. What he wanted was not to redesign the machine, but to make the experience of an MRI easier to handle. Driven by this motive, he started applying the human-centered approach to find out what the needs and requirements of his customers are. He interviewed former users of the machine, talked with managers from different

companies, and pediatricians to better understand the process and a lot of volunteers, which has all led him to develop a better solution for children (Kelley & Kelley, 2013).

Figure 1. Pirate ship as one of nine "amusement parks" for MRI (Hayes, 2013)

Figure 1. shows the machine that Dough has designed. Considering the fact that children are still using their imagination and see the world as an adventure, Dough and his team created an MRI machine that felt like an adventure. The figure shows an example of a pirate ship, but there are also other examples, in fact, nine different "adventures" that help kids go through the process of MRI.

Having the feeling that they are a part of the crew on the pirate ship, children, in most cases, no longer needed to be sedated to withstand the MRI. This was beneficial for both – the consumers (children) and the hospital – less need for anesthesiologists.

Although everyone may not have had the chance to use Airbnb yet, most people have by now at least heard of it. But what most people are not aware of is that this company launched as a struggling start-up. In 2009, Airbnb was on the verge of collapse, due to its income of barely 200 dollars per week. The founders of the site had no other option but to put themselves into the shoes of their customers and see the problem from their perspective. What they noticed was that the pictures posted on the site were of low quality which repelled potential customers from even considering renting the room on Airbnb. To solve this problem, one of the founders – Graham suggested they all travel to New York, take the customers' list of requirements in mind, rent a camera and replace the existing photos with professional ones. They felt the consequences of their actions immediately one week later, as their weekly revenue had been doubled. Afterwards, the team said that the turning point was when they decided to step away from a scalable way of solving

the problems and engage with customers to understand the problem from their perspective (Advani, 2020).

2.2.2. Design thinking in research

The project to develop a seafood to go concept was conducted in the year 2009 by The Norwegian association for seafood producers (NSL). The project involved people from NSL, Nofima (Norwegian research institute for aquaculture, fish and food), two fish companies and one consultancy company. In the first phase of the project, research was conducted and showed that there is a significant increase in consumption of seafood in daily life amongst Norwegians over the last three years. Additionally, the research showed a growing interest among individuals in eating healthy food to go instead of the majority of fast food currently dominating the market. Based on this research, the partners decided that launching "Seafood to go" would be a great success.

The next task for the partners was to become empathetic with their customers through observation – to talk to people, conduct online research, attend food fairs, etc. They were able to conclude following:

1. "To go" food should be eaten with one hand. Drivers are consumers and they have to eat with one hand.

2. This kind of food is usually lunch – it does not have to be a complete dinner.

3. People have bad experiences with "to go" food and often have a negative attitude. However, fish is eaten because it is healthy.

4. Food has to be delicious to children because they are usually consumers on long rides since food entertains them.

5. And many more.

In the next phase, they had to take all the obtained information and make simple prototypes that will first be tested amongst themselves. After detailed testing of various ideas, two of them were chosen to be further evaluated. "Autowrap", the second of the two final ideas, was easy to handle, did not create a mess and, as the name indicates, can be eaten in the car (Olsen, 2014).

The designers developed several ideas:

1. Wraps in cylinder-shaped packages that fitted the cup holder
2. A food package in the function of a table in the car
3. Different food and drink holder solutions for the car

Figure 2. Kellog's Cornflakes advertisement (Singh & Sharma, 2020)

Kellog's Cornflakes are one of the best examples of how Design Thinking can be utilized (Singh & Sharma, 2020). In the beginning, W.K. Kellog wanted to find a replacement for baked bread that was served to patients in hospitals. Since this product was hard to digest, he wanted to find something that would be easier from that point of view. He decided to start observing the problem in his brother's hospital to understand it better.

He tried many solutions and tested different types of grains before he succeeded with his invention of cornflakes. What he did was ask for feedback from his customers. He collected the feedback and tried to improve and adjust based on the opinions he received. Finally, after a lot of testing, he has come to the solution of cornflakes, which are practically an essential breakfast in every home today. Not only did he solve the hospital issue, but he also created something that is widely used in the everyday life of most people worldwide.

2.2.2.1 Application of Design thinking for purpose of waste reduction

Since the content of this thesis work focuses on developing a product from waste (scrap) within the lumber industry, it is important to present how Design Thinking has been used in these or similar purposes prior.

The Design Thinking method was applied in the case of solving the municipal solid waste problem within Bengaluru, India (Agrawal et al. 2019). Detailed research had been conducted on the issue, starting from the empathy phase. First, the available documentation and publication were investigated through an online survey that involved stakeholders and authorities from the waste management field. The problems occurred in both landfilling, as well as waste recycling. Bengaluru, with a population of over 12 million people, is one of the largest cities in India and therefore, the fact that they produce approx. 6300 tons of solid waste (Agrawal et al. 2019) per day is not surprising. Most of this waste, an estimated number of 400-600 million liters (Agrawal et al. 2019), ends up in rivers and lakes causing inevitable pollution and water toxicity. This caused a lot of health connected problems for the locals, especially amongst children who are showing a disproportional increase in respiratory disorders.

Using Design thinking approach, various different solutions were suggested (Agrawal et al. 2019):

a) To save the oceans, people can use microbes to degrade plastic into a simpler organic compound which ensures the desolation of leached particles in the water, so they are no longer toxic to the ecosystem.

b) Garbage collection pipelines can be installed to replace the garbage trucks. Each house, office and other public places would be connected to this pipeline system that goes into the collection center. There would also be sub terminals that will clean and remove the waste stuck in the pipes.

c) To achieve resource recovery, it is possible to install three types of bins: for recycling, for general waste and garden material. For example, paper waste would go into the recycling bin and would later be recycled and utilized.

If any of the above-mentioned methods were to be successful, prototyping and testing phase would be done in the future.

A group of IT consultants, designers and researchers offering high-quality design and help for companies – Not All Bad (2021), have conducted a case study about how to reduce food waste in households using the Design Thinking method. They started their research by dividing the customers into different groups of people depending on their daily nutrition routine. It was found that most people order a lot of food they eat because they do not have time to cook. Based on this,

the team has come up with an idea to offer each of these customers a suitable solution while reducing food waste on a household level.

The idea is that grocery shops could take the food near its expiration date and sell it cooked at an affordable price. The cooked food would be suitable for freezing and microwave heating. This way, the shops would reduce the waste, build up a reputation and increase profit, while the customers would have a timesaving, affordable option with waste reduction at the same time. The results have shown that young people would like to try this option, but older people are a bit skeptical towards this method of nutrition, but they are willing to reconsider after hearing more about the idea and its benefits.

2.2.2.2. Utilization of wood waste

The term Municipal solid waste (MSW) encompasses all solid waste coming from houses and commercial activities, but also from production in construction and demolition field (waste from concrete, steel, timber, building debris and similar). There is an increase of MSW in world which leads to increase of pollution (Azambuja et al. 2018). In order to reduce its impact on the environment, MSW can be recycled, and that is what most of EU countries are doing. However, there are also other possible utilizations of waste and one of them is the utilization of wood waste in construction and demolition to produce particleboards (Jang et al. 2007).

The research was conducted in Brazil where particleboards have been produced from the wood waste by segregating the material into classes and classifying it by an automatic sieving process. There were different types of particleboards produced: four different types for four different classes of waste (MDF – medium density fiberboard, MDP – medium density particleboard, plywood, and timber), one mixture of 25% from each class and one control sample made with Pinus particles. The dimensions of particleboards were 50x50x1.5 mm. There are differences between these six types based on their particle size, physical and mechanical properties of the particleboards and their performances on each scale differ.

For example, the target density of the particles was 0.75 g/cm^3 and this was only reached by the mixture of all waste collected from construction and demolition. Besides density, the measured values were also water adsorption and thickness swelling, where, in both cases, after 24 hours, the control sample, MDF and plywood have shown higher performance than the other of the materials.

Although none of the materials has reached the requirements in terms of thickness swelling, recycled materials used for particleboard production showed better results.

When it comes to mechanical properties, the most important values measured were MOE (Modulus of Elasticity in bending) and MOR (Modulus of Rupture in bending). All samples tested have shown similar performance when it comes to MOE property, but recycled timber has shown the best performance for MOR characteristics. However, the problem is that none of the treatments has fulfilled the standard requirements for both of these values.

As an overall conclusion, the researchers have indicated that wood waste has potential for use in production, whereas the particleboards produced with timber residues have shown the best performances. Since the observed materials failed to meet the requirements in mechanical properties, to improve these properties, it is suggested to carry out further studies. (Azambuja et al. 2018).

Figure 3. Chairs made out of pine needles (Aleksić, 2018)

Tamara Orjola, a Dutch designer, has found a way to utilize pine needles from pine trees that take up 20-30% of pine's mass, but very often end up unused (Aleksić, 2018). By applying the standard manufacturing techniques of crushing, soaking, steaming, carding, binding, and pressing the needles, they can be transformed into a composite material that can be a raw material for various textiles, paper and furniture. She used the obtained material to produce a couple of little chairs and a carpet that can be seen in Figure 3.

"All this started with research on forgotten techniques of manual wood processing that have succumbed to the mass production of furniture that is not ready to adapt to more sustainable production," said designer Tamara Orjola (Aleksić, 2018). She also mentioned that even big corporations like IKEA could make a profit using this approach, because of the immense scale of lumber waste potential. This application also indicates that the pine needles are also a high-quality material, and they also look aesthetically pleasing (Aleksić, 2018).

2.2.3. Multidisciplinary approach to innovations

Along with the focus on innovations, the Stanford d. school also focuses on the innovators themselves. In this school, students come voluntarily to work in multidisciplinary teams and learn from faculty staff and industry experts with diverse backgrounds. (Kelley & Kelley, 2013) They are given real-life challenges to solve. A wide array in every individual's field of expertise gives to these teams' different points of view which leads them to create innovative solutions (Hrovatin et al., 2008).

Figure 4. 4 SIDES 4 - The winner (Hrovatin et al., 2008)

Using the Stanford d. school principles, students from four faculties and experts from five companies worked together on solving the problem of lack of notoriety of lumber industry products from Slovenia on the international market. The project aimed to develop a strategy for the intelligent dwelling. After the theoretical introduction was made, participants interviewed manufacturers from the Brest factory to better understand their desires and demands. What they wanted from participants was to develop ideas on how to integrate furniture into a concept of the intelligent interior. Their central focus was to make future houses neutral and adaptable to everyone's needs, therefore the furniture needed to be multifunctional (Hrovatin et al. 2008). The individuals change their moods and desires throughout the day, therefore they need to have an environment where they can work, relax and socialize. The

winning project is shown in Figure 4. where the concept of four different sides for different activities has been developed.

Another example of the effectiveness of the Stanford d. school principles comes from the experience of students in competitive programs. At the end of 2020, multidisciplinary, international teams of students and supervisors gathered to solve problems of companies in the Lahti region within an annual program called the Lahti Venture Program. The program aimed to develop innovative ideas for real-life company problems. The groups worked on problems from three companies, but the winning group worked on solving a problem of obsolescence in the maintenance service of a company named FerroPlan (https://www.ferroplan.fi/en/main/). The company produces high-quality conveyors for handling piece items and bulk cargo. Their managers explained that they wanted students to create maintenance services for their customers that would serve as an added value to their products and give them a competitive advantage in the market. Firstly, the group investigated the competitors, their approaches to maintenance and the satisfaction of their customers. It turned out that most of the companies have the same approach to maintenance: they give a phone number to their customers who, when a problem occurs, call them to fix it. The group found this to be a very obsolete way of communication with customers, as it did not show the best results. After investigating the market, existing and potential customers' needs the group came up with a groundbreaking idea: to develop an app for maintenance. The previous maintenance method was mainly corrective, acting only once the problem had occurred. The newly developed app would offer preventive maintenance solutions and act based on predetermined calculations. And that is exactly what a customer, whose production line depends on the work of the conveyor, needs.

This idea was pitched to the company and an independent group of judges and the team won first prize in Lahti Venture Program being awarded as the most innovative idea of all in the year 2020. The most important thing that had led this group to winning was the diversity of backgrounds which enabled teammates to see the problem from different angles and come up with a solution that was satisfying from both economic and technical points of view. At the time, the group was

not familiar with the design thinking approach. Only later, after learning a lot about the topic, they became aware that Design Thinking was what led them to victory[1].

[1] This example comes from my own experience – I was a member of the winning team.

3. PHASES OF DESIGN THINKING

All innovations, as can be seen from Figure 5, require the balancing between three important factors: business, people, and technology (Kelley & Kelley, 2013). The innovators should be able to find the best possible combination of these factors to create successful innovation.

The technical aspects or feasibility are the first important thing that has to be taken into account in the process of innovation. It is possible to think of many innovative ways on how to improve the technology, but the real question is – can that idea work? That is exactly what feasibility does – answers the question of whether some idea can or cannot be turned into reality.

Another important factor is the business factor or viability. Some technologies fulfil all technological requirements and can work, but it is important to make sure that they are also affordable. That means that the product must be produced and distributed in an economically viable way, allowing the enterprise to thrive.

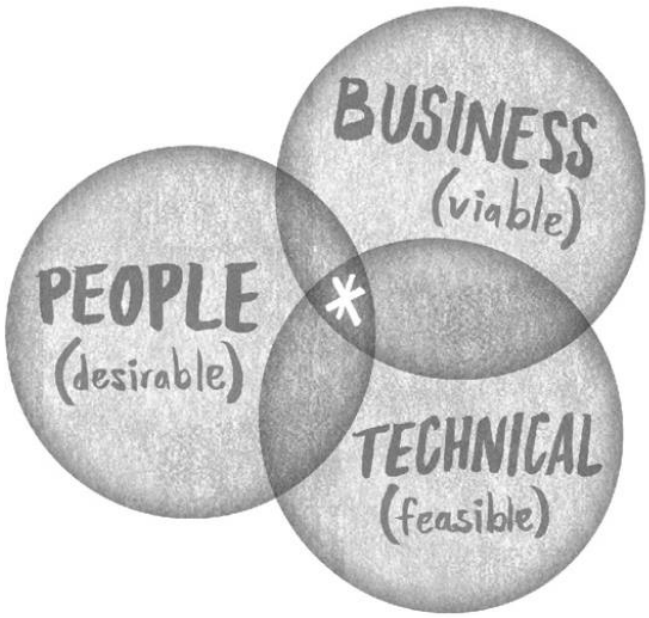

Figure 5. Balance between viability, desirability and feasibility (Kelley & Kelley, 2013)

The last but not least important factor are the people and how to make the product desirable to the customers. It is more than just an observation of customers' behavior. Innovators must dig deep into the feelings and motivations of their customers to understand their needs. Kelley brothers

(2013) do not indicate that this factor is in any way more important than the other two influencing factors, but they do say that technological aspects are taught in schools and business aspects are already being handled by companies, so the real innovation potential lies in the human factor.

The so-called fathers of Design thinking (Gerstbach, 2017) state in their book "Creative Confidence" that there are four main steps or phases that they distinguish in their approach to innovations.

1. Inspiration

   The first step is often called the "Empathize" step because, at this very beginning of the innovation process, innovators should acquire an empathic understanding of the problem. To gain new ideas, innovators have to connect with the needs and desires of their future customers. One of the ways to research this phase is to talk to people – mostly through interviews. It is recommended to search for examples of innovations from other industries during this phase. The point of this phase is to be proactive, to interact with users and to "get into their (users) shoes".
2. Synthesis

   After the thorough research done in the first phase, innovators come to the position when they must gather all the information acquired and analyze it. The task is to start recognizing patterns and to find the "hidden" meaning to "make sense" of all gathered information. After conducting a thorough analysis, innovators can conduct a synthesis and define the key problems.

Figure 6. Empathy map used by designers in Synthesis phase (Kelley & Kelley, 2013)

It is advisable to draw an empathy map with sections “say”, “do”, “think” and “feel” as shown in Figure 6. A “do” section should contain everything that people do. A “say” section should contain everything people say. The same applies to the “think” and “feel” sections. The map should be observed a whole year after all observations have been made. It serves as a helping tool to draw out some insights and conclusions about eventual unexpected patterns, some contradictions, or new, surprising things.

3. Ideation and experimentation

   Many ideas must be generated in this step of the process. The main advice is to be quick in exploring the ideas and not to spend too much time on only one idea. This helps innovators improve existing concepts and develop new ones. The experimentation part can be done using some simulators for testing or crafting hundreds of products’ prototypes to test them.

4. Implementation

   Before the whole new idea approaches the market, it is necessary to refine its design and a roadmap to the market. Depending on the products’ characteristics, these things can vary, because it is very different to launch a website than to present a new product. An increased number of companies are starting to implement this phase to learn more about their market and target customers. For example, Clover Food Lab start-up began with only one food truck at the university only to end up opening restaurants for sustainable vegetarian food (Kelley & Kelley, 2013).

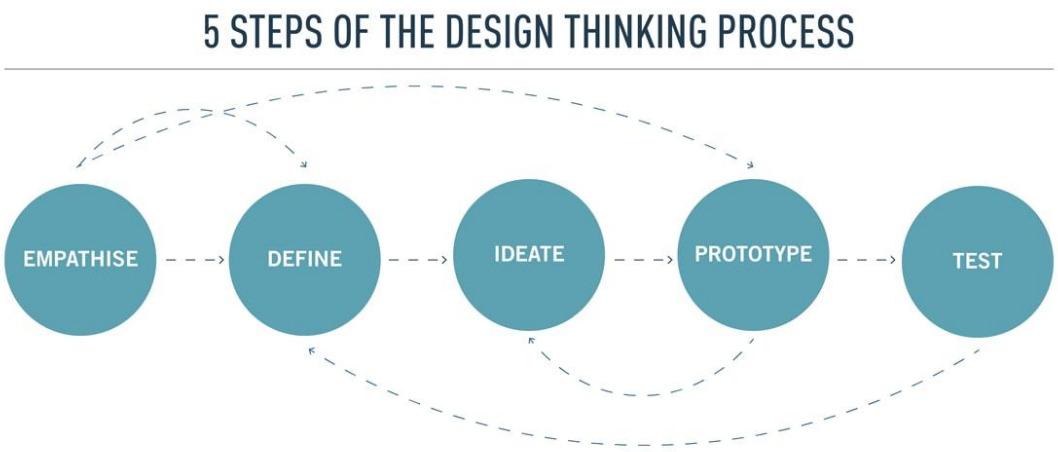

Figure 7. Five phases of iterative Design Thinking process (Stevens E., 2021)

Although Kelley & Kelley (2013) described only four phases of Design Thinking, in practice, there are usually five stages to be distinguished. Basically, the approach with five phases does not differ from the aforementioned approach, but it is considered more practical for this study and therefore will be followed in the following application part.

The process of Design Thinking, according to Müller-Roterberg (2018), is an iterative process in which all of the phases are connected, and, in any phase of the process, the innovators can go back to each phase. The visual presentation of the way different phases influence each other is presented in Figure 7. The same author distinguishes two groups among these phases. The first two phases ("Understand" and "Define") describe the source of the problem and the actual problem, therefore they are called a problem space part of Design Thinking. The solution to the problem comes in the next three phases ("Ideate", "Prototype" and "Test") where a solution is to be found and tested.

1. Understanding phase

Very similar to the empathy phase, this is the first step in the process where they try to understand the actual problem that they will be solving. The important things to note in this phase are the participants – the people who will be involved in the process, the technological aspect – what technologies are available, and the questions – innovators have to address the right questions to the right customers.

2. Define phase

This phase can also be called the "Observe" phase because it requires a lot of observations and detailed research on the source of the problem. The methods used in this phase are usually interviews or surveys conducted with customers with the final definition of the problem as the outcome of the methods applied. It is recommended to narrow down the research field and find one prototypical user whose problem will be solved in detail.

3. Ideate phase

This phase is best approached with a plethora of creativity in mind. This is a phase in which the separate ideas should be analyzed from a customer's point of view. The innovators should put themselves into the shoes of customers and try to find the bottlenecks of each idea that they have come up with to find the one that represents the most suitable solution.

4. Prototype phase

The visualization of the selected ideas should be done in this phase of the process. The idea is to be modelled or simulated, drawn, designed or simply, brought to life. The prototyping phase can be implemented to products as well as to services. Only after this phase is finished, are designers ready to step into the final phase of the process – the test phase.

5. Test phase

Further development of the selected ideas comes in the final phase – the test phase. It consists of a discussion of several experiments, market analysis and production processes needed for the implementation of the selected ideas. It is the final phase that comes only after the prototyping phase is successfully finished and developed prototypes and it pays off to test them properly. Customer feedback is also a part of this phase.

4. APPLICATION IN PRACTICE

4.1. Introduction to wood industry in Bosnia and Herzegovina

The practical application of the Design Thinking method will take place in the lumber industry in Bosnia and Herzegovina. Bosnia and Herzegovina has a long tradition in forestry and wood processing and is the regional leader in the forest coverage of the territory with 53% of the territory covered with forests (Bisnode BH d.o.o, 2016). This industry is export-oriented and accounts for about 10% of total country exports. Compared to neighboring countries, it stands out for its high profitability and relatively low financial risk, while the efficiency of asset turnover can be further improved. The financial assessment of companies in the lumber industry is slightly above the average of the Bosnian economy, and their business can be compared with companies in the same industry in Slovenia, Croatia and Serbia (Wood Industry and Forestry Association, 2020).

As raw materials, most of the companies are using beech, fir, spruce, and pine, but there are also vast amounts of oak and all other types of wood (Wood Industry and Forestry Association, 2020). A wide range of products are made in Bosnia and Herzegovina, from solid wood furniture, through solid wood panels, all the way to construction carpentry, parquet and floors and sawn timber.

The lumber industry is a significant branch of Bosnia and Herzegovina's economy. Its development is based on the use of predominantly domestic raw material resources and is traditionally export-oriented. The lumber industry is organized within several small and medium-sized privately-owned enterprises and is the only branch of the Bosnian economy that has had a surplus in international trade for many years. Given the quality of raw materials, mostly beech, and the pronounced trend of using wood as an ecological and renewable material in the world, it is realistic to expect an increase in production and exports of the lumber industry in Bosnia and Herzegovina (Wood Industry and Forestry Association, 2020).

Taking all this into consideration, it is safe to say that the lumber industry in Bosnia and Herzegovina has immense potential, but also a lot of place for growth and development where the Design Thinking approach can be very helpful.

4.2. Introduction to project "Innovative and profitable use of residual material in the wood industry"

The aim of the project "Innovative and profitable use of rest lots in the lumber industry", conducted by a Bosnian consulting and engineering company Targer Ltd. [http://targer.ba/], is to collect the information about different types of residual material produced in lumber companies in Bosnia and Herzegovina and find a new, profitable solution for the reuse of these materials. In the previous sections, there are many examples of similar solutions coming from all parts of the world, but the goal of this project is to extort an innovative and profitable solution for the lumber industry in Bosnia and Herzegovina. The project aims to utilize Design Thinking to find this solution, with the help of various companies involved. The author of this study is participating in this project as a part of Targer Ltd. team that is leading the entire project. Currently, besides Targer Ltd., there are four companies from the wood sector that are taking part in this project:

1. EL Company, Visoko, Bosnia and Herzegovina [http://el-companydoo.com/]
2. Megadrvo, Bijeljinja, Bosnia and Herzegovina [http://www.megadrvo.net/sr/]
3. Nova DI Vrbas, Banja Luka, Bosnia and Herzegovina [http://nova-di-vrbas.ba/bs/]
4. BH Service, Vitez, Bosnia and Herzegovina (a representative of the Italian manufacturer of woodworking machines Biesse)

All these companies are based in the lumber industry sector and even though they all have a different product assortment, they are all dealing with the same problem: large amounts of residual material left over during the production phase.

During the first phase of the Design thinking – Empathize phase, the initiators (Targer Ltd.) are trying to connect with representatives of lumber companies to better understand the problem and the needs of the companies, but also to gain first-hand information. In this case, all participants can be considered innovators, but lumber company representatives are the ones that know the market and can also be considered customers.

Currently, these companies are facing a problem of very large amounts of residual material, but they are, in most cases, able to find some temporary solutions for their utilization. For example, in most cases, companies are using the residues for ignition to heat the dryers in their firms. This

solution is, essentially not the kind of solution that brings profit to the companies. The project aims to find a better, environmentally friendly and more profitable solution for the companies. The project is divided into six interactive workshops moderated by Targer Ltd. Each workshop is hosted by one of the participating companies. The author of this study contributed to the workshop's organizing, realization, and overall concept growth by preparing presentations, investigating possible ideas, and conducting the full research with help of other participants. There will be five workshops, e.g. project phases, because there are five phases to the Design thinking process, and each workshop will focus on one of those phases.

4.2.1. Empathize phase

The first workshop was hosted by a company called Nova DI Vrbas. The aim of the first workshop was for participants to get to know each other, to present companies involved, learn about the types of residual material, and discuss current ways of utilizing residual material from wood processing.

During the workshop, along with the discussion, the participants had a chance to take a tour inside the company and see the process of making wood products from the beginning until the end. The tour was long since the company covers an area of about 395.840 m^2 and is one of the largest companies in this area. The primary activity of the company is the production of solid wood furniture, veneered, panel and upholstered furniture, with technology that entails the process from primary processing, drying of raw materials, through the production of solid boards to the production of the final product. The briquette factory also has briquette production facilities.

Nova DI Vrbas classifies a lot of residues in its production, and it is a waste of a different kind. During the tour, participants were able to see firsthand the boxes with production residual material, mostly from the first phases of production. One of the examples are slats that can be seen in Figure 8. below.

Figure 8. Slats as residual material from Nova DI Vrbas

Another very widely present type of residual material coming from manufacturing is shown in Figure 9. In front of the Nova DI Vrbas company grounds, there are tons of residual material, called plates, as shown in the image. It looks like a vast landfill of wooden products, but in fact, most of this residual material will be used for heating as mentioned before.

Figure 9. Tons of plate type of residual material in front of Nova DI Vrbas

However, as their representative believes (but does not have valuable data now), this company, similar to all other participating companies, produces most of its residues in the form of sawdust, shown in Figure 10.

Figure 10. Sawdust at Nova DI Vrbas

Sawdust is present everywhere in the company, especially within the first phases of production and manufacturing. That being said, this company was most interested in solving the problem of sawdust residues.

After the company tour and introduction made by their representatives, the participants came back to the office with a clearer vision of the problems Nova DI Vrbas faces. The innovators (Targer Ltd. representatives) presented various possible ways for wooden residues utilization did worldwide.

Figure 11. PlanToys product made from PlanWood material (PlanToys, 2021)

One of the most interesting ideas to all the participants was the idea of manufacturing toys for children using a special material made mostly of sawdust. This material is called PlanWood, and it is a special material made by the company named PlanToys from Thailand. This material is used to manufacture eco-friendly toys, shown in Figure 11, for children worldwide.

Even though this is a very intriguing idea and is, in the opinion of all participants, very profitable, the problem is the fact that the new company would have to arise to make this idea work. The reason for that is that there are no toy manufacturing companies in Bosnia and Herzegovina, there are only small, usually family businesses that are using primary raw materials for their production.

Figure 12. Wooden wedges (United Abrasives, Inc. / SAIT, 2021)

Another interesting idea arose by sheer chance. Namely, during the introduction of the companies at the beginning of the meeting, EL Company's representative showed to the participants some of the products that his company is specialized in. For Bosnia and Herzegovina's market, products like wooden fences for animals are something new, before unseen within the country.

Besides the main products mentioned above, EL Company's representative showed one additional product that he makes a profit from – wooden wedges, shown in Figure 12 and Figure 13. that are widely used in the assembly of carpentry, doors, windows and similar.

Figure 13. A package of wooden wedges (32 pieces) from EL Company

As it can be seen in Figures 8. and 9., Nova DI Vrbas classifies a very huge number of wooden slats as a type of residual material that occur during production. At this point, the company representative was not sure whether the company has a bigger amount of sawdust or slats, but it is clear to everyone who visits the company that both types of residual material are present an issue. Therefore, the idea that came

to the minds of participants to make wooden wedges from slats was undoubtedly intriguing to all participants.

During the first workshop, the participants have also done an approximate calculation on the company's profit from this specific product. The selling price of a package shown at Figure 12. is 3.5 BAM (1.8 €).

The price of 1 m^3 of wood is approx. 1200 BAM (600€). The quantity of wood used for one box is 0.02*0.018*0.1*32/2=0,000576 m^3. This means that approx. 1700 boxes can be made from just one cubic meter of wood. Considering that one box costs 3.5 BAM, it is easy to calculate that approx. 6000 BAM (3000 €) would be made for the price of 1200 BAM (600€). The profit, in this case, would be 4800 BAM (2400 €), but it is important to mention that production costs have not been considered, therefore this calculation is considered only as an approximate calculation.

However, knowing the approximate amount of money that comes from a product that is easy to construct and produce and can be made from residual material such as slats, gives a very positive outcome from the first workshop. After the rough calculation has been done, wooden wedges have become a very interesting topic to the participants.

The workshop continued until the end of the day when the participants stated that it is of high importance to try to find a suitable solution for the problem of sawdust residues, not only at Nova DI Vrbas, but at all participating companies. The companies have committed to finishing the survey provided by the initiators with more precise data that they need to provide to be able to find the most suitable solutions. The results of a survey are presented in the following section.

4.2.1.1. Results of a survey

A survey has been conducted among participating companies and six other companies from Bosnia and Herzegovina as a part of empathize phase. In order to better understand the market, initiators have created a survey sent to a various companies in Bosnia and Herzegovina. Eight companies responded to a survey and the results of this survey are to be presented and discussed at the second workshop.

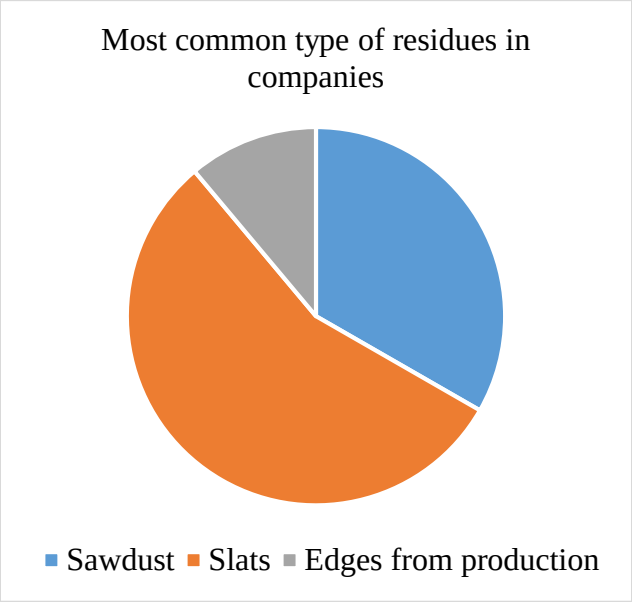

Figure 14. The most common type of residual material in companies

The survey results have answered many important questions. Firstly, it was found out that 77.8% of respondents state that the most widely used raw materials in their companies are beech and oak. The second place is taken by MDF (medium density fiberboard) with 55.6% of companies using this material for production.

Figure 14. shows a graph with information about the most common types of residual material in companies. The red color (55.6%) stands for slats, which makes it the most common type of residual material. Despite expectations, sawdust takes the second place with one-third of companies stating that sawdust is their most common residual material type. Only one company (11,1%) considers edges gained through production as their most frequent residual material type.

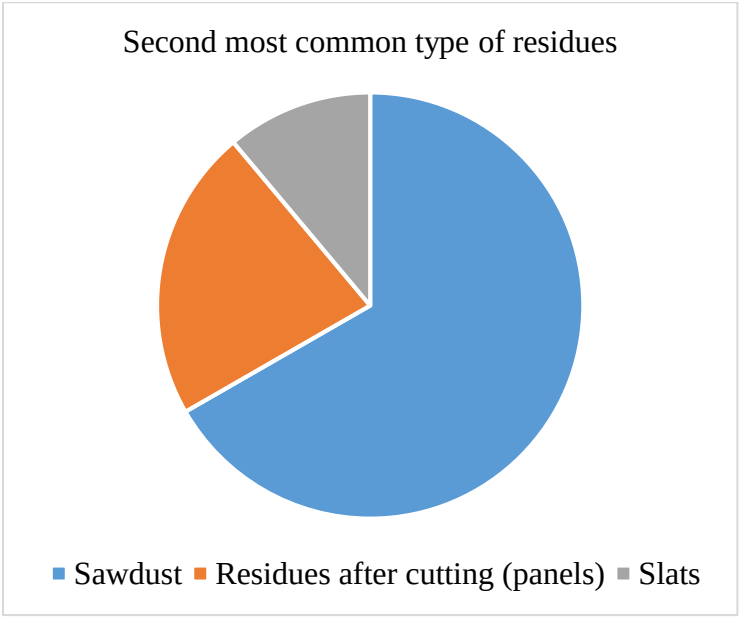

Figure 15. Second most common type of residual material in companies

Out of the five companies that claim slats are their most common type of residual material, 75% of them also state that they take up to 30% of all residual material in companies. Based on the survey results, common dimensions of these slats are (10-20) cm x up to 20 cm x (20-30) mm and yearly, companies record approx. 500 – 1000 m^3 of slats as residual material.

With 66.7%, sawdust is the second most frequent type of wooden residual material among respondents, which can be seen from the graph in Figure 15. Residues after cutting (panels) take the second place, while slats, as the second most frequent type of residual material, are only present at one company (11.1%). 100% of respondents state that sawdust takes up to 30 m^3 of all of their residual material, while on a yearly basis it means approx. 500 – 1000 m^3.

Based on further results, 66.7% of respondents are already utilizing their residual material. In most cases, they use it in boiler rooms or for briquette and pellet manufacturing. Only two companies have stated that they use them to make some office elements only for their own needs.

Even though the results of a survey have mostly been expected, it can be very useful for further research. The second workshop will entail a discussion about these results and the presentation of further ideas and possibilities for wooden residual material utilization. After obtaining the above-presented results, it is easy to conclude that the focus of this project should be on finding optimal solution for utilization of slats and for sawdust. In the end, all types of residual material can be turned into sawdust.

The results of this survey lead to the conclusion of the first phase of Design thinking process. The survey and research have provided the necessary information to understand, mark and define the problem, which brings the project to the next level - the second phase of Design thinking.

4.2.2. Defining a problem

The second workshop was hosted by EL Company. The main topics of discussion were the potential ideas that each participant has researched. The ideas were more precise than during the first workshop and were a result of the discussion at the first workshop.

In the beginning, EL Company's representative has presented the production process of his company to all of the participants. The company is smaller compared to last workshop's host Nova DI Vrbas and therefore, the number of products is smaller. EL Company's work is based on the

export of products designed for pets (pet fences and houses) and they produce a vast amount of residual material during the whole production process.

Figure 16. Sawdust mixed with small wooden cubes

Figure 17. Slats in EL company

There are different types of residual material in the production process, as can be seen in Figure 16 and Figure 17. Similar to the survey results, slats and sawdust are the two most frequent residual materials present in this company. The left figure shows a huge amount of sawdust mixed with small solid parts that have a cubic shape, while the figure on the right side represents residual material in a form of slats with different dimensions.

However, these are not the only locations where the company is storing its residual material. The largest amount of residues is stored outside of the factory building, as can be seen in Figure 18. Needless to say, this company has a huge amount of residues and therefore, a very huge potential to utilize them.

After the tour, the ideas were presented and discussed. It was concluded that the main focus of this workshop, as well as all future workshops, will be to find a solution to the problem of sawdust and slats. The outcome of these workshops can be a solution for both problems or just for a problem of sawdust, because, as said before, slats can always become sawdust.

Figure 18. Production residual material in a form of a plate stored outside of fabric

The discussion has led to the construction of a graph that represents possible ways to utilize slats and sawdust, presented in Figure 19. In fact, there are three different paths that participants can take to find the best solution for their problem: new technology, new utilization, and new business model.

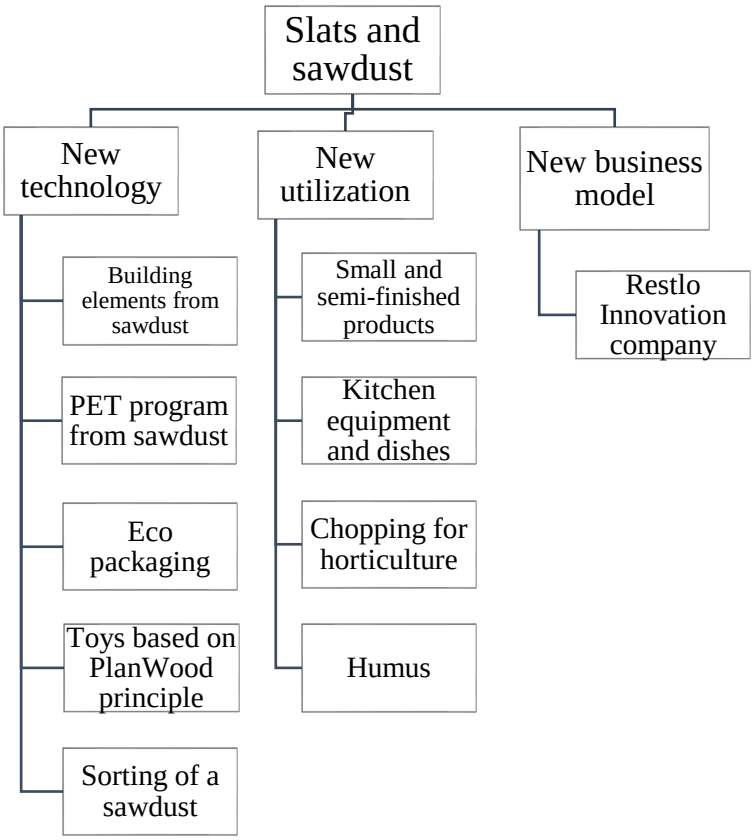

Figure 19. Different ideas for possible utilization of slats and sawdust

1. New technology

This path has five possible solutions in which a company can consider utilizing new technology, meaning that with existing resources a company would not be able to manufacture these products. One of the most intriguing ideas are the building elements, e .g. building bricks, presented at Figure 20, or isolating material made mostly out of sawdust.

The bricks made mostly out of sawdust are eco-friendly bricks that provide a significantly good sound and heat insulation on objects, and they are completely resistant to seismological vibrations. Besides that, they are very light, and their price is reasonable and affordable. Their biggest disadvantage is the fact that they have poor moisture resistance.

For example, a company from Italy named Isotex with a branch in Banja Luka, whose brick can be seen in Figure 20, is offering a complete service of building objects using these types of bricks. However, this company does not produce the bricks, so the participants have agreed to contact this company in order to get information about technology that they are using.

Figure 20. An example of building brick made by Isotex (Isotex product catalog, 2021)

Because of its insulating properties, sawdust is and can be used as an insulation material instead of Styrofoam. The participants have agreed that these two utilization options are very intriguing and have great potential, therefore will be further analyzed in upcoming workshops.

The new technology needed to produce toys was already discussed. However, another intriguing idea that needs to be investigated is the possible utilization of sawdust for the purpose of eco-packaging. Since the European Union is planning to ban the use of Styrofoam in the near future, this solution would be very helpful.

The study touched upon another significant issue – a problem of fractionation of sawdust. In order to make

these products, the sawdust needs to be sort by its size. The innovators and researchers investigated this issue in the upcoming workshops.

2. New utilization

New utilization essentially entails considering and researching different ways to use the sawdust that are already known to the participants. The most interesting idea, in this case, was the application of residual material for the purpose of horticulture development. Namely, wooden residual material can be used as a mulching material in the garden for growing several of plants. The most used type of these residual materials in this case is actually bark – a part of wooden raw material that usually ends up discarded as waste. These products can be packed in bags and distributed to large garden centers.

When it comes to small finished and semi-finished products, it is easy to say that taking this path would probably be very reliable. The idea arose during the tour of the EL Company where the participants were able to see that most of the company's profit came only from products made from slender wooden boards that could easily be some company's residual material. Therefore, the term "small finished and semi-finished products" represents industrial symbiosis.

In this concept, each company should sell their residue (not sawdust) to other companies that might need it. This way the companies would be connected, and the amount of residual material would significantly decrease. However, it does not solve the problem of residual material completely, because the new utilization would still make waste during production.

Kitchen equipment and dishes were discussed briefly, as there are a lot of small start-up businesses in Bosnia and Herzegovina that are producing kitchen accessories. In most cases, these products are based on wooden components combined with epoxy resin. The biggest disadvantage in the case of epoxy resin is the product price, which makes it less accessible to consumers in Bosnia & Herzegovina.

3. New business model

Even though a new company or a new business model could and probably would arise from most of the above-mentioned solutions, the Restlo Innovation Company is the only example presented in this case, as it contains all the above-mentioned ideas.

Namely, this company would have the purpose of manufacturing different kinds of products from production residual material. Companies existing in Bosnia and Herzegovina would sell their residual material to this company that would then utilize it differently based on their type, properties, shape and amount of delivered residual material.

This company could, in fact, specialize in making all the products from the "New utilization" phase and probably some products like PET program (housing and other useful facilities made esoecially for animals) and eco-packaging from the "New technology" phase. The cost-benefit analysis for both the new company, as well as for existing wood companies is still to be calculated.

Having defined the three possible paths that the project could take, the participants have managed to pinpoint the problem these companies are facing. In fact, from this point on, the aim of the project will be to find the use-value for slats and sawdust and in all the upcoming workshops, the main focus will be set on these two residual material types.

4.2.3. Ideate phase

The participants have now found themselves in the middle of the project and the entire process of Design thinking. The problem has been defined and the goals are set. There are several ideas, some of them mentioned in previous sections, but the new ideas arise quite frequently. In the first workshop, the company representatives have mentioned that one of the main upcoming problems for them is the fact that, by 2024, they will need to find an alternative for ESP (Expanded Polystyrene, Figure 21) – a material commonly used in the transportation of lumber industry goods. This problem intrigued the participants and had them organizing a third workshop in the Megadrvo Company.

According to the Directive of the European Union and Council (2018), "all packaging on the EU market is reusable or recyclable in an economically viable way by 2030". Also, this year, European Union banned the use of many plastic products among which is also a polystyrene foam used for food and beverage packaging.

Polystyrene has contaminated and harmed both the environment and our health as a result of its widespread use. Namely, plastics take up 25-30% of landfill space. Polystyrene, when discarded as waste, does not biodegrade or break down in any other way, and it can last for thousands of years in the environment. Foam polystyrene has been discovered in water, particularly near coasts.

Polystyrene can cause cancer and digestive disorders for the sea animals, but can also be harmful to wild creatures (Miller, A. et al. 2009).

Figure 21. An example of Styrofoam packaging used nowadays for transportation matters (Flagel, 2020)

Unfortunately, Styrofoam is commonly used as packaging material in Bosnia and Herzegovina as well. Therefore, finding an alternative for this type of material would be very beneficial for all export companies in Bosnia and Herzegovina. Brainstorming among participants was very intense, but only two ideas have made it to the end of the workshop.

- Textile packaging

  The idea about this kind of packaging arose during the brainstorming and it was inspired by the bubble packaging shown in Figure 22. Basically, the idea is to pack sawdust residues from production into bubbles, like those in a bubble wrap, to make a material that could replace EPS.

Figure 22. Plastic bubble wrap (Safe packaging, 2020)

Eventually, participants realized that, due to the properties of sawdust, the bubbles would have to be a lot bigger than the ones currently used in bubble wrap. Since the main advantage of this type of packaging would be its eco-friendliness, it is impossible to even consider packing sawdust residues into any kind of material made from plastic. Therefore, participants came to the idea to pack sawdust residues into residues coming from the textile industry, which is where the name "Textile packaging" arose. This way, industrial symbiosis would also be achieved.

The principle is simple. First, the textile bubble wrap would have to be sewn. After that, sawdust residues from fabrics need to be collected and then, the wraps must be filled with sawdust residues of the proper amount. A sketch of this idea is to be seen in Figure 23.

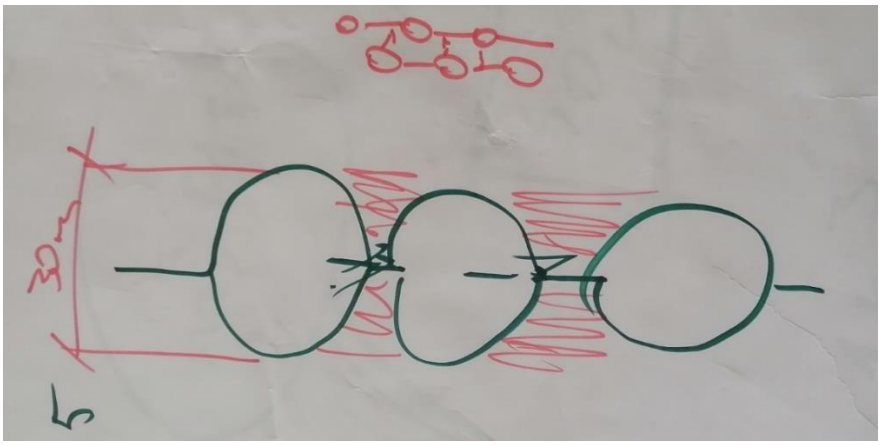

Figure 23. A sketch of textile packaging idea

This idea seemed very fascinating to all of the participants; however, it needs further experimentation that will show possible bottlenecks which may not be initially obvious. For example, one of the bottlenecks is for sure the fact that sawdust is usually wet which could lead to mold problems if packed as a textile wrap. On the other hand, the process of drying the sawdust is energy consuming and costly. However, what is definite, is that this is the kind of product that the participants were aiming for and the idea will be further analyzed.

- Mushroom packaging

The second possibility that participants have observed is the so-called mushroom packaging – an eco-friendly, bio-degradable kind of packaging. This type of material is very easily produced using hyphae – a vegetative, root part of fungus shown in Figure 24.

(Flagel, 2020). Mycelium is, in fact, a name used to describe a mixture of agricultural waste with hyphae. Many types of waste can be used as agricultural waste and one of them is sawdust or wood chips from the lumber industry.

Figure 24. Hyphae (Flagel, 2020)

Figure 25. Mycelium packaging used for wine bottles (Froelich, 2016)

The process of production is simple:

1. Agricultural waste (sawdust) is collected, pasteurized, and left to cool down below 35°C.
2. Hyphae, a white root part of the fungus is grown and ready to be mixed with waste.
3. Sawdust is put into a mold of desired shape, mixed with hyphae, and left to grow for cca. 4 – 5 days.
4. By that time, the material should have grown together into one piece forming a solid structure
5. The last step is to put the acquired structure under pressure to remove the water out of it and prevent actual mushrooms from growing

6. The gotten solid structure, shown in Figure 25, has mechanical properties like those of polystyrene foam.

Figure 26. Eco-furniture (Froelich, 2016)

Besides packaging, this material structure can be used for a variety of other products. For example, one very interesting application is as eco furniture, shown in Figure 26. Another great use comes in form of a substitute for organic or petroleum-based plastic. The products made from mycelium foam as the base material have properties like those of plastic. Other than that, mycelium has found its application in footwear and as a leather alternative. However, it is safe to say that the use of mycelium for packaging matters is the most valuable of all applications.

4.2.4 Prototyping phase

The fourth phase of Design thinking was the subject of the fourth workshop held in Nova DI Vrbas. Up to this phase, participants have faced many obstacles and have come up with many different ideas (all presented in this thesis work), but only two of these ideas will be prototyped and tested in the end – mushroom and textile packaging.

Between the workshops, participants have made a prototype for textile packaging using residue from the textile industry and sawdust–lumber industry residue. The outcome is presented in Figure 27. There are three different kinds of pillows stuffed with sawdust. They differ in size and amount of sawdust used to fill the pillows. In this prototyping phase, the kind of textile that was used is the same kind that is used for actual pillows, which can be very costly. However, this was satisfying for the prototyping phase because mechanical properties are the ones that were being measured.

Figure 27. An example of pillow stuffed with sawdust, dimensions 5x5

The pillows were knit and stuffed with sawdust. The testing of its properties was done by participants. Namely, one of the participants stood on a 1m tall table and threw hard, solid, wooden parts directly at a wooden part protected with textile packaging and later with Styrofoam to make the comparison. As the experimental wooden part, participants have used a residual wooden plate from Nova DI Vrbas with 50x20x10 (cm) dimensions. The Styrofoam used in the experiment was 5cm thick and for testing, participants have used one and two layers of Styrofoam to protect the wooden part. Pillows of three different dimensions (20x20, 10x10 and 5x5) represented textile packaging alongside the most realistic type of so-called textile packaging presented at Figure 28.

Figure 28. The most realistic type of textile packaging

The results of testing in this improvised environment were very similar because both materials acted almost the same. For example, Styrofoam, as well as all textile packaging, broke apart as the load hit it, leaving a significant indentation on the surface of the wooden part. The observing participants noticed that the damage was more significant in the case of Styrofoam when compared to all types of textile packaging. Further, detailed measurements should be done to obtain valuable results. The improvised conditions and lack of measuring devices are reasons why this testing is only approximate. However, it helped participants gain a better perception of the whole idea and its benefits.

The second experiment was done with mycelium. The experiment was implemted with the help of prof. Osmić who deals with the cultivation of mycelium to grow mushrooms for years. The process rests as follows:

1. Mycelium is grown in a laboratory. According to prof. Osmić, who is specialized in these technologies, approx. 2 months are needed to grow mycelium properly.

Figure 29. Mycelium grown in lab and ready to be utilized

2. Grown mycelium, shown in Figure 29, is mixed with different kinds of residues, from agricultural to sawdust. It is advisable to use a mixture of straw and sawdust in order to obtain the properties needed to grow mushrooms.

3. The mixture of mycelium and residue must be left for 4-5 days in a dark environment to grow properly. The needed temperature is around 20°C with humidity between 70 and 80%. The mixture must be covered with nylon. Also, it is advisable to pierce nylon with a needle to assure airflow during the process. Figure 30. shows how the mixture should look 2 days after it has been planted. The picture is taken up close to show how mycelium has started to spread among sawdust.

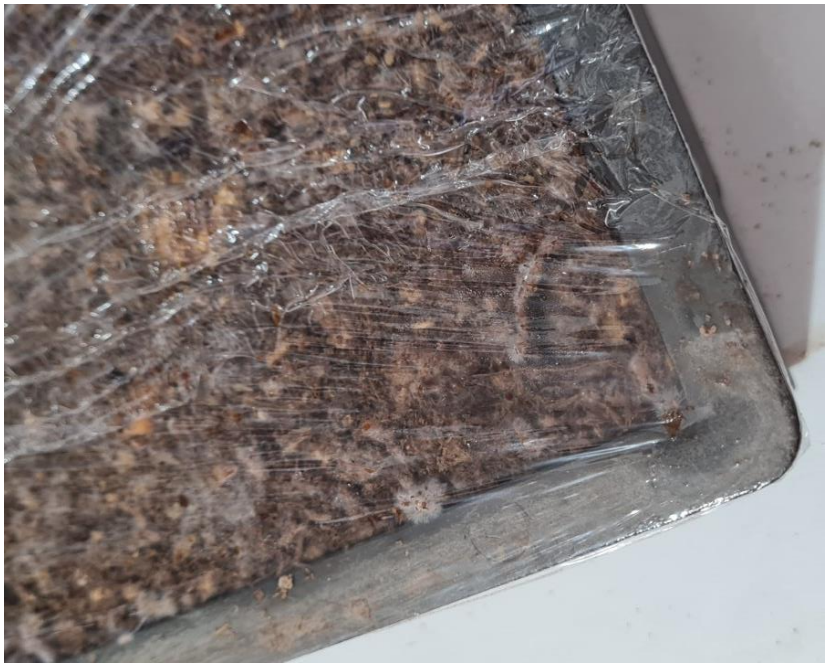

Figure 30. Mixture of mycelium with sawdust 2 days after planting – mycelium started spreading

4. Approx. 3 days after the mixture has been mixed, assuming that all environmental conditions are satisfied, the acquired mixture should look like one in Figure 31.

Figure 31. Mixture of mycelium and sawdust 3 days after planting

5. To avoid mushrooms from growing out of the mixture, it needs to be dried out. That can be achieved using different methods – either pressure or high temperature. Either way, the mushrooms are “killed” and the mixture can be further utilized as packaging material. Questions regarding the lifetime and properties of acquired material arose. The properties of the final product can be manipulated. Some properties of the mixture, like stiffness, could depend on the quantity and quality of mycelium and waste mixed. That means that, to obtain properties like those of Styrofoam, participants have to find the right ratio of mycelium and sawdust. For this to be achieved, further experiments must be conducted. Its ability to mitigate circumstance is why this product is already being developed and produced throughout the world, most commonly by a company named Ecovative [https://ecovativedesign.com/].

Figure 32. Four different samples used for experiments with mycelium

Four different samples of sawdust and mycelium mixture, shown at Figure 32, were planted and grown. The sawdust used in these experiments is the low granulation sawdust.

First sample, the one with the biggest amount of mycelium (10%) and humidity around 70% was the first one to start germinating. Other samples (2,3) were planted with 5% of mycelium and 50% humidity which turned out to be a bad principle, because the lack of humidity negatively affected the whole germinating process. In fact, germinating almost did not happen at all. In the last case (4), 3% of mycelium was mixed with sawdust on 60% humidity. This sample germinated a bit slower than the first sample, but the overall process was successful.

With knowledge acquired up to this phase of Design thinking process, it can be concluded that mixture of mycelium with low granulation sawdust germinates at the fastest speed when the humidity is at least 70% and the percentage of mycelium as high as possible. However, participants agreed that further experiments, with

different types of sawdust also need to be conducted in order to find the most successful formula. Prof. Osmić suggests the repetition of the whole process with a coarse granulation sawdust, as he believes that could fasten the overall process.

As mentioned above, further experiments are going to be made, but the results are beyond the scope of this thesis work. In the next chapter, the cost and efficiency of this packaging will be presented to the market of Bosnia and Herzegovina.

4.2.4.1 Cost – benefit analysis

The cost-benefit analysis will be done as precise as possible at this stage. The mixture of mycelium with sawdust will be compared to Styrofoam – its competitor as a packaging material and with briquettes – its competitor in sawdust utilization. The price of 1 m^3 of Styrofoam will be compared to the assumed price of 1 m^3 of mycelium packaging.

The purchasing price of Styrofoam on the market of Bosnia and Herzegovina differs, but is approx. 70 BAM/m^3 (70 BAM = 35 €). On the other hand, the purchasing price of mycelium, according to prof. Osmić, who is a potential mycelium supplier, is 1.5 BAM/1L (1.5 BAM = 0.75 €). When it comes to purchasing sawdust, the situation is a bit different because companies sell sawdust for the different price and some also give it away for free. Therefore, the approximate purchasing price of sawdust will have to be considered. Participants agreed that it would be approx. 20 BAM/m^3 (20 BAM = 10 €).

Table 1. The comparison of Styrofoam and mycelium eco-packaging

	Styrofoam	**Mycelium eco-packaging**	
Purchasing price (€/m3)	35,00	sawdust: 10,00 mycelium: 7,50	17,50
Operational costs (€)			10,50
Profit (€)			8,50
Total (€)	35,00		36,50

On 100kg of sawdust, 3 – 5 L of mycelium is used. This means that 200 kg of sawdust (an estimated amount of sawdust in 1 m^3) would be mixed with a maximum of 10 L, so the price would equal 15 BAM (7.5 €). Taking this into account, it can be concluded that the combined price for raw materials equals 35 BAM (17.5 €). Operational costs (for example manpower) per 1 m^3 is approx. 60% of the total raw material price – 21 BAM (10.5€). Combined, all the costs would equal 56 BAM (28 €). Of course, profit must be considered. Participants agreed on a profit margin of 30% of the combined costs mentioned above, which would equal 17 BAM/ m^3 (17 BAM = 8.5 €). Concluded, the total cost of mycelium packaging is 73 BAM/ m^3 (73 BAM = 36.5 €).

On the other hand, mycelium eco-packaging is a competitor to briquettes in terms that it uses the same raw material – sawdust. Therefore, it is beneficial to compare costs and benefits of briquettes manufacturing to the costs and benefits of mycelium – eco-packaging.

Calculation for the total costs of manufacturing briquettes is taken from a company Megadrvo that has a complete briquettes production facility from start to finish within its company. The calculation will be based on 1t (1000 kg) of sawdust, so the previously made calculation cannot be taken into account.

In order to gain a desirable mixture with 1t of sawdust, 30 – 50 L of mycelium is required. As mentioned above, 1 L of mycelium costs 1.5 BAM (3€), which means that 45 – 75 BAM/t (22.5 € -37.5 €) would be the total cost for mycelium. Sawdust can be purchased for the price of 20BAM/ m^3 which, when recalculated, means that 1t of raw sawdust costs 100 BAM (50€). Combined, both materials can be purchased for the price of 145 – 175 BAM (72.5 – 87.5 €) approximately.

Table 2. Cost analysis for mycelium eco-packaging with 1t of sawdust

<table>
<tr><td></td><td colspan="2">Mycelium eco-packaging</td></tr>
<tr><td rowspan="2">Purchasing price (€/t)</td><td>sawdust: 50,00</td><td rowspan="2">72,50 – 87,50</td></tr>
<tr><td>mycelium: 22,50 - 37,50</td></tr>
<tr><td>Operational costs (€)</td><td colspan="2">43,50 – 52,50</td></tr>
<tr><td>Profit (€)</td><td colspan="2">35,00 - 48,00</td></tr>
<tr><td>Total (€)</td><td colspan="2">150,00 - 175,00</td></tr>
</table>

Operational costs have to be taken into account here as well. Again, it will equal 60% of total raw material price 87 – 105 BAM (43.5 – 52.5 €), which, when added up, means that the total price to produce mycelium eco-packaging with 1t of sawdust is between 232 BAM (116 €) and 280 BAM (160 €). Profit is calculated as 30% of the final price, which means that, in total, when costs and benefits are summed up, mycelium eco-packaging costs 300 - 360 BAM (150 – 175 €)/t of sawdust.

Production of briquettes, as a competitor in this case, based on the calculation made by Megadrvo is a bit less expensive. Annually, this company produces 8320 t of briquettes. In their case, 4 people work, 8h per day, which equals 32 hours/day. However, it has to be summed up with 2 hours of maintenance, so it equals 34 hours/day. They work 6 days per week, which equals 204 hours per week. Weekly, company produces 96 t of briquettes. 204 hours multiplied with 10 BAM (hourly salary) equals 2040, divided by weekly production of 96 t equals 21,25 BAM/t. Amortization and maintenance together cost 9 BAM/t, same as electricity. Summed up, production of a briquette costs 40 BAM (20€), while cost price recapitulation per 1t amounts 225 BAM (112.5€).

Table 3. Cost recapitulation of briquettes

Costs (€)	Production of briquettes
Manpower (€/t)	1020,00
Maintenance	1,00
Amortization	3,50
Electricity	4,50
Total	18,50
Cost recapitulation	112,50

It is obvious that the production of briquettes is definitely of lower cost than the production of mycelium eco-packaging. However, there is a very important advantage of mycelium eco-packaging that can compensate the price. Namely, mycelium eco-packaging will become an essential for the companies, not only because it is eco-friendly and protects our environment, but because of the upcoming ban in use of Styrofoam from European Union side. Therefore, mycelium eco-packaging may not be beneficial from cost point of view, but there are other benefits that compensate the price and can be considered even more important.

5. CONCLUSION

Waste of any kind is a significant world issue. This forced people all over the world to try and reduce the amount of waste we, as humans, produce in our day to day lives. In Bosnia and Herzegovina, itself, which is not considered to be an industrially developed nation, there are still significant residue producing companies, often in form of lumber and forestry companies. I employed the Design thinking method as a tool for my research, which took place from April to September of 2021. Design thinking is a relatively recent approach to innovation that is centered on the interaction between innovators and customers. This method showed to be very successful in narrowing the focus of the work from all wood residue to sawdust utilization and it helped to maintain this focus and avoid unnecessary latitude.

This study has followed all five steps of Design thinking method applied in lumber industry in Bosnia and Herzegovina. It has shown to be a very effective strategy for recognizing a problem and determining an appropriate solution. The primary benefit of this strategy applied in lumber industry in Bosnia and Herzegovina is that it uncovered multiple solutions to a problem. Finally, it is safe to declare that all of the proposed ideas have potential and should be further investigated. Participants will continue to work on bringing the concept of mycelium eco-packaging to life. Further mechanical property testing will be carried out to ensure that the optimal qualities are obtained for the various applications that this type of mixture can be utilized for.

Different solutions were presented. However, one of the ideas presented stood surely above the others in solving the sawdust residue issue within the lumber industry – the eco-packaging solution. This solution is, in my opinion, the most beneficial for all involved parties. It does not only tackle the issue of excessive product residue within the lumber industry but is also very eco and environmentally friendly. Eco-packaging, which is manufactured from a combination of sawdust residues from the lumber industry and mycelium, raises the prospect of replacing Styrofoam as a general packaging material, reducing the usage of plastic in transportation and packing. The solution is fully environmentally friendly and may even be used to make furniture. Because this is a fairly new technology, it has not been fully researched, so it is quite possible to expect that, in the years to come, many different applications are to be found.

From cost–benefit analyses, it can be concluded that this kind of packaging is definitely to be considered in the future. Even though the estimated price is a bit higher than the price of Styrofoam, it should not represent a major issue, as Styrofoam is destined to be discarded soon due to its harmful effect on the environment. However, what's very beneficial from this point of view is the fact that the predicted total price for mycelium packaging costs only 1.5€ more than Styrofoam, which is, in essence, negligible. Mycelium eco-packaging is the optimal utilization way for wood industries as well, at least according to participants in this research. The reason is simple – considering the amounts of sawdust needed for this purpose, mycelium eco-packaging would solve the problem of sawdust residuals for companies. Also, it is important to note the fact that, by solving a problem of sawdust residues, the problem of all wood residues is solved, as all other types of wood waste can very easily be converted to sawdust, while sawdust cannot be converted to, for example, slats. Therefore, the mixture of mycelium with sawdust is the solution that has been searched for from the beginning of this research.

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