TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Materials and Environmental Technology

WOOD MATERIAL RECYCLING ANALYSIS IN DOORS AND FRAMES PRODUCTION

PUITMATERJALI RINGLUSSEVÕTU ANALÜÜS USTE JA LENGIDE TOOTMISES

MASTER THESIS

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(On the reverse side of title page)

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Department of Materials and Environmental Technology

THESIS TASK

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Study program, KVEM12/20 Technology of Wood, Plastics and Textiles

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Thesis topic:

(in English) Wood material recycling analysis in doors and frames production

(in Estonian) Puitmaterjali ringlussevõtu analüüs uste ja lengide tootmises

Thesis main objectives:

1. Obtain an overview of present wood material handling and scrap recycling
2. Determine processes needed for different methods of wood scrap recycling
3. Study alternative methods of recycling and propose a cost calculation model

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Compiling an overview of product groups produced and finding the minimum processing allowance in the production processes	June 2021
2.	Data collection and analysis of current wood material usage and scrap recycling by departments	December 2022
3.	Finding alternative methods of wood scrap processing and their cost	February 2023
4.	Creating and testing the cost calculation model for scrap recycling. Analysis of the cost of different recycling methods	May 2023

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PREFACE

The master thesis was carried out in a wood company that produces doors and door frames. The company's production is large, and the product selection is wide, there are products with different qualities and surface treatments. According to this, the amount and type of wood scrap generated differ, and thus the recycling methods for wood scrap also vary.

Presently wood scrap is handled according to existing knowledge, but observations have shown that the current wood scrap handling process is not adequate. Present process does not provide an overview of whether the steps performed today to recycle the scrap products are reasonable and cost-effective. Since the company's own goal is to focus more on material saving and wood material reuse, this topic also received support.

In the course of the work, the use of material and the handling of scrap products were mapped in all departments of the company. Reprocessing methods of scrap products were explored and alternative solutions, in addition to today's solutions, were also considered. Based on the obtained data, a model for calculating the costs of reprocessing was created, based on material and labour costs.

The thesis uses company’s internal statistics and information obtained by interviewing the people responsible. The obtained data were processed and analysed using Microsoft Excel, the program was also used to create a recycling cost calculation model.

Special gratitude goes to the head of the company's Safety and Quality department, who has encouraged and supported this research.

Keywords: wood scrap, wood scrap recycling, material saving, cost-efficiency, the master thesis.

LIST OF ABBREVIATIONS AND SYMBOLS

FSC – Forest Stewardship Council [1, 2]

PEFC – The Programme for the Endorsement of Forest Certification [2, 3]

Yield – evaluated by factory level and by departments level. Sent out material by volume divided with input sawn material volume from the same period

WIP – work in progress

RPA – difficult defects repairing area

FTE - an employee who works full-time

Material allowance - the minimum necessary allowance needed for processing the product into end length

INTRODUCTION

The environment and its preservation have become an increasingly topical issue. People have become more environmentally conscious, and actions regarding how, what, and how much to consume have become more and more important. As wood is renewable environmentally friendly material it requires less energy for processing than any other material. Thus, it has gained wide interest in how to use it wisely and effectively. [2, 4]

The price of wood on the market is also a determining factor. Industries consume wood as raw material in large quantities; therefore, it is relevant to use wood effectively without wasting it. Regarding the costs, it is beneficial to have an overview of the use of wooden material and its recycling possibilities. Scrap material generated in industries has mostly already gone through several production processes, which have already generated cost for the company. Important is to understand what the possible uses of such materials are.

The Master thesis is carried out in a company JELD-WEN Eesti AS, which produces doors and door frames. Based on preliminary observations, the present recycling process is not being followed as it is described. Useful material also ends up in waste, which could be used inside the company. In addition, there is no overview of the cost efficiency of the existing wood scrap recycling process, so it is not known whether today's actions are reasonable.

The master thesis focuses on material usage inside the company and its material recycling process. The main objectives of the work are:

- To understand processes where wood scrap occurs by product type and by the department, to investigate what is done with the wood scrap within the company's capabilities;
- To determine processes which will be needed for recycling and analyse the cost of different recycling methods;
- To study alternative methods for wood scrap recycling and propose a cost calculation model for wood recycling.

This approach is also in line with the company’s goals by the year 2050: zero manufacturing scrap to landfill and 100% recycled or harvested materials will be recycled from external sources or internal processes [5].

The work is based on data obtained by interviewing various parties and collecting internal company data. The work analysis and data processing were done in the Microsoft Excel program. The complexity of work comes from the fact that the company has seven different departments, and the collection of data is not common across departments. Many decisions are made based on knowledge and experience.

Since the product range is wide, different products are produced, in the further course of the work it was necessary to focus on one department’s main products. This data was used as the base of the recycling model, and the cost of different recycling methods were estimated.

Having a better overview of the handling of scrap material and reprocessing methods creates more flexible opportunities for the use of scrap material. The model dataset does not determine which is the mandatory recycling method but shows the cost to the company of different methods. Over time, however, the needs regarding the product/material obtained from the processing of scrap material may be various, so different options for recycling the material can be considered according to the need.

1 OVERVIEW

A company named JELD-WEN was founded in the United States of America in 1960. At that time, the company consisted of only a sawmill, where 15 people worked. Today, the company operates worldwide, in 20 different countries. [6]

JELD-WEN entered the European market in 1993 and since then the company has grown continuously. In 2006, the company bought Vest-Wood, Europe's largest door manufacturing company from Denmark, which also included the production unit in Rakvere. [6]

JELD-WEN has set itself the goal of being environmentally friendly in its field of activity, focused on sustainability and environmental protection. Already in the product development process, the focus is on these goals. More and more raw materials are procured from sustainable suppliers. [1]

The company has a renewable, sustainable timber sourcing policy. It has FSC and PEFC multi-site chain of custody certifications dedicated to promoting responsible forest management [2, 3]. All doors produced in JELD-WEN meet the EU Timber Regulation, which goal is to prevent the trade in illegal harvesting of timber. [1]

JELD-WEN Eesti AS factory is in Rakvere, Estonia. The factory has 7 departments: Component, Component 2, Doors 2, Doors department, French frames, Cassette, and Scandinavian frames. [7]

The eight department, the Sawmill, was closed at the beginning of 2023, due to the global situation and increased labour and energy costs [8]. Since this department is now closed, it will not be discussed in the scope of this thesis.

1.1 Literature overview

Wood material has many good properties, it is renewable resource of energy and as it is a natural material, it is also environmentally friendly. Wood has remarkable properties regarding thermal and mechanical characteristics and therefore it is increasingly used in various applications. [2, 9]

The terms green production and sustainable solutions are used more and more, so more attention is paid to the properties of wood such as low carbon impact and low embodied energy. Embodied energy refers to wood material that requires less energy for processing than any other material. [2]

Trees use carbon dioxide to produce wood and release oxygen. Carbon will remain into the wood material during different kinds of processing and usage stages. It is common that wooden material that has outlived its useful life or is no longer suitable for its original purpose, is reused in another structure: smaller product, chips, sawdust, or fuel as bioenergy. Carbon will be released when the wooden material deteriorates or burns (Figure 1.). [2, 10]

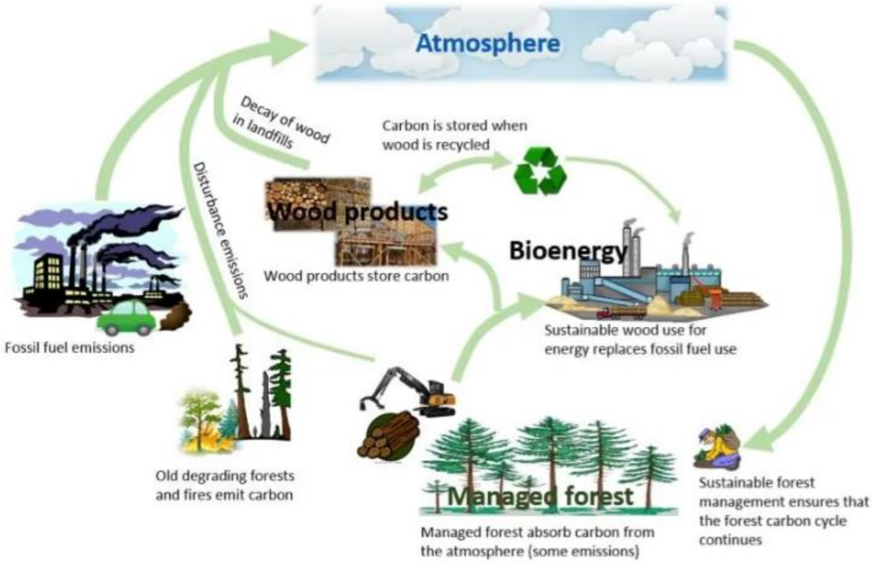


Figure 1. The sustainable forest carbon cycle [10]

However, regarding wood, it must be understood that this material does not grow as quickly as it is harvested. The demand for wooden material is high considering its good properties and wide field of use. This, in turn, raises the question of how to use the wood material that has already been harvested economically and efficiently. [11]

1.1.1 Regulations and circular economy

According to the concept of circular economy, it is a production and consumption model in which existing materials and products are reused, repaired, borrowed, and recycled for as long as possible to extend the product's life cycle. [12]

In 2020, the European Commission adopted a new circular economy action plan for a cleaner and more competitive Europe. For nearly 80% of products, their environmental impact is already determined at the planning and design stage. Thus, it is predicted that within a couple of decades, the amounts of waste will grow in such a way that they will start to strongly affect the surrounding environment. [12, 13]

In response to the Commission's decision, the European Parliament adopted a resolution in 2021 with the aim of reducing the impact of production and consumption on the environment. It is desired to achieve carbon neutrality, a sustainable and non-toxic circular economy by 2050. [12, 13]

In order to achieve the goals of the Green Deal, a functioning circular economy is needed, so in 2022, the European Commission adopted decisions to accelerate the transition to a circular economy. The goal is to empower consumers in the green revolution and promote sustainable products. [12, 13, 14]

In relation to timber, this approach and set goals are also supported by the EU timber regulation, which aims to regulate trade in timber. The focus is to prevent the sale of illegally harvested wood, which directly impacts the environment and the economy. Also, that illegal lumber would not be used for the production of products, and for sale on the European market. The regulation also aims to strengthen the countries' forest management systems in order to preserve their biological environment and thus more valorisation of the available material [15, 16]

Also following the principles of the circular economy, wooden material should be planned more consciously already at the stage of product design, considering the accompanying residues and costs. When handling the material, it is important to understand the need for the product in the market in order to avoid unnecessary actions. In addition, already at the initial production stage, should be considered the amount needed for production, to avoid unnecessary misuse and excessive consumption of wood. [17]

1.1.2 Cascade use of wood material

The cascade use of wood is one of the widely used concepts for which several explanations and definitions can be found. In general, wood cascade use refers to reusing wood material or reprocessing it to give the wood more value. This means prioritizing the use of existing material rather than taking new material from nature. In addition, the focus is on how to use the production residues resulting from the material processing as effectively as possible. [18]

This concept also highlights the importance of the end use of the material. For example, it would first make sense to use the natural resources-based materials for the production of buildings or furniture, which have longer life-service, and the resulting residues or scrap for some other product with smaller life-service. [18]

Wood material has many uses, but the most valuable is primarily lumber, which can be used to produce various products. A less important but primary use of wood can also be the production of pulp and paper. The by-product generated during timber processing could be used to produce wood-based panels. For heating and energy purposes could be used any kind of wood, but more wisely is to use the residues generated during processing, or residues from harvesting and other discarded wood. After the burning, the ash could be used as fertilizer, thus the material would be perfectly recycled. [19, 20]

In the case of cascade use, there are different stages. The first stage is considered where the wooden product is used once more before it is used for energy. The multi-stage approach is that the material is used several times before it is utilised and used for energy purposes. Using the scrap material firstly for energy usage is not considered as cascade use, as the energy should be in the end-of-materials life cycle. The lower Figure 2. describes the cascade use in a simplified form. [4, 18, 21]

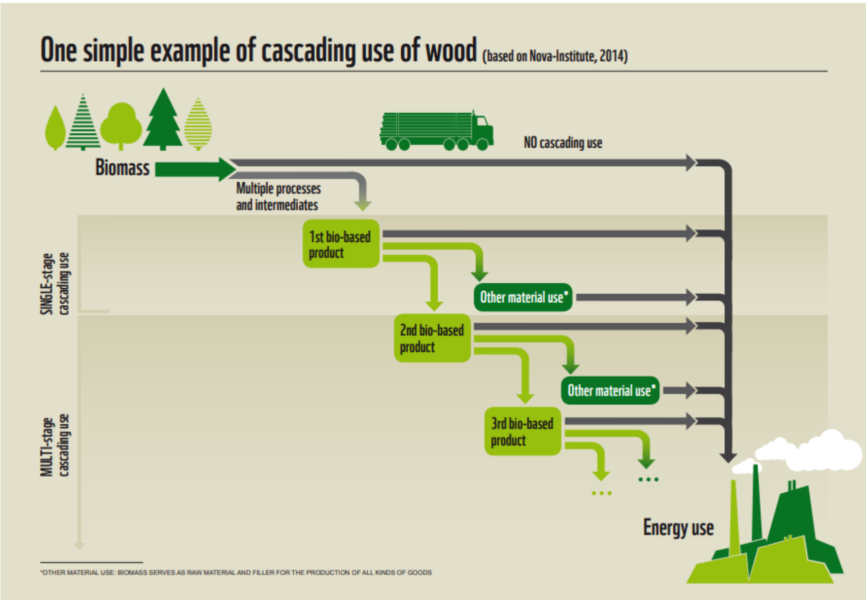


Figure 2. Cascading use of wood [21]

Cascading use of wood has been discussed and researched in many ways. In general, the cascade use of wood is more environmentally friendly, in the sense that fewer resources are taken from the environment. In addition, the resource is also saved in the form of wood processing since there is no need to process the round log, the existing material has already undergone several processes. [11] With cascade use of the material, the life of the material is extended and thus also postpones the release of carbon [9].

Although with cascade use, the efficiency of material use increases, but each subsequent step also affects the mechanical properties of the material, depending on its processing. In reprocessing of wooden scrap material, it must be considered that the residues often contain some kind of additives in the form of glues, paints, or other chemicals, it may also contain metals and inorganic materials. Diversity in composition is something that makes recycling and processing the material difficult. [9, 22]

It should also be considered that in the case of greater processing, it is very difficult to assess the real impact on the environment, so it remains unclear whether such an activity is actually beneficial. The use of cascade wood increases the number of resources required for its processing and therefore production costs increase. During the lifetime of wood, industry increase. Thus, the cascade use improves resource efficiency, as the wood is used several times before being used for heating, but in other hand the material needed for energy production decreases, which may lead to the search for other energy sources. [23, 24]

The use of wood and its processing are also influenced by the economical factor which in turn is affected by public support and commercial factors. The market and demand for wood dictate the price of the material, which also determines how the material is ultimately used. Here, a situation may arise where the recycling of wood is more expensive than buying green wood, which, however, is not in accordance with the principles of cascade use. There may also be a situation where too high-quality material is used for the purpose of obtaining energy, simply because of what is currently available on the market. [11, 19, 25]

2 MATERIALS AND METHODS

2.1 Preparation and data collection

Within the scope of this work, it was important to understand the operation of the entire company and the cooperation between departments. It was crucial to understand the flow of materials within the company and different material processing processes. Also, which products are produced by departments, to understand what type of scrap material may occur in each.

The company has a document, which is created in the year 2018, that describes the process of recycling scrap products within the company. The document describes scrap processing based on each department and its production. The process is based on standard products, and there may be several ways of scrap recycling depending on the product. [7]

The observations were carried out in departments, focusing on locations where scrap materials were stored or collected. In parallel, the established scrap process was studied to understand the causes of scrap generation.

Analysing the process does not give a clear overview of what data should be used or considered when deciding on which way to reprocess the products. The analysis also reveals the fact that the present process is no longer up to date, as the company's product mix has increased over time and the technical possibilities for reprocessing have also changed. [7]

To get an overview of today's situation, several interviews were conducted with the responsible persons of each department. Also, the head of the safety and quality department and quality specialists were interviewed, who are most exposed to various products and their quality problems. The quality department specialists are also the best aware of the product specifications and have information about what the customers' requirements are.

To get an overview of the company's handling of scrap, a mapping had to be carried out, the main questions which were asked by the people responsible were:

- Which products are produced in the department ?;
- What are the different processes ?;
- Therefore, what type of scrap is produced in each process ?;

- What is done with the scrap material in the present situation?

The interviews were conducted based on questions described before, and the Microsoft Excel program was used to store the obtained data.

Interviews were conducted in eight departments [7], including the Sawmill, as this department was still working at the time of mapping. This department also includes the company's boiler house, which was investigated, to understand the principles of its operation, for further analysis.

During mapping, the information obtained were grouped, so that these could be processed and drawn further conclusions from it. The aim was to group products that would need a similar way of processing and could have similar end use. The grouping of results was mainly based on circumstances:

- occurs due to process, and machine errors;
- different types of defects resulting from wooden material;
- products with surface treatment;
- products without surface treatment;
- products with millings and/or drillings.

The assessment of technical limitations was based on what the factory's product range is, and what products are currently produced, and therefore would be a realistic and logical continuation, considering the products' characteristics, and areas of use.

To get a better understanding of today's situation and to see which department should be considered first in the further analysis, it was necessary to study and collect data regarding the volumes of material usage per department. This information was first obtained by conducting interviews with quality department people, in order to gain a more precise understanding of the form in which data is collected in the company and to gain access to the corresponding internal statistics.

2.1.1 Collection of data on material usage

The company collects data on how much material is taken in (input), how much of it was produced in the stock (WIP), however, if the data has a minus sign, it shows how much material was used from the stock, and how much was produced as a finished product (output). The data is registered in an internally used program. The program automatically calculates the yield value and provides an overview by departments, months, and years.

Yield is found by the formula [26]:

$$Yield\ (\%) = \frac{Output\ \ material\ (m^3) + WIP\ (m^3)}{Input\ material\ (m^3)} x\ 100\% \tag{2.1}$$

Since the yield gives an overview of how much of the material was realised as a finished product, to find the percentage/proportion of wood scrap generated, it was necessary to conclude that all material used is 100%, and thus the yield must be deducted from it.

Wood scrap percentage was found with the calculation:

$$Wood\ scrap\ (\%) = 100\% - yield\ (\%) \tag{2.2}$$

For finding out the wood scrap amount in cubic metres (m^3) from the input material, the calculation was done:

$$Wood\ scrap\ amount\ (m^3) = \frac{Input\ (m^3)\ x\ Wood\ scrap\ (\%)}{100\ \%} \tag{2.3}$$

2.1.2 Collection of data on material processing allowances

To understand the raw wood material types used in products production, it was necessary to review different product groups. The company has a system where all data and information about their products and raw material used is available. It is crucial to have an overview of material usage, to plan the correct material, according to the customers' needs [26].

Products are created in the system according to the requirements established by the quality department, so it is possible to obtain a product with the right dimensions and corresponding quality from the raw material, considering all the processing stages. [26]

Drawings have been prepared separately for the main product groups, which are the basis for both the planning department to create a correct bill of material in the system and for production to check the correctness of the input material in the processes.

The general rules are described in a document intended for internal use, stipulating the minimum necessary processing allowances based on product groups, which are the basis for the creation of each new product, to avoid wood material wastage. [27]

2.2 Cost calculation method

The structure and logic of the cost calculation method have been created by the author considering the circumstances that came to light during the research and what information was available and usable at that time. The program used for calculations was Microsoft Excel.

The basis for creating the model was the present situation regarding wood scrap reprocessing and the alternative methods proposed by the author. Since the purpose of the model is to show the financial cost of different reprocessing methods, considering material and labour costs, it was necessary to find corresponding data. The work does not consider the costs associated with processing.

Scrap material that is not used in the company, including sawdust, is resold to a nearby company to produce its own products. Therefore, it was necessary to find out on what basis this kind of scrap material is calculated and what is the income from it.

To find the cost of recycling products, it was necessary to know the process stages of each reprocessing method, and how many products per hour can be processed in each process.

In addition, it was necessary to find information on how many pieces per hour can be produced per person in each process. To find the cost, it was also necessary to know the company's established labour cost in euros per hour.

The model is built on the principle that it considers the dimensions of the scrap product to be processed, in cubic metres, to be able to estimate the cost of placing the product into the scrap collection container. In addition, the input data is the average price of the same product type, considering different surface treatments. The product price has been considered, as this would have been an income for the company if the product had not been scrapped. This amount is used as a basis for calculations and to create a reference moment.

To summarise the above, the input information required to analyse and compare wood scrap recycling were:

- cubic metres of the scrap product;
- the average price of the product;
- necessary processes for recycling;
- in different processes, how many pieces could be produced per hour;
- how many people are needed to produce the corresponding pieces (FTE);
- how many products can be obtained from one scrap product;
- if the product has been previously purchased, what was the purchase price per piece;
- if the product goes to the scrap collection container, what is the income per cubic metre.

The data found through calculations were:

- labour cost per product produced in the process, €/pcs (2.2.1);
- labour cost of recycling one scrap product, € (2.2.2);
- the total cost of recycling the scrap product, € (2.2.3);
- the cost of scrap product if it goes to the collection container, € (2.2.4);
- the cost of new product(s) from scrap material, € (2.2.5).

To find labour cost per pieces produced in process the calculation was done:

$$Labour\ cost\ (€/pcs) = \frac{labour\ cost\,\frac{€}{h}}{pieces\ produced\ in\ the\ process\ per\ person\ in\ one\ hour} \tag{2.4}$$

To find the labour cost of recycling one scrap product the calculation was done:

$$\begin{aligned} &Labour\ cost\ of\ recycling\ one\ scrap\ product\ (€) \\ &\quad = sum\ of\ pieces\ produced\ in\ process\ \ x\ labour\ cost\,\frac{€}{pcs} \end{aligned} \tag{2.5}$$

To find the total cost of recycling on scrap product the calculation was done:

$$\begin{gathered} Cost\ of\ scrap\ product\ recycling (€) = \\ labour\ cost\ of\ recycling\ one\ scrap\ product\ (€) + average\ price\ of\ the\ product\ (€) \end{gathered} \tag{2.6}$$

To create a comparison, the price of the product was also found out, if it has to be collected in a scrap container, the following calculation was made:

$$\begin{gathered} Cost\ of\ material\ going\ into\ container\ (€) = \\ Average\ price\ of\ the\ product\ (€) - (scrap\ product\ m^3\ x\ price\ of\ waste\ material\ per\ m^3) \end{gathered} \tag{2.7}$$

To find out how many scrap products it is necessary to reprocess to obtain the desired product, a calculation was made:

$$Cost\ of\ new\ product(s)\ from\ scrap\ material\ (€) = \frac{cost\ of\ scrap\ product\ recycling\ (€)}{products\ gained\ from\ one\ scrap\ product} \tag{2.8}$$

3 EXPERIMENTAL

3.1 Material usage in JELD-WEN Eesti AS Rakvere factory

In the Rakvere factory, a wood scrap processing routes have been described and established in 2018, but during initial observations and several interviews, it has become clear that this process does not work in this form today.

The described process is complicated by the fact that it is developed specifically based on the product, not based on the product group. According to the product characteristics, the reprocessing options outlined in the process are also different, which makes it difficult to follow. In some cases, the process brings out various reprocessing methods per product, therefore arises the possibility to approach subjectively and choose the seemingly easiest method, which however may not be the most useful.

According to the present process, the material which is not possible to recycle should be collected into a scrap collection container. The process does not clearly state that material with surface treatment and material without surface treatment should be sorted into separate scrap collection containers. There is no common understanding within the company that it is important to separate these materials as these are resold to a nearby company that uses them to manufacture its own products [26].

In addition, today's process does not consider the cost of reprocessing the wood scrap. Therefore, it can be said that there is no comprehensive overview of the data and documented knowledge as to whether the reprocessing methods established today are useful or not.

3.1.1 Component department

The component department produces raw materials for all other departments. Before the beginning of 2023, also material from the Sawmill was processed. Due to the closure of the Sawmill, all material in the corresponding cross-section is bought in. [26]

To get an overview of material usage, the following Table 1. shows how much material was taken into the department in the year 2021 and how much of it was realised into a product.

Table 1. Yield of Component department in 2021 [28]

Month	**Input, m³**	**WIP, m³**	**Output, m³**	**Yield, %**
01	5,781	- 137	4,557	76.4
02	8,193	- 207	6,348	75.0
03	10,443	499	7,310	74.8
04	8,658	- 138	6,619	74.9
05	8,601	- 200	6,553	73.9
06	10,198	443	7,400	76.9
07	4,907	121	3,612	76.1
08	5,965	- 654	5,064	73.9
09	12,161	1,022	8,350	77.1
10	9,533	- 339	7,495	75.1
11	9,508	243	6,907	75.2
12	8,629	- 224	6,869	77.0
Total	102,576	429	77,084	**75.6**

From the Table 1. it can be noted that 75.6% of the incoming material was realised as a finished product, which means that 24.4% of the material went to waste. Since accurate data is not collected in this department, there is no exact overview of how much material was classified as another product, it can only be concluded that 24.4% of incoming material went to waste, including both sawdust and wood scrap material.

For obtaining an overview of by-products and wood scrap recycling the mapping was carried out and the results are brought out in Table 2. [29]

Table 2. Component department wood recycling [29]

Type	**Where occurs**	**Reason**	**Ways of reprocessing**
Sawdust	In TM, in finger joint lines and on a saw	When the material is being calibrated and sawn into length. When the material is cut, for finger jointing.	Collected and sold to another company.
Cut pieces of wood	TM (wood eye)	Due to the process (material that do not meet quality requirements or is not suitable for finger jointing because of its dimensions)	Material goes into scrap collection container (sold to another company).
Cut pieces of wood which do	Sorted out before finger joint lines (CRP and V8)	Due to process errors	Defect is cut out on a saw. If cutting is not possible, then classified in lower quality.

not meet in a certain quality			If recycling is not an option, the material goes into scrap collection container (sold to another company).
Machinery setup scrap	In different processes	Operator and/or process errors	Defect is cut out on a saw. If cutting is not possible, then classified into suitable quality. If recycling is not an option, the material goes into scrap collection container (sold to another company).

Based on the obtained study results, it can be concluded that the department has a good overview of wood scrap handling. The department has well-functioning internal agreements regarding the use of material. As the products produced are raw materials, the proportion of technological scrap is high.

3.1.2 Component 2 department

The component 2 department mostly produces glue boards for the Scandinavian frames department and rails and stiles (door components) for other JELD-WEN factories. To a lesser extent, glue boards are also produced for the cassette department and for other JELD-WEN factories.

The following Table 3. gives an overview of how much material was taken into the department in the year 2021 and how much of it was realised into a product.

Table 3. Yield of Component 2 department in 2021 [28]

Month	**Input, m³**	**WIP, m³**	**Output, m³**	**Yield, %**
01	2,059	59	772	40.3
02	2,622	- 69	2,069	76.3
03	2,879	47	2,220	78.7
04	2,957	- 14	2,341	78.7
05	2,928	- 27	2,516	85.0
06	3,105	251	2,786	97.8
07	1,365	46	1,347	102.0
08	1,941	86	1,764	95.3
09	3,118	- 315	2,915	83.4
10	2,715	429	2,291	100.1
11	2,534	- 98	2,188	82.4
12	2,808	- 25	2,568	90.5
Total	31,032	370	25,775	**84.3**

Looking at the data reported by month is not comprehensive and this is questionable whether all the entries have been made correctly, as some yield results are unrealistically high. Based on the analysis of existing data 84.3% of the material was converted into a finished product and only 15.7% of the material went to waste. However, it is not possible to conclude from this figure how much the proportion of sawdust and how much is the wood scrap of the product itself, as no relevant data has been collected.

In this department, lots of decisions regarding material recycling is made by the shift foreman, who assesses according to his experience and knowledge what and how is most reasonable to recycle. [30]

The following Table 4. gives an overview of the by-products and wood scrap that occurs in the Component 2 department and their different processing methods.

Table 4. Component 2 department wood recycling [30]

Type	**Where occurs**	**Reason**	**Ways of reprocessing**
Sawdust	In planers and on a saw	When material is sawn into lamellas and when material is planed	Collected and sold to another company.
Lamellas with different type of defects	In planers	Quality defects and/or process errors	Glued for another product. What are with suitable cross-section is glued together for frame glue board.
			Recycled/planed into the stile.
			Classified into lower quality product.
			Lamellas are glued together for ground spacers.
			If recycling is not possible, the material goes into scrap collection container (sold to another company).
Glue boards with different type of defects	In gluing presses	Quality defects and/ or process errors	If possible, used to produce a smaller/ shorter product by cutting out the defects.
			Glue boards with gluing defects are cut so that it would meet the requirements for finger jointing.
			If recycling is not possible, the material goes into scrap collection container (sold to another company).
Cut pieces of wood	On a saw	When defects are cut out of a material	If the material meets the requirements for finger jointing, sent to Component department.
			If not possible to finger joint, the material goes into scrap collection container (sold to another company).
Side products	In planers	Wood scrap which occurs	Knot free material – glued together for interior frame glue board.

		when producing other products	Used to produce spacers which are necessary for the material storage and packaging.
			If recycling is not possible, the material goes into scrap collection container (sold to another company).

As a result of the mapping, the decisions made internally are well managed. Many decisions are made by the leading persons, where reprocessing is based on the need for a specific material/product, whether the customer has also sent an order for the given product [30].

There are certain principles within the department, which are based on the fact that a smaller product is first tried to be obtained from the product scrap, and if this is not possible, other options are considered. This is for the reason of avoiding excessive additional activities and associated costs. [30]

3.1.3 Doors 2 department

The doors 2 department produces mainly glue boards for the doors department, for all door parts (stiles, panels, top, and bottom rails, architraves). To a lesser extent is produced French frames glue boards, lamellas for honeycombs, glass slats for exterior doors, and glue board panels for other factories.

Table 5. Yield of Doors 2 department in 2021 [28]

Month	**Input, m³**	**WIP, m³**	**Output, m³**	**Yield, %**
01	1,819	- 380	8 553	449.4
02	1,506	- 18	1 374	90.1
03	1,703	191	1 338	89.8
04	1,424	- 27	1 157	79.3
05	1,448	- 9	1 032	70.7
06	1,491	40	986	68.8
07	698	89	442	76.1
08	1,107	- 145	830	61.8
09	1,804	- 126	1 218	60.5
10	1,621	84	946	63.6
11	1,551	159	1,182	86.5
12	1,244	- 116	839	58.1
Total	17,415	- 260	19,897	**112.8**

The Table 5. above gives an overview of how much material was taken into the department in the year 2021 and how much of it was realised into a product.

It can be seen from the given results in Table 5. that there are errors in the data in the first month of the year, as the yield result is unrealistically high. This result affects the average result of the year, which means this number is also not realistic.

Excluding the first month of the year, it is possible to calculate the yield result with the formula 2.1. [26]. In this way, the yield result is 73.5%, which means that the proportion of scrap is 26.5%. However, it cannot be concluded how much of 26.5% is sawdust and how much is finished product scrap, because there is no collection of accurate data in this department either.

The following Table 6. gives an overview of the by-products and wood scrap that occurs in the doors 2 department and their different processing methods. [31]

Table 6. Doors 2 department wood recycling [31]

Type	Where occurs	Reason	Ways of reprocessing
Sawdust (dry)	In planers and on a saw	When the material is sawn into lamellas and when the material is planed	Collected and sold to another company.
Wrong size lamella (thickness, width and/or length)	In planers	Operator and/or setup errors	Used to produce smaller/shorter product.
			If smaller/shorter product is not an option, the material is glued together for ground spacers.
			If recycling is not possible, the material goes into scrap collection container (sold to another company).
Machinery setup scrap	In planers	Operator and/or process errors	Glued together for ground spacers.
			If not possible to glue, then the material goes into scrap collection container (sold to another company).
Lamellas that do not meet quality requirements	Before gluing the lamellas, in glue presses	Due to the process	Used to produce a shorter product by cutting out the defects.
			If shorter product is not possible, the material is classified into suitable quality.
			If the material is not suitable into another quality, the material is glued and cut so that it would meet the requirements for finger jointing.
			If finger jointing is not an option, the material is glued together for ground spacers.
			If recycling is not an option, the material goes into scrap collection container (sold to another company).

Gluing defects / glue boards which do not meet quality requirements	In gluing presses	Process errors / Defects not detected before pressing	Used to produce a smaller/ shorter product by cutting out the defects.
			If smaller/shorter product is not possible, the material is cut so that it would meet the requirements for finger jointing.
			If finger jointing is not an option, the material is cut for ground spacers.
			If recycling is not an option, the material goes into scrap collection container (sold to another company).
Cut pieces of wood	On a saw	When defects are cut out of a material	If material meets the requirements for finger jointing, sent to Component department.
			If not possible to finger joint, the material goes into scrap collection container (sold to another company).
Slats with defects	In planer	Process error	Not possible to recycle, because of the small cross section, the material goes into scrap collection container (sold to another company).
Honeycombs with defects	In honeycomb press	Process error	Due to the small cross-section and milling, it is not possible to recycle wooden material. Honeycombs are damaged when lamellas are removed. Lamellas go into scrap collection container (sold to another company), honeycombs go to waste.

Also, as a result of this mapping, it can be said that doors 2 department has an overview of the use of material. Mistakes were made during data collection, so it would not be correct to draw further conclusions based on yield results.

However, similar logic applies within the department as in the component 2 department, where it is based on the principle that a smaller product is first tried to be obtained from the remaining product, and if this is not possible, other options are considered. [31]

3.1.4 Doors department

The doors department produces interior doors of different quality and surface treatments, also door architraves. From year 2023, the department also produces exterior doors for cottages. In addition to the production of doors, the sanding of different types of glue boards is also carried out in this department.

Following Table 7. gives an overview of how much material was taken into the department on year 2021 and how much of it was realised into a product.

Table 7. Yield of Doors department in 2021 [28]

Month	Input, m³	WIP, m³	Output, m³	Yield, %
01	395	25	346	93.9
02	659	9	632	97.2
03	694	- 13	665	94.0
04	528	3	502	95.7
05	691	96	565	95.7
06	757	29	760	104.2
07	260	- 228	423	74.8
08	534	132	348	89.8
09	690	- 17	651	91.8
10	671	- 36	645	90.6
11	799	113	690	100.6
12	523	- 161	626	88.9
Total	7,201	- 50	6,853	**94.5**

94.5% of the incoming material was realised as a finished product, which means that 5.5% went to waste. This department also does not collect exact data, so it is impossible to determine how much of this is sawdust and how much is finished product scrap. It also raises questions as to whether the yield data for some months is still realistic, as it is quite high.

The following Table 8. gives an overview of the by-products and wood scrap that occur in doors department. [32] It can be said that the department has a good understanding of wood processing. The department's handling of scrap is complicated by the fact that the parts that are processed and put together have already undergone several processes and, in some cases, have also received a surface treatment.

If defects appear after the door components are pressed together, untreated doors and for doors whose components are separately covered with stain/lacquer, can be taken apart again and components with defects can be replaced. Doors that go through the lacquer line in one piece, cannot be repaired afterwards. [32]

Table 8. Doors department wood recycling [32]

Type	Where occurs	Reason	Ways of reprocessing
Sawdust (dry)	In planers and on a saw	When the material is planed and/or sawn	Collected and sold to another company.
Untreated stiles (of German doors)	In production line	Quality defects and/or processes errors	Used to produce a shorter product (rails) by cutting out the defects (due to volumes).
			If not possible to produce shorter product, material is cut so that it would meet the requirements for finger jointing.
			If recycling is not an option, the material goes into scrap collection container (sold to another company).
Untreated stiles and rails (except German doors)	In production line	Quality defects and/or process errors	Material is cut so that it would meet the requirements for finger jointing.
			If recycling is not an option, material goes into scrap collection container (sold to another company).
Untreated panels	In production line	Quality defects and/or process errors	Used to produce a smaller product by cutting out the defects.
			If smaller product is not possible, the material goes into scrap collection container (sold to another company).
Untreated architraves	In production line	Quality defects and/or process errors	Used to produce a shorter product by cutting out the defects.
			*If with smooth profile – cut for ground spacers.
			If recycling is not possible, the material goes into scrap collection container (sold to another company).
Cut pieces of wood	On a saw	When length is cut, and defects are cut out of a material	If material meets the requirements for finger jointing, sent to component department.
			If not possible to finger joint, the material goes into scrap collection container (sold to another company).
Stained / lacquered door component	In production line	Quality defects and/or process errors	Material goes into separate scrap collection container (sold to another company).
Lacquered doors	Lacquer line	Quality defects and/or process errors	Doors are cut in half and sent to separate scrap collection containers (sold to another company).
Sanded glue boards	In grinder	Process errors	Material goes into scrap collection container (sold to another company).

3.1.5 French frames department

The French frames department produces frames of different profiles, widths, and lengths, which are intended only for the French market. No other products are produced in this department. Frames are made from both components and glue boards. [26]

Following Table 9. gives an overview of how much material was taken into the department in the year 2021 and how much of it was realised into a product.

Table 9. Yield of French frames department in 2021 [28]

Month	Input, m³	WIP, m³	Output, m³	Yield, %
01	1,070	62	628	64.4
02	1,541	93	885	63.5
03	1,309	- 25	805	59.6
04	1,479	- 5	916	61.6
05	1,547	34	950	63.6
06	1,781	31	1,046	60.5
07	1,112	252	679	83.7
08	1,285	- 167	733	44.1
09	2,058	- 9	1,234	59.5
10	1,458	- 60	874	55.9
11	1,675	20	980	59.7
12	1,515	- 137	962	54.5
Total	17,830	89	10,692	**60.5**

60.5% of the incoming material was realised as a finished product, which means that 39.5% is a scrap, both sawdust and finished product. The wood scrap material is being registered to some extent, but still, there is no comprehensive data or recorded information about how much material was classified as another product.

The following Table 10. gives an overview of the by-products and wood scrap that occur in the French frames department. [33]

The mapping and data collection result can be argued that the material output of the department is quite low, which raises questions why the obtained data show this.

Table 10. French frames department wood recycling [33]

Type	Where occurs	Reason	Ways of reprocessing
Sawdust (dry)	In planers and on a saw	When the material is planed and/or sawn	Collected and sold to another company.
Machinery setup scrap	In different processes	Operator and/or process errors	Material goes into scrap collection container (sold to another company).
Cut pieces of wood	On a saw	When length is cut, and defects are cut out of a material	Material goes into scrap collection container (sold to another company).
Frame / top piece component with different type of defects	In a planer	Quality defects and/or process errors	Sent to the component department for reprocessing.
			*Single pieces go into scrap collection container (sold to another company).
Milled frame components which do not meet quality requirements	In a planer and in the correctional area	Due to the process	If quality defects are repairable, material is repaired.
			If possible, used to produce a shorter product by cutting out the defects.
			If recycling is not an option, primed material and untreated material go into separate scrap collection containers (sold to another company).
Side product	In planer	When the frame component is milled from raw material	Used to produce spacers (sold to a client).
			If there are no orders, it goes to the shredder, and becomes sawdust.

In the further analysis, where it was made clear what type of products and what raw materials are produced, turned out that frame profiles are mainly planed directly from the component (raw material). As the frames have unique profiles, the proportion of sawdust is high. The Figure 3. below shows one example of how the frame profile is planed from the raw material, also as mentioned above, where the resulting by-product is created.

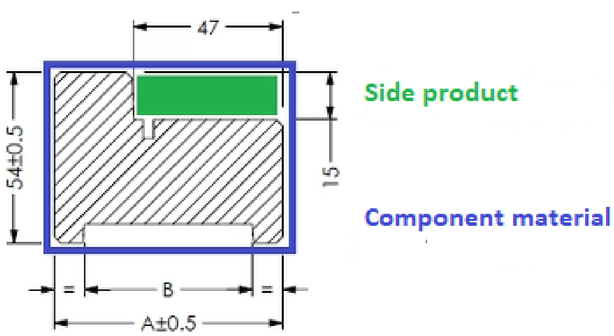


Figure 3. Drawing of frame profile planing

According to the demand, the side product is sold or just processed into sawdust. The generated wood scrap is not in sufficient size to be processed in other ways.

3.1.6 Cassette department

The cassette department produces cassettes, cassette slats, cassette bows, veneer/foil-covered architraves and frames, and different types of slats. Also staining and lacquering of door components and frames are done in this department.

Following Table 11. gives an overview of how much material was taken into the department in the year 2021 and how much of it was realised into a product.

Table 11. Yield of Cassette department in 2021 [28]

Month	Input, m^3	WIP, m^3	Output, m^3	Yield, %
01	145	6	70	52.5
02	196	- 2	81	40.1
03	216	- 4	128	57.4
04	234	21	134	66.2
05	172	- 14	108	54.7
06	183	- 107	109	1.3
07	67	123	47	255.7
08	136	- 135	99	-26.5
09	216	136	114	115.4
10	249	13	184	79.1
11	112	- 27	44	15.1
12	171	2	85	50.6
Total	2,096	11	1,203	**57.9**

The Table 11. gives an overview of the use of the material, but it is not complete. The error comes from the system where the products are not created correctly, the amount of material needed to produce one product has not been considered. It is possible to get information on how much material is taken in the department, but the output data is not realistic, therefore the yield result cannot be considered.

The following Table 12. gives an overview of the wood scrap that occur in the Cassette department. [34]

Table 12. Cassette department wood recycling [34]

Type	Where occurs	Reason	Ways of reprocessing
Sawdust (dry) / MDF and HDF dust	In planers and on a saw	When materials are planed and/or sawn	Collected and sold to another company.
Excess MDF and HDF	On a saw	The material is bought in a certain size and then the necessary pieces are cut out.	Material goes into separate scrap collection container (sold to another company).
Wooden material with defects	Before planing	Due to the process	Sent to the component department for reprocessing.
			Broken material or material with metal - goes into scrap collection container (sold to another company).
Machinery setup scrap	In planers and/or CNC	Operator and/or process errors	Material goes into scrap collection container (sold to another company).
Cut pieces of wood	On a saw	When length is cut, and defects are cut out of a material	Material goes into scrap collection container (sold to another company).
Slats with defects	In a planer	Material defects and/or process errors	If possible, used to produce a shorter product by cutting out the defects.
			If recycling is not possible, material goes into scrap collection container (sold to another company).
Defects in veneer/foil covered material	In wrapping line	Process and/or setup errors	If possible, used to produce a shorter product by cutting out the defects.
			If shorter product is not possible, material is sent to component department for reprocessing.
			*If slats - material goes into separate scrap collection container (sold to another company).
Cassettes with defects	In the production	Material defects and/or process errors	If not repairable, untreated material and material with surface treatment go into separate scrap collection containers (sold to another company).

It is important to point out that the door components which are stained and/or lacquered in the cassette department are sent to the doors department, therefore defective products are not sorted out in the cassette department [34]. The handling of scrap material in this department is complicated by the fact that the mainly produced products have such a small cross-section and mostly have a surface treatment, therefore these products cannot be recycled.

However, scrap registration is partially done in the department. The scrap of the frames is registered in the system, but a scrap of the slats is counted per container. There is no information about the products classified as another, shorter product. Therefore, there is no unified scrap accounting system, and the obtained data are neither comparable nor useful for further work.

3.1.7 Scandinavian frames department

The Scandinavian frames department produces the main output of the factory, where door frames with different profiles, widths, lengths, and surface treatments are produced. The mix and complexity of products is constantly increasing.

The Scandinavian frames department has an overview of material use and what material has gone to waste. Material classified as another product or moved into a scrap collection container is registered in the system. However, there is no clearly described process for scrap data collection, it is done on the basis of verbal agreements. Data regarding scrap classification and flow are entered into the system manually and it is based on the best knowledge. [26]

Following Table 13. gives an overview of how much material was taken into the department in the year 2021 and how much of it was realised into a product.

Table 13. Yield of Scandinavian frames department in 2021 [28]

Month	**Input, m³**	**WIP, m³**	**Output, m³**	**Yield, %**
01	1,983	71	1,468	77.6
02	2,491	- 7	2,118	84.8
03	3,475	- 92	2,703	75.1
04	2,615	54	2,089	81.9
05	2,794	- 72	2,352	81.6
06	3,366	94	2,614	80.4
07	1,314	- 790	1,118	25.0
08	2,284	798	1,644	106.9
09	4,043	- 33	2,841	69.5
10	3,167	- 177	2,326	67.8
11	3,027	113	2,198	76.4
12	3,355	- 151	2,368	66.1
Total	33,916	- 192	25,839	**75.6**

75.6% of the incoming material was realised as a finished product, which means that 24.4% of the material went to waste. This includes sawdust and the finished product scrap.

The following Table 14. gives an overview of the by-products and wood scrap that occur in the Scandinavian frames department and what is done with it. [35]

Table 14. Scandinavian frames department wood recycling [35]

Type	Where occurs	Reason	Ways of reprocessing
Sawdust (dry)	In planers and on a saw	When the material is planed and/or sawn	Collected and sold to another company.
Cut pieces of wood	On a saw	Producing a smaller product or cutting material so that it would meet the requirements for finger jointing	Untreated material and material with surface treatment go into separate scrap collection containers (sold to another company).
Machinery setup scrap	In planers, Rilesa and CNC	Operator and/or process errors	Used as long as it is possible to get required result.
			If material can no longer be used, it goes into the scrap collection container (sold to another company).
Full filled frame component with different type of defects	After planer and hybrid (UV+putty) line	Quality defects, and/or process errors	If repair is permitted according to the quality rules, the material will be repaired and moved to the next process.
			If repair is not permitted according to the quality rules, the material is sorted out. Sorted material moves to RPA area, where difficult defects are repaired, and material is sent back to initial process.
			If all the defects cannot be repaired, material is used to produce a smaller product by cutting out the defects. If possible, the leftover part is sent into component department for reprocessing.
			If recycling is not possible, material goes into separate scrap collection container (sold to another company).
Frame component with wet UV	After hybrid (UV+putty) line	Process error	Handled separately, the material is disposed of, because of the dangerous chemical. The material is not recycled.
Primed/painted frame component with different type of defects	After priming/painting (Makor 1 or 2)	Process errors	Material goes through the process again, is repainted. Repairing is also done if necessary.
			If repainting is not an option, material goes into RPA area where difficult defects are repaired, and material is sent back to initial process.

<table>
<tr><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td>If all the defects cannot be repaired, material is used to produce a smaller product by cutting out the defects. If possible, the leftover part is sent into component department for reprocessing.</td></tr>
<tr><td>If recycling is not possible, the material goes into separate scrap collection container (sold to another company).</td></tr>
<tr><td rowspan="3">Frame components covered with foil/veneer</td><td rowspan="3">After wrapping line</td><td rowspan="3">Operator and/or process errors</td><td>If the ends are loose, these are cut off.</td></tr>
<tr><td>Used to produce a smaller product.</td></tr>
<tr><td>If not possible to produce smaller product material goes into separate scrap collection container (sold to another company).</td></tr>
<tr><td rowspan="2">Untreated frame component with different type of defects</td><td rowspan="2">In planer and after Rilesa/CNC</td><td rowspan="2">Operator and/or process errors</td><td>Used to produce smaller product. If possible, the leftover part is sent into component department for reprocessing.</td></tr>
<tr><td>If not possible to recycle, the material goes into scrap collection container (sold to another company).</td></tr>
<tr><td rowspan="2">Milled frame component</td><td rowspan="2">Rilesa and CNC</td><td rowspan="2">Quality defects and/or process errors</td><td>If quality defects are repairable, material is repaired.</td></tr>
<tr><td>Otherwise, milling defects are not repaired. Untreated material and material with surface treatment go into separate scrap collection containers (sold to another company).</td></tr>
<tr><td rowspan="2">Assembly errors</td><td rowspan="2">Mounting hinges and strike plates</td><td rowspan="2">Due to process</td><td>If defects are repairable, these are repaired.</td></tr>
<tr><td>If defects are to severe, untreated material and material with surface treatment go into separate scrap collection containers (sold to another company).</td></tr>
<tr><td rowspan="4">Milled upper part of the door frame (top)</td><td rowspan="4">Top mill</td><td rowspan="4">Operator and/or process errors</td><td>Used to produce a shorter product.</td></tr>
<tr><td>If not possible to produce shorter product, material is cut so that it would meet the requirements for finger jointing.</td></tr>
<tr><td>If recycling is not possible, untreated material and material with surface treatment go into separate scrap collection containers (sold to another company).</td></tr>
<tr><td>*If top pieces are with milled grooves, material is not recycled, it goes into suitable scrap collection container.</td></tr>
</table>

The material handling of the department is voluminous, and the specifics of the product are different, which makes the overall scrap handling difficult. Internal agreements regarding scrap recycling have been made, but these are not aligned with the documented process which creates confusion about how the material should be handled. [35]

3.2 Analysis of company's material usage

By summing up the data of all departments in terms of how much material was taken in the year 2021, it is seen which department has the largest volume of production. From the Figure 4. below, the highest material usage results reported are by component department, which is logical since this department produces raw materials for all other departments. The proportion of scrap material is the highest in this department, however, since this department produces raw materials which do not have any special complexity other than a specific cross-section and quality, therefore the wood scrap material can only be sawdust or small pieces of wood that are not suitable for reprocessing and end up in the scrap collection container.

The component department is followed by the Scandinavian frames department, which is the company's largest department and produces the company's main products. The wood scrap proportion in this department is considerable, as it includes products scrap and also sawdust.

The department is followed by the component 2 department, which produces material mainly for the Scandinavian frame department, so it is logical that the proportion of material usage is higher compared to following departments.

It can be seen that the proportion of scrap in the French frames department is quite high. However, product uniqueness, quality, and production technology must be considered here. To produce the frames, it is necessary to use material with a larger cross-section than usual, so that it would be possible to plane the finished product.

Regarding doors 2 and doors department, mistakes were made in the data registration and in case of doors 2, one month's data was deliberately omitted from the calculation to get more accurate result. In the case of the cassette department, there is also a problem with the correctness of the input information, which is why the results obtained are not accurate. Therefore, the data isn’t the most adequate and further conclusions cannot be drawn from it.

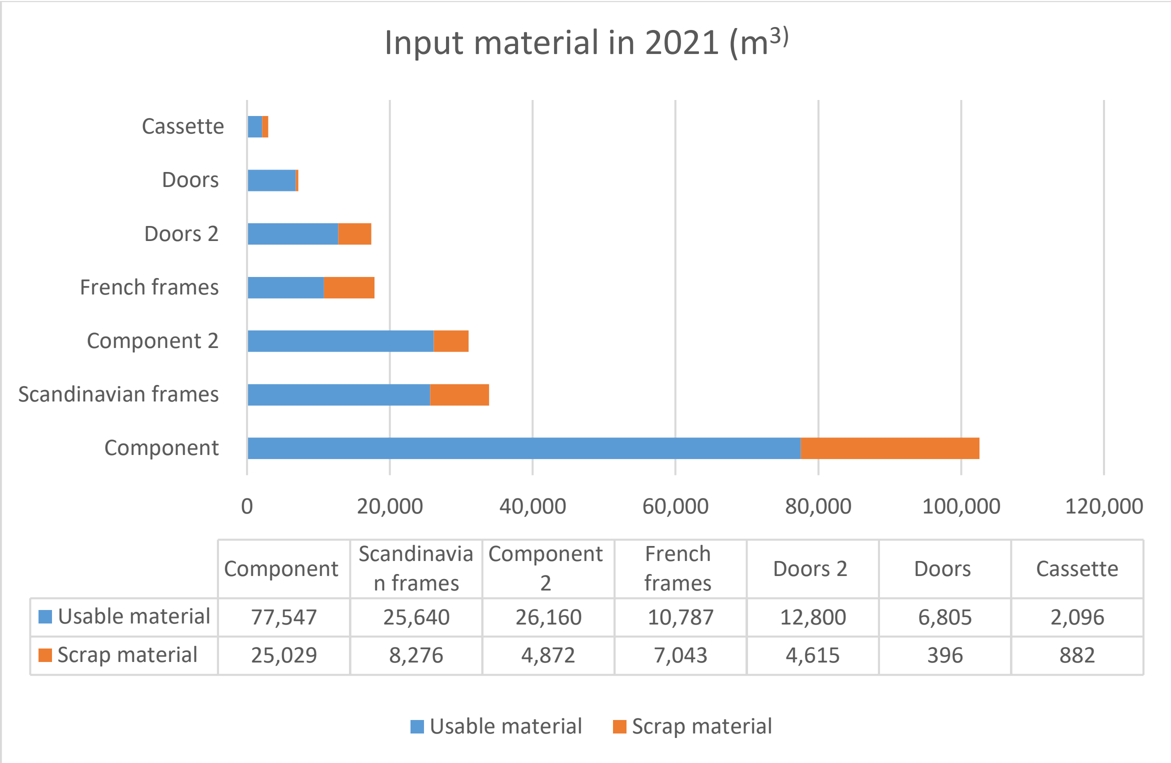


Figure 4. Wood scrap amount of input material in year 2021 (m^3)

In the author's opinion, it is reasonable to base future work on one department and its main products, considering the following facts. The Scandinavian frame department is the largest, with the volume and complexity of products constantly increasing over time. In addition, in terms of end products, compared to other departments, the amount of scrap in the Scandinavian frame department is the highest. There is also data on the handling of scrap in the Scandinavian frame department, which can be used in further work. It is also necessary to consider the fact that in the case of other departments, mistakes have been made in data entry and collection, which is why more precise information would be needed to perform further analyses.

3.3 Main products and wood scrap in the Scandinavian frames department

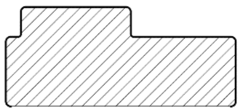
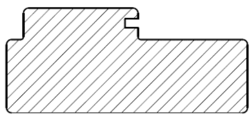
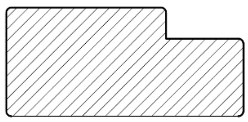
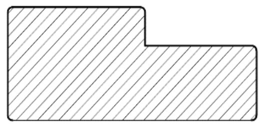
To analyse the recycling methods of the Scandinavian frames department, it is important to have information on which are the main products that should be focused on reprocessing. The sales volumes of year 2022 have been extracted to obtain information on which product group and which width have been recently the best-selling products (Table 15.). It can be concluded from it that the more a product is produced, the more of wood scrap of this product group can be generated, and therefore this product group is the raw material for recycling.

Table 15. Sales data of year 2022 [36]

Product group	Width, mm	Total units, pcs
Product A	92.5	731,960
Product B	92	663,884
Product A	100	236,741
Product C	105	213,746
Product AA	92.5	201,043

The data is arranged in the table starting with the product with the highest productivity. Products A, B, C and AA are named invented by the author of the work to describe the products that are produced the most. The Table 16. below also gives a better overview of how these products visually look and what the standard material used for their production.

Table 16. Product descriptions [37]

Product A	Product AA	Product B	Product C
			
Knotty material	Knotty material	Knotty material	Knot-free material

Product A and product AA are both interior door frames of the same size, the only difference between them is that product AA has a sealing groove. The standard material used is knotty. This product is produced in many different widths, but the mainly produced width is 92.5 mm. [37]

Product B is an interior door frame, but its surface treatment can vary. It is used also in bathrooms; therefore, this product uses both interior and exterior paint. In the product list, this product is also available in widths other than 92 mm, but the volumes are considerably smaller. The price range of product B is quite similar to product A. [37]

Product C is similar in appearance to product B but is intended for external use only. The products are produced only from knot-free material and mainly with a width of 105 mm. Due to the material used, the price of this product is significantly higher, almost twice as compared to products A, B and AA. [37]

To verify this line of reasoning, the scrap data collected in the Scandinavian frame department was also compared. As stated earlier, the collection of scrap data does not follow a specific process, so the work's author did not consider it reasonable to base only on this data.

However, it can be seen from the collected scrap data in the Table 17. that the logic was accurate because the five most produced products also give the highest scrap results. The Table 17. below shows the data for comparison of both years 2021 and 2022.

Table 17. The five product groups with the highest scrap volume in 2021 and 2022 [38]

Product group	**Width, mm**	**Total units in 2021, pcs**	**Total units in 2022, pcs**
Product B	92	100,913	116,821
Product A	92.5	54,163	66,032
Product C	105	49,748	36,574
Product A	100	38,056	20,931

The data in the Table 17. shows that the order of product groups is not the same as when comparing the sales data, but the product groups match. The difference regarding data collection is also that in scrap registration the product A and AA are counted as one product, as the only difference is the sealing groove, which is done additionally, meaning the product itself is the same [38].

Based on the Table 17. presented, it is reasonable to use the product A and C in further analysis, to get an idea of costs regarding different recycling methods. As both products A's and B are resembling by shape- and in cross-section dimensions, there is no need to analyse them separately. Also, these products are produced by using standard knotty material, and the end use of these products is common.

3.3.1 Material length allowances in standard processes

Minimum length allowances are established for products in order to prevent waste of material already in the early stages of production. This rule is developed for all products and is also followed when new products are being created. The exception only concerns products with a smaller sales volume, for which it is not reasonable to create a separate stock article, therefore standard product's component is used [26].

Within the scope of this work, the lengths of the products produced in Scandinavian frames and their allowances were analysed in order to understand whether, in the case of cutting to length in the standard process, the cut pieces of wood should be considered in wood scrap analysis.

According to internal documentation the minimum allowances for Scandinavian frames are [27]:

- straight from component material 6 mm -/+12 mm;
- from glue board 11 mm -0/+7 mm;
- for the component from which two top pieces are produced 11 mm (for moulding) + 15 mm (for milling and end cutting)

The document specifies the minimum necessary allowances in length for processing products so it would be possible to obtain the length of the end product, but it does not prohibit the use of a longer component. [27]

As part of this work, frames that have bigger allowances were also investigated. These are the frames that have standard profiles and widths, but non-standard lengths. These are so-called low-runner products because they have lower sales than standard (high-runner) products. The result showed that the current length allowance for these products is 22-51 mm.

Examining the products, the results showed that the sales volumes of the exterior frame top pieces are also smaller, so the component with minimum length required, is not used for these products. The current allowance varies for different products from 112 to 312 mm.

3.3.2 Difficult defects repairing area (RPA)

Difficult defects repairing area, shortly RPA, is an alternative method that did not start until year 2022. The process is so new for the company, which is why it has not been possible to perform a cost-effectiveness analysis or properly implement it into today's scrap handling process.

Internal rules have been developed in the company, starting from the raw material, thus there are restrictions on the material that must be followed. This is so that in standard processes it would be possible to effectively perform manual repairs, keeping the line in steady operation. If the corresponding requirements are not met, the product needs more repairing than the standard process allows, the product goes to scrap. However, this does not mean that the material is so bad that it cannot be used at all, but that there is no resource in the process to fix it. [26]

Therefore, internal agreements were made, and it was decided to send products with large production volumes to a separate process - RPA, where the correction of these products is carried out and then returned to the original process.

In the standard process, the employees have to follow a number of quality rules that specify exactly how big defects are allowed and which defects are not allowed to be repaired, then practically everything is repairable in RPA. What has been pointed out that cannot be repaired are products which have millings or drillings, machine errors resulting from the process, such as undersize, wheel marks, and material crushing. [39]

Based on the initially collected data, it is known that if an employee in the standard process can repair an average of 30 frames per hour, then in the RPA area the employee can only repair 4 frames per hour [26, 39]. It is also logical, because considering the number and size of defects, which is why this material has got into that area in the first place, the repairing takes more time.

Table 18. Products repaired in RPA in 2022 [38]

Product group	**Width, mm**	**Total units in 2022, pcs**
Product A	92.5	1345
Product B	92	8953
Product C	105	4963

According to internal statistics, the number of products shown in the Table 18. was manually repaired outside of the standard process. Since there was no data for product A with a width of 100 mm, it can be concluded that this product was not directed to the RPA area.

3.4 Alternative methods for wood scrap recycling in Scandinavian frames department

Alternative methods for wood scrap recycling are considered based on the principle of what is possible within the company's capability and for which products are needed within the company.

As products have different surface treatments, measures, and qualities, it is not possible to use one scrap product for producing another product for the customer. It is possible to produce raw material from scrap material, directing the scrap directly to the first step of the production process. In addition, it is possible to use the scrap material to produce wooden auxiliary material used within the company, which is otherwise purchased.

The alternative methods presented in the following Table 19. are additional solutions found by the author for present reprocessing methods in Scandinavian frames department, which should also be considered and analysed to create a point of comparison between different scrap handling methods.

Table 19. Alternative recycling methods

Wood scrap type	**Alternative recycling methods**
Full filled frame component with different type of defects	Recycling in component department. To produce packaging material (spacers, ground spacers etc). *Knot free material - to cassette component 25 x 98.
Primed/painted frame component with different type of defects	
Untreated frame component (without FJ) with different type of defects	Recycling in component department. To produce packaging material (spacers, ground spacers etc).
Milled frame component	Repair the material in RPA. Recycling in component department. To produce packaging material (spacers, ground spacers etc).
Assembly errors	Recycling in Component department. To produce packaging material (spacers, ground spacers etc).
Milled upper part of door frame (top)	To produce packaging material (spacers, ground spacers etc).

As part of the work, it was investigated whether sawdust and the cut pieces of wood could also be used as heating material inside the factory, but it turned out that this is not possible or useful.

The company has two types of boiler houses: for wet sawdust and for dry sawdust. The wet sawdust boiler house is used when the consumption is higher, and the outside temperature is lower. However, since there is no wet sawdust inside the factory after the sawmill closure, it must be outsourced. In case of lower consumption, dry sawdust boiler house and sawdust from the factory could be used, but it would not be reasonable in terms of costs. [40]

In addition, under the current conditions, it is not possible in the company to process frames that are covered with veneer or foil. As it turned out, sawdust that is sold to another company also has separate requirements. For example, there must not be large pieces of wood or other material inside the sawdust, which would occur when processing this type of products. [40]

Regarding frames that have been used for machine setting or have already been milled in subsequent processes, cannot be repaired. The material used for the machinery setup is undersized or of a non-standard shape, also has different material defects as there is never a perfectly good material used for setups. The drillings are generally done throughout the entire frame, intended for the assembly of jambs, and the milled parts for hinges and strike plates, are too deep.

There are several options for processing wooden material, but since the technical capability and the product groups produced by the company must be considered within the scope of this work, the options for additional processing are quite limited.

The following subsections outline the circumstances that are important to consider to be able to analyse the reprocessing of wood scrap material.

3.4.1 Recycling in component department

There are requirements that needs to be followed to reprocess the wood scrap material in the component department. The Table 20. shows the limitations of the material in thickness, width, and length, that needs to be followed so that raw material could be finger-jointed again.

Table 20. Requirements for material finger-jointing [7]

	Thickness, mm	**Width, mm**	**Length, mm**
Wooden material	19-61	92-126	250-769

It can be concluded from the Table 20. that door frame piece, which standard length is 2077 mm cannot go directly to the finger-jointing process as it needs an additional cut into suitable length. Depending on the frame width, is can also need a cut into suitable width.

The minimum length for finger-jointing is 250 mm, meaning the shorter pieces cannot be technically finger-jointed and need to go into scrap collection container. Therefore, it can be immediately concluded here that the cut pieces of wood created by cutting in standard processes cannot mainly be used because these are too short for finger jointing.

The material sent to the component department for finger-jointing is sorted and the defects are cut out. The material will remain in its original profile. During the process, a component of the corresponding length is produced according to the minimum length allowances required for processing. Then the produced material is sent to the planer, where lamellas with a suitable cross-section are made, which in turn are glued together. The goal is to produce a new raw material for a product that was recycled. [29]

Using the example of the most produced product A, it is shown in Figure 5. how lamellas of the required size are planed out of product A, so that these would be suitable for gluing a new glue board for the same product.

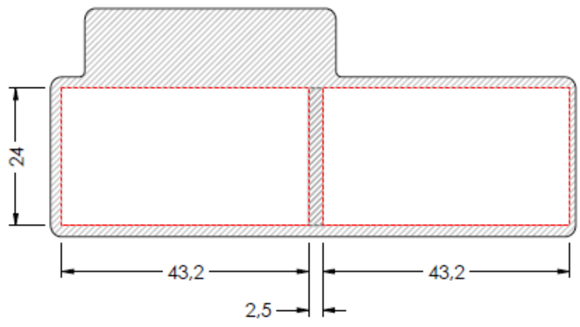


Figure 5. Planing the lamellas using the example of product A 92.5 mm

The hatched part of the figure shows the surface that becomes sawdust during planing. The 2.5 mm is considered as the saw kerf which is standard in the company [26].

To obtain a glue board that is suitable to produce a new product A with width 92.5 mm, four lamellas with measure 24 x 43.2 mm are needed (Figure 6.), considering the minimum allowances and end product tolerances [27].

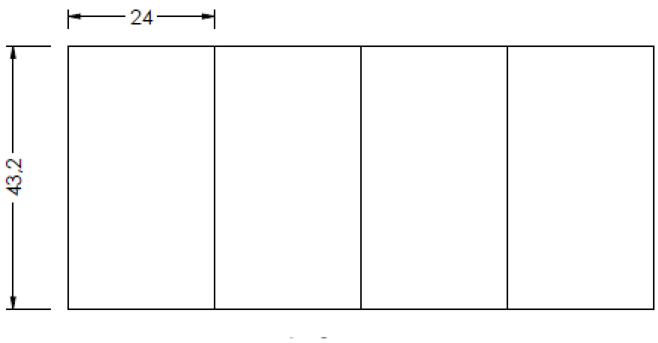


Figure 6. Glue board for product A 92.5 mm

The raw material is always in bigger dimensions than the end product because it needs allowances for processing. Therefore, it is logical that from one end product scrap, it is not possible to get enough material for new raw material with the required dimensions. Here also needs to be considered the material losses which occur when defects are cut out and the material is processed. From the example of product A, it can be concluded that in order to reproduce the glue board of the same product, it is necessary to recycle several scrap products.

An alternative option for recycling would be if one of the wooden spacers, which is needed for packaging the final products, could also be produced from scrap material. The example below (Figure 7.) is based on product A.

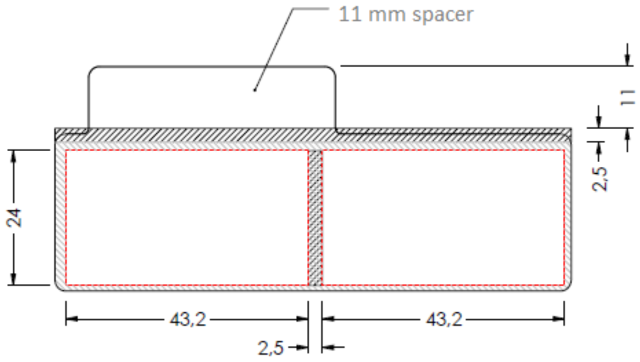


Figure 7. Spacer 11 mm and lamellas 24 x 43.2 mm from Product A 92.5 mm

In Figure 7. the hatched part is also the part that becomes sawdust, but compared to the previous reprocessing method, the amount of sawdust generated is less, because at its expense one wooden spacer would be produced.

When reprocessing the material, the alternative recycling methods of knot-free material should also be examined, since the quality and price of this material is significantly higher than that of the standard material. Therefore, the author suggested that the production of raw materials for the cassette department from product C should also be considered.

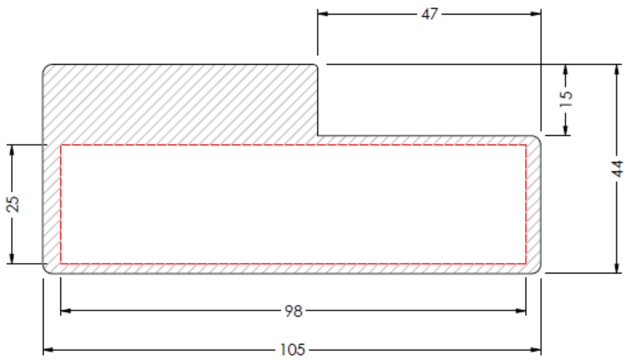


Figure 8. Production of component 25 x 98 from product C

To produce raw material for the cassette department from product C, it is necessary to cut the scrap material to the required length for finger-jointing. According to the standard process, the material is reprocessed and then calibrated into cross-section 25 x 98 mm (Figure 8.).

Figure 8. shows that a large part of the material would turn into sawdust during processing, which is why the production of spacers from the upper part of the profile could also be considered with this method.

3.4.2 Packaging material and its production

To use the packaging material or to produce it, it is necessary to comply with the established requirements (Table 21.). The requirements arise from the fact that the company has determined the maximum height of the pallets, within which the packaged products must remain. Therefore, the thickness of the packaging material has strict requirements. Also, the packaging material must not remain over the pallet, because it can damage other pallets when these are loaded into truck, therefore also strict requirements in length.

Table 21. Packaging material requirements [41]

Packaging material type	Thickness tolerance, mm	Length tolerance, mm
Spacers	+/- 0,5	+/- 1
Ground spacers	+2 /-10	+/- 1

Table 22. Spacers used in the factory [41, 42]

Type	Thickness, mm	Width, mm	Length, mm	Pcs used in 2021	Pcs used in 2022
Spacer Pine	4	25	780	340,479	391,891
	12	30	780	213,031	99,208
	30	30	780	4864	23,104
	20	30	780	100,620	65,360
	25	25	1100	0	93,636
	12	30	1100	0	0
	30	30	1100	27,911	25,311
Spacer Pine with groove	30	40	800	43,350	45,135
	30	40	900	8640	2970
	30	40	1000	25,720	17,670
	30	40	1200	11,520	9660
	25	40	630	0	1940
Spacer Pine + foam	11.5	40	780	122,880	175,030
	20	40	780	246,324	210,705
	32	40	780	59,919	50,614
Spacer HDF	3	50	800	0	0
	3	80	800	0	0

The wooden spacer used in the Rakvere factory are shown in Table 22. The table shows the number of spacers used in year 2021 and 2022, from which it can be concluded which size of spacers are used the most.

The Table 22. shows that the five most used spacers in 2021 and 2022 are:

- spacer pine 4 x 25 x 780 mm;
- spacer pine + foam 20 x 40 x 780 mm;
- spacer pine 12 x 30 x 780 mm;
- spacer pine + foam 11,5 x 40 x 780 mm;
- spacer pine 20 x 30 x 780 mm.

The most used in the factory is a 4 mm spacer, but the factory does not have the technical capability to produce such a thin spacer, so this product still needs to be purchased. [26]

HDF spacers are cut from bigger material inside the company, that is the reason why there is no information about their usage, therefore ordered quantities in the Table 22. [26]

Comparing the dimensions of the spacers, it becomes clear that in the further analysis it is worth considering the production of two spacers. These would be 11.5 mm and 20 mm, as the difference in thickness with 12 mm spacer is only 0.5 mm and the fact that the width of the spacer is not decisive. The main difference between the last four spacers listed, is that two of these are wooden spacers and the other two are covered with foam.

Using the example of product A, with width 92.5 mm, it has been calculated how to produce a spacer 20 x 40 x 780 mm (Figure 9.) so that it would meet the requirements set for the packaging material.

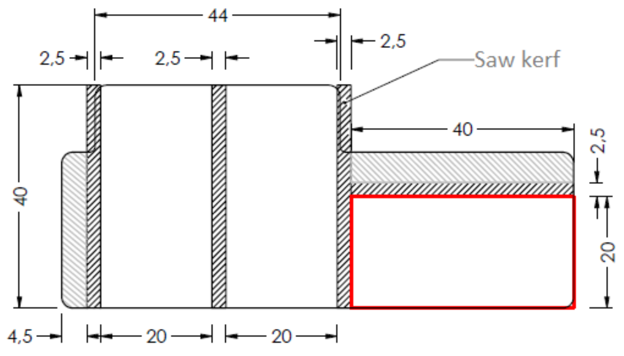


Figure 9. Spacers 20 x 40 x 780 mm from Product A 92.5 mm

The Figure 9. shows that 3 spacers measuring 20 x 40 mm from product A could be produced. Here again, the hatched part shows what will become sawdust.

As the next example, a smaller-sized spacer has been taken and it has been calculated how it would be possible to produce it from product A.

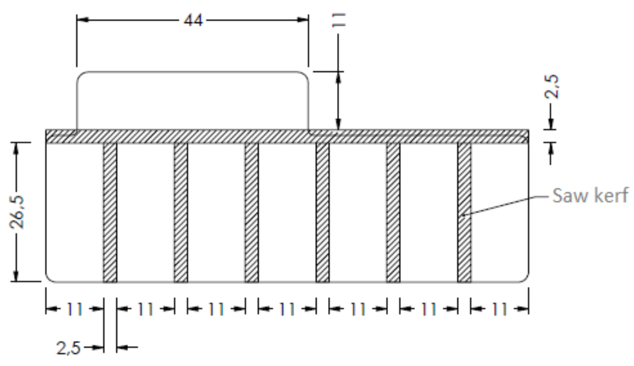


Figure 10. Spacers 11.5 x 40 x 780 mm from Product A 92.5 mm

It can be concluded from Figure 10. that the amount of sawdust generated is smaller compared to the previous production method and more pieces are also produced.

However, to get spacers in the right length, it is necessary to make cuts to the length on the scrap material. Taking as a basis that the length of the standard product in the example of product A is 2077 mm and the saw kerf is 2.5 mm, two cuts should be made per frame to obtain 3 components, from which, the spacers with corresponding cross-sections could be produced (Figure 11.).

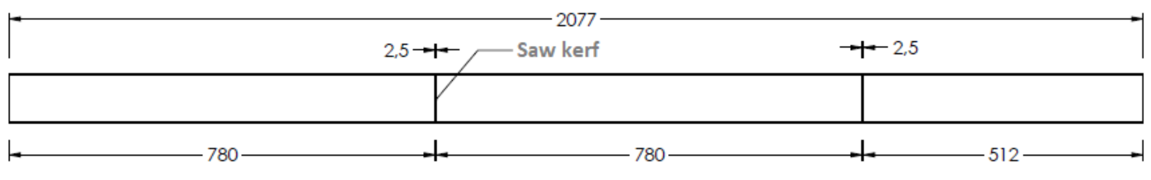


Figure 11. Cutting into length from product A

Based on the standard product with a length of 2077 mm, it is not possible to obtain all cut components with the exact size, which is 780 mm. In order to still be able to use the remaining part with a length of 512 mm, two spacers instead of one should be used in the production, placing them in an offset, so that they could give the required length.

As for the ground spacers, these are also necessary when packaging the products on the pallet, so that the products would be stable and not fall between the boards of a pallet. Like the spacers, the ground spacers have limitations in terms of length and thickness. The ground spacer must correspond to the width of the pallet, therefore for the basis of the following analysis, the width of the standard pallet is taken, which is 800 mm [41].

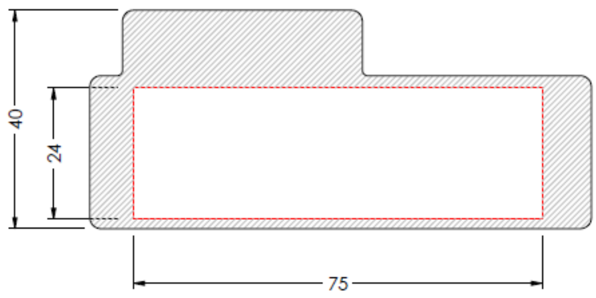


Figure 12. Ground spacer from product A

As an example, product A was taken as a basis and how it would be possible to plane ground spacers from it in the corresponding size (Figure 12.). The hatched part is what would become sawdust. It can be seen from the Figure 12. that the part that turns into sawdust is quite large, so it would be worth considering the possibility of producing a spacer in addition to the ground spacer (Figure 13.).

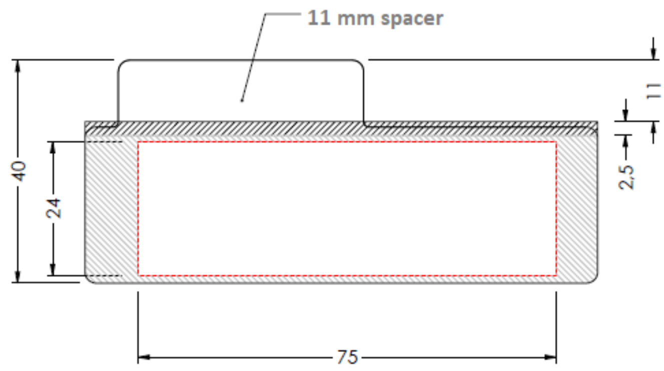


Figure 13. Production spacer and ground spacer from product A

Taking the standard product length as a basis, it is also necessary to make two cuts to produce ground spacers (Figure 14.). Like the spacers, the last part is too short and in the packaging process, therefore there needs to be used two instead of one, to secure the pallet.

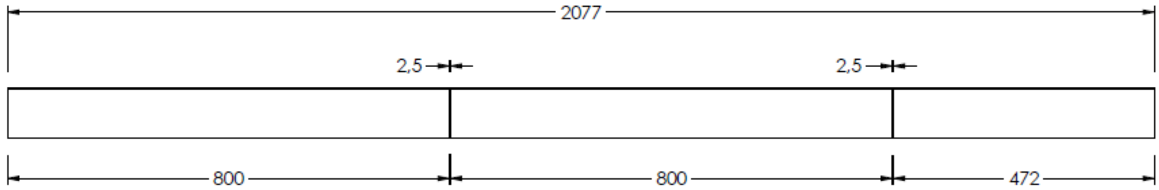


Figure 14. Cutting into length from product A

Using two shorter ground spacers or wooden spacers at the same time to ensure the stability of the products on the pallet, is also common in present practice, so this approach would not cause problems in the packaging process.

4 RESULTS

4.1 Cost calculation model for wood scrap recycling

The purpose of the cost calculation model was to create a database that shows the cost to the company of different reprocessing methods. The company does scrap recycling, but it is not known whether today's activities are beneficial in terms of costs.

The model was created in a way that the obtained results are found with formulas, therefore, the results found can be easily checked and if necessary, the input information could be corrected. It also shows which data need to be found out before having results regarding costs. This work was based on the reprocessing methods presented in section 3.1.7. Also based on alternative methods proposed by the author of this work, in section 3.4.

The calculations made for this work were based on product A, with a standard-length of 2077 mm and based on product C, with standard length of 2040 mm. Product groups A and C were chosen because products A and B are very similar in terms of their properties and price. However, product C is only made of knot-free material and therefore almost twice as expensive as the other listed product groups.

The average price of product A is 3.32 € and the average price of product C is 6.45 €, which is counted as the price of the material. In the author's opinion, it is not correct to use the price of a cubic meter of lumber as the basis for calculations, because it only gives an idea about the material used, but not what processing has already been done to the product.

The work does not publish data of the labour cost €/h and process outcomes, as it is internal information of the company, but this data is used in the model for calculations to obtain the most realistic results and so that it would be possible to draw conclusions.

4.1.1 Cost of present wood recycling methods in Scandinavian frames department

The methodology described in chapter 2 was used to find the cost of current reprocessing methods in Scandinavian frames department. The products were grouped according to what their further process would be. Considering the method established to calculate the material cost, it was also possible to group product with different surface treatments into one. Table 23. Gives an overview of costs of present recycling methods on example of product A.

Table 23. Cost of recycling methods on example of product A

Recycling method	Labour cost of recycling one product , €	Labour cost + material cost of recycling one product, €	Cost of new product from scrap material, €	Cost of material going into scrap collection container, €
Manual repair	0.38	3.71	3.71	3.13
*Painted/primed frames – recoating + manual repair	0.77	4.09	4.09	
RPA	2.88	6.20	6.20	
Smaller product, the leftover part is sent for reprocessing (new glue board)	0.36	3.68	18.41 1)	

1) The price is formed by reprocessing several scrap products into the raw material of a new product.

Scandinavian frames also process top pieces, which are intended to cover the upper part of the frame, so these calculations were also made (Table 24.). To get the shorter product rework cost, the top piece average price was entered into the model. The average cost of product A top piece with a length of 886 mm is 1.64 euros.

Table 24. Cost of recycling methods on example of product A top piece

Recycling method	Labour cost of recycling one product, €	Labour cost + material cost of recycling one product, €	Cost of new product from scrap material, €	Cost of material going into scrap collection container, €
Used to produce a shorter product	0.07	1.70	1.70	1.55
Sent for reprocessing (new glue board)	0.25	1.89	5.71 1)	

1) The price is formed by reprocessing several scrap products into the raw material of a new product.

As part of this work, calculations were also made with product C to give an overview of today's process. Table 25. shows the material recycling costs for knot-free end-product.

Table 25. Cost of recycling methods on example of product C

Recycling method	Labour cost of recycling one product, €	Labour cost + material cost of recycling one product, €	Cost of new product from scrap material, €	Cost of material going into scrap collection container, €
Manual repair	0.38	6.84	6.84	6.23
*Painted/primed frames – recoating + manual repair	0.77	7.22	7.22	
RPA	2.88	9.33	9.33	
Smaller product, the leftover part is sent for reprocessing (new glue board)	0.41	6.86	38.13[1)]	

1) The price is formed by reprocessing several scrap products into the raw material of a new product.

Like product A, separate calculations were made in the model also for the product C top piece, to get the shorter product rework costs (Table 26.). The average price of product C top piece with a length of 988 mm is 3.06 €.

Table 26. Cost of recycling methods on example of product C top piece

Recycling method	Labour cost of recycling one product, €	Labour cost + material cost of recycling one product, €	Cost of new product from scrap material, €	Cost of material going into scrap collection container, €
Used to produce a shorter product.	0.07	3.13	3.13	2.97
Sent for reprocessing (new glue board)	0.25	3.31	10.03[1)]	

1) The price is formed by reprocessing several scrap products into the raw material of a new product.

4.1.2 Cost of alternative methods of wood recycling in Scandinavian frames department

Alternative methods were introduced in the chapter 3.4, for which cost calculations have been made in the model. The calculations are based on product A and C. The following Table 27. shows the costs if the wooden spacers would be produced from products scrap on example of product A.

Table 27. Cost of producing spacers on example of product A

Product A	Cost of recycling the scrap product, €	Purchase price of same amount, €	Cost if material goes into scrap collection container, €
Spacer 11 x 40 x 780 mm	9.25	6.96	3.13
Spacer 20 x 40 x 780 mm	6.45	2.97	

From Table 27. the purchase price of spacers is also given for comparison, considering the amount that can be obtained by recycling the scrap product. The data shows that if the same quantity of spacers is bought in, the costs are lower compared to self-production.

Below in Table 28. are the calculations regarding the ground spacers. Since this product has not been previously outsourced by the company, there is no comparison point for this product.

Table 28. Cost of producing ground spacers on example of product A

Product A	Cost of recycling the scrap product, €	Cost if material goes into scrap collection container, €
Ground spacer	4.04	3.13
Ground spacer + 11 mm spacer	4.22	

Ground spacers have not been outsourced by the company before, because as brought out in chapter 3.1, both component 2 and doors 2 departments use the scrap material generated in their own department for production of ground spacers.

Table 29. Cost of reprocessing into raw material on example of product A

Product A	Labour cost € + material cost of recycling one product, €	Cost of new product from scrap material, €	Cost if the material goes into scrap collection container, €
Glue board	3.76	15.03 1)	3.13
Glue board + 11 mm spacer	3.93	15.73 1)	

1) The price is formed by reprocessing several scrap products into the raw material of a new product.

In present rework practice, the longer scrap product is always made into a shorter product first, and the remaining material is sent to the component department for reprocessing. Calculations were made in the model as to if the shorter product was not produced but the material was sent directly to reprocessing (Table 29.).

As with product A, calculations were also made on the example of product C to get an overview of the costs of alternative recycling methods. Since in the case of product C it is only a knot-free material, the production of raw materials for the cassette department was also considered for this product.

Table 30. Cost of producing spacers on example of product C

Product C	Cost of recycling the scrap product, €	Purchase price of same amount, €	Cost if material goes into scrap collection container, €
Spacer 11 x 40 x 780 mm	12.34	6.96	6.23
Spacer 20 x 40 x 780 mm	9.55	2.97	

Table 30. also shows what the purchase price would be if the same number of spacers, which can be obtained by reprocessing one scrap product, were purchased instead.

Like product A, the cost of the ground spacers was calculated, if they were made from product C scrap. Like mentioned before, for this product, it is not possible to show the purchase price. The results are presented in Table 31.

Table 31. Cost of product C recycling into ground spacer

Product C	Cost of recycling the scrap product, €	Cost if material goes into scrap collection container, €
Ground spacer	7.05	6.23
Ground spacer + 11 mm spacer	7.35	

The following Table 32. shows the results where the shorter product is not made first, but the product is sent directly into reprocessing. The outcome is the new glue board for the same product. In addition, what would be the costs if the product was reprocessed into raw material for the cassette department.

The costs discussed in the tables, where one product is processed into another product or raw material for the same product, the company still receives income in the form of sales. However, spending on packaging material is an internal company expense, from which it is no longer possible to get income.

Table 32. Cost of Product C recycling into raw material

Product C	Labour cost € + material cost of recycling one product, €	Cost of new product from scrap material, €	Cost if the material goes into scrap collection container, €
Glue board	6.96	29.00[1)]	6.23
Glue board + 11 mm spacer	7.14	29.73[1)]	
Component 25 x 98 mm	6.91	8.63	
Component 25 x 98 mm + 11 mm spacer	7.08	8.85	

1) The price is formed by reprocessing several scrap products into the raw material of a new product.

The material that goes into the scrap collection container is sold. If to consider the average price of product A, which is 3.32 euros, the company will get only 0.19 euros per product if this product is sent into container. In the example of product C, the average price of the product is 6.45 euros, the company will get back 0.22 euros. The received amounts do not compensate the cost of new material which will be needed for producing the product. With this method, the cost of a new product is therefore the cost of collecting the product into the scrap collection container + the average price of the product.

5 DISCUSSION

5.1 Present scrap recycling process

The range of the company's products is large, so the decision was made to continue with the Scandinavian frames department, which produces end products. The decision was made based on the volume of production and the percentage of scrap in the department. The correctness and availability of data were also considered.

The complexity of end products compared to the raw material is that the final products have different dimensions, profiles, surface treatments, and millings, which makes the recycling of these products more difficult. In the case of raw material, only different cross-sections and qualities must be considered.

Another factor was that the data collection in the departments does not take place on the same principles, there are errors in the system and/or entries, and product replacements or scrap data are not registered. Although, due to the mapping, it became clear that the present approach to raw materials is quite well understood, because alternative solutions have been found within the departments, based on knowledge and experience.

To highlight the costs of different recycling methods, the products with the largest sales volume and the largest amount of registered scrap were selected as the basis of the calculations. The calculations were based on technical data, how much scrap products can be processed per hour, as well as FTE.

It can be seen from the Figure 15. that regardless of the product, the proportion of the results between different reprocessing methods is the same. For both product A and product C, the cheapest solution is to reprocess the raw materials. It can be seen from the given results that repairing the product in the RPA area is the most expensive method. However, these results give a wrong idea, as here the differences and outcomes of different methods must also be considered.

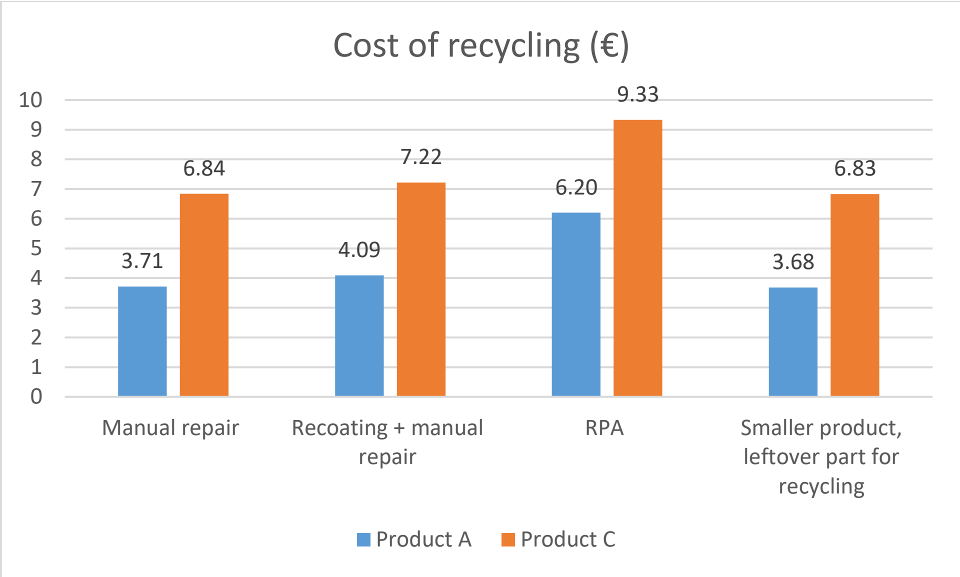


Figure 15. Cost of recycling one scrap product (labour cost + material cost) €

In the case of manual repair and recoating, which is a standard part of the process, the frame is not processed either in length or width, the product remains in its original size and is ready for sale. To get the correct cost of recycling, the income received for the sold product should be deducted. The result is the same with the RPA area, where the frame is not processed in any way, only several manual repairs are made, therefore after this process the product is ready for sale in its original dimensions.

A product that is originally made into a smaller product and the leftover part is sent for reprocessing, only the smaller product becomes a ready-to-sell product. In order to obtain the new product from scrap material, it is necessary to reprocess several scrap products in order to create enough material for the production of new raw material. This requires more time and several processes before the desired end result.

Figure 16. results again show clearly that the proportions regarding different products reprocessing, are the same, therefore it is not so important to consider the price differences of different products, but it is important to understand the principle that the more processes are needed for reprocessing, the more expensive the product itself becomes.

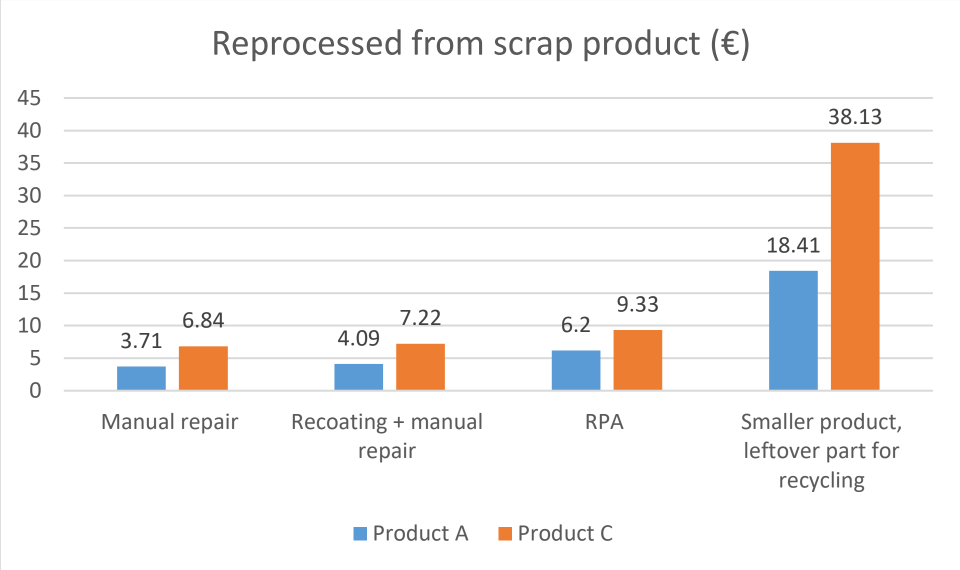


Figure 16. Cost of a new product reprocessed from the scrap product (€)

From the results, it can be concluded that manual repair and overpainting in the standard process are good solutions, as these are the most inexpensive methods, and as a result, the product is ready for sale. However, this is on the assumption that it has been possible to comply with the established quality requirements from the raw material, that the product does not need more improvements than the standard process provides.

If the product also must undergo external repair of the process, the cost of reprocessing this product and thus the value of the product itself will increase. However, despite this, it is better to see from these results that the cost price of the product increases significantly when reprocessing the product into a new raw material, which is clearly the most expensive solution for the use of the material. This is also a logical result since in this method the product is returned to the original process not sent to the next process, as with other methods.

If to consider that the average price of product A is 3.32 euros and the price of a smaller product from it (top piece) is 1.64 euros, the price of reprocessing is still the most expensive compared to other methods. It is also important to note here that the result is only a raw material, that still needs to be processed according to the standard process, so it would have the required profile and measures. However, this also adds costs, and therefore also increases the price of the product.

In addition, in this work, the cost that would be incurred if the material was not processed around but thrown into a scrap collection container was brought for comparison. For the material that goes into the scrap collection container, the company gets income, as this material is sold for another company, but it is not a considerable amount.

When placing the material in the scrap collection container, it must be considered that since this product is not recycled in any way, it is not useful in terms of material saving, since there needs to be purchased new raw material for it or plan from scrap material, which increases the costs.

5.2 Alternative scrap recycling methods

When dealing with the recycling of scrap material, it was analysed whether and what are the alternative methods for reprocessing the material. However, considering the company's products and the technical limitations, alternative methods are quite limited. It was analysed whether something could be done differently compared to the present process, for example, is it reasonable to first cut out a shorter product from scrap material, or this material should be sent directly to its original process.

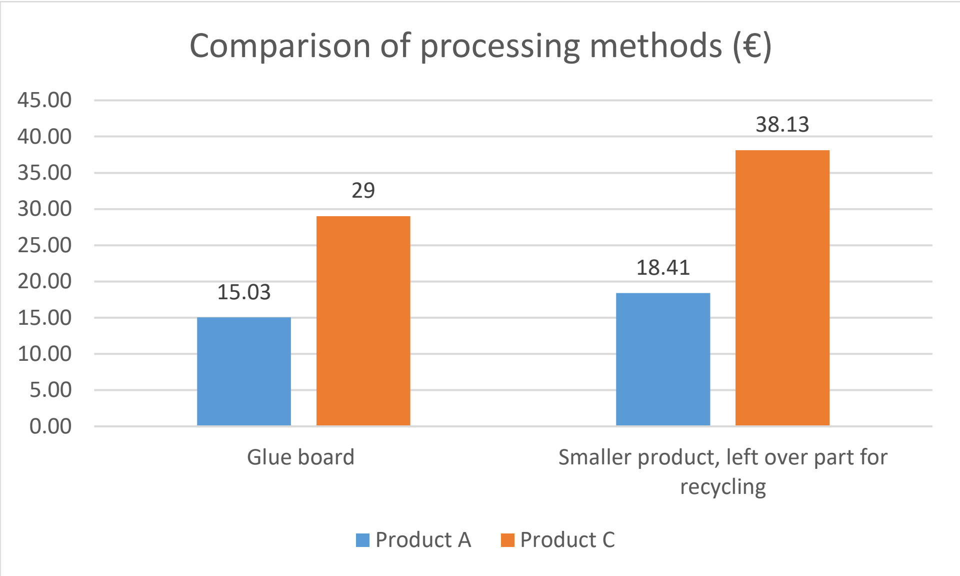


Figure 17. Comparison of processing methods (€)

The obtained results showed in Figure 17. there is a price difference in the reprocessing methods. If first a shorter product is produced and the rest of the material is sent for recycling, the price of the new product will increase. However, if the material is sent directly into circulation, it has a bigger outcome and, as a result, lower costs. At this point, however, it must be noted that in the case of a more expensive method two sales products are created, with which it is possible to receive income. This is, of course, if the smaller product is needed and sold.

It was also considered whether it would make sense for the company to produce packaging material that has been purchased so far (Figure 18.). Except for the ground spacer, where its cost was found if it had been produced from frame scrap.

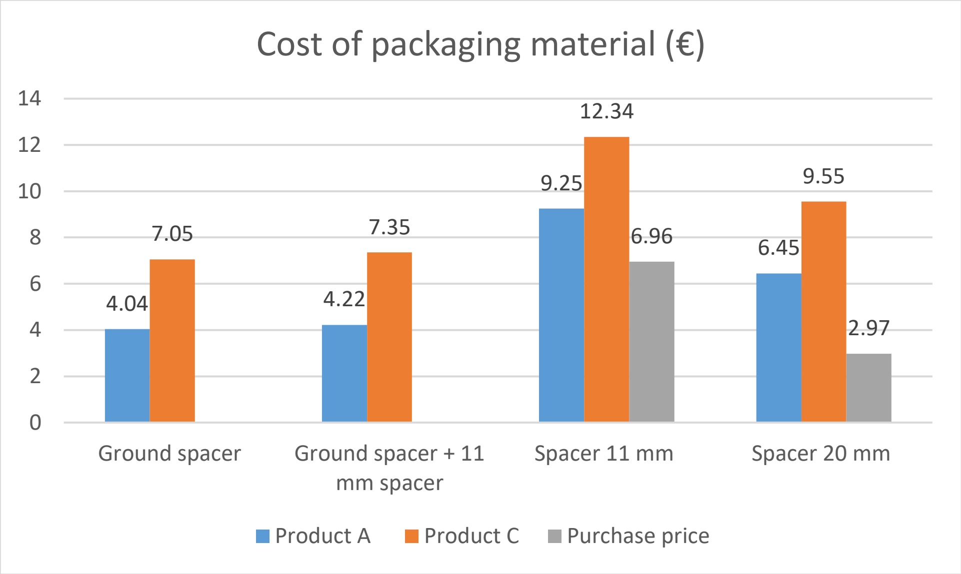


Figure 18. Cost of producing the packaging material compared to purchase price (€)

It can also be seen from the given Figure 18. that regardless of the product, the price of the product is determined by the number of processes required for reprocessing. In addition, it is clearly seen the price difference between producing spacers and purchasing them. Producing the spacers, the costs are higher, so it would not be a reasonable reprocessing method. Also, it might not be worth considering the production of ground spacers since the scrapped final product is used for its production. So far, the ground spacers have been glued from raw material scrap in component 2 and doors 2 departments, where the material has not yet gone through so many processes and is therefore less expensive.

However, in the production of packaging material, it is important to understand that with this method, the products received are not sold, the company does not earn income from it. Therefore, the production of the packaging material itself is only an expense for the company, and since this material is not used to produce end products, it is necessary to plan new material for production.

If the company should consider the production of packaging material in the future, it would be worthwhile to change the thickness tolerance of the spacers from +/- 0,5 mm to +/- 1 mm. In the author's opinion, it is not reasonable that the ground spacer, which is also used for packaging, has a thickness tolerance of +2/-10 mm, while the spacer has a very strict limit of +/-0,5 mm. If a tolerance of +/-1 mm is used, it would be possible to equalize the measurements and there would be no need for a separate 12 mm thick wooden spacer. The 11 mm spacer could be used immediately or by adding a foam strip to it. Equalization of the widths should also be considered so that a 20 mm spacer could be used in the same way.

Considering the quality of the scrap product, it is not the most reasonable to use a knot-free material to produce packaging material. Knot-free material is more expensive and more valuable than standard material, therefore it was analysed whether this material could be used to produce new raw material (Figure 19.).

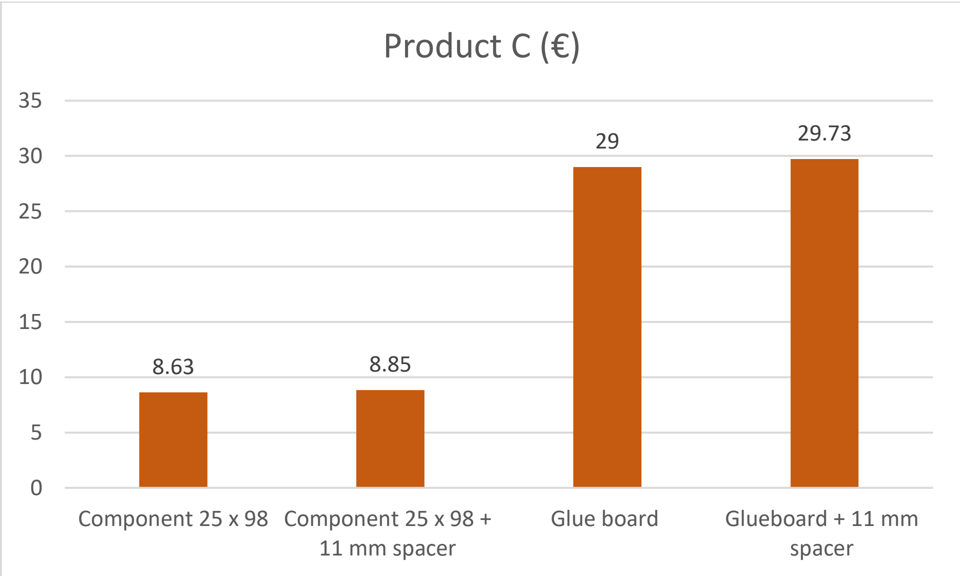


Figure 19. Cost of production of raw material from product C (€)

The production of packaging material is certainly not reasonable if this product could become with less expense a new raw material for the cassette department. The Figure 19. also shows the cost of producing a new glue board of an equivalent product, which is significantly more expensive, but the final cost of the end products themselves should also be estimated here to get a more realistic result.

In any case, it can be concluded from these results, that the important difference is whether to use the material for internal purposes of the company or for sale. In addition, the abundance of processes and the quality of the material used should be considered, as this directly affects the costs.

5.3 Conclusions and impact

In this work, data was collected on today's material handling and reprocessing methods, and alternative methods were also analysed. To find the recycling costs, a calculation model was created, considering the necessary processes and human labour needed to achieve the desired results. The calculations were based on the most produced products by Scandinavian frames department, to give a general overview of costs in relation to different methods.

The calculated results of recycling costs do not determine the method for reprocessing, it gives an overview of the costs that the company should consider when choosing a certain recycling method. This is also reasonable given the fact that the model does not consider production capacity and the amount of scrap products that needs to be reprocessed.

In the framework of this work, the secondary costs associated with reprocessing, such as transport, cost and maintenance of machines, and energy use, have not been discussed. This work would be a good basis for further research and analysis, as it provides a full overview of the present handling of material and scrap products.

Considering the reprocessing of the scrap product into another product, should be ensured whether there is a need for this product. Otherwise, a situation may arise where the material will remain in the warehouse and lose its properties over time. Such recycling of scrap is not reasonable, as new scrap is produced from scrap, which in the end has no use at all.

The thesis brings out the importance that needs to be understood when making decisions regarding material recycling within the company. It is important to understand the fact that the more different processes are needed to reprocess the scrap product, the more expensive the output will be. However, from the point of view of saving material, it is useful to use the material as well as possible and not to waste it. Here, it would also be important to assess the resources needed for scrap products reprocessing. Thus, it may not always be possible to achieve both cost savings and material savings.

However, in terms of material and cost savings, it is also important to understand the fact that it is always more reasonable to continue the original process, rather than redirecting the material back to the initial process. Considering RPA area, the material is manually repaired and then sent back to its original process, thus no additional machining is done. When a scrap product is sent into component department for reprocessing, the product is reprocessed into raw material. To obtain enough material to produce a new product, it is necessary to process several scrap products, therefore several processes will be needed which increase the costs, this is also supported by the calculations presented in chapter 5.1 and 5.2.

Considering the known information, it can be extracted from Scandinavian frames scrap product register, how many products were thrown into the scrap collection container in 2021 and 2022, because lack of resources in the standard process. The following Table 33. reflect the products that could have been repaired in RPA and what would have been the potential income and also saving for the company, considering the average price of the products. Excluded from the data are products that were identified as having process and machine errors that cannot be repaired.

Table 33. Material collected into scrap collection container and the possible income if repaired in RPA

Product group	2021, pcs	2022, pcs	Income if repaired in 2021, €	Income if repaired in 2022, €
Product A 92.5 mm	1,597	1,752	5,302.04	5,816.64
Product B 92 mm	4,368	4,563	14,501.76	15,149.16
Product A 100 mm	1,092	1,094	3,625.44	3632.08
Product C 105 mm	5,627	5,839	36,294.15	37,661.55

The accuracy of the data can be doubted because, as mentioned earlier, there is no exact documented process for scrap data collection. When making the scrap entry, people can write a reason in free form, so the rating can be subjective.

Nevertheless, the product groups selected in this work provide significant results. The results also show that since the price of knot-free material is considerably higher, it is also possible to save the most with these products. That is why it would be worthwhile to put more focus on valuing knot-free products to save costs.

Compared to other reprocessing methods, repairing difficult defects is the most reasonable in terms of costs and output. The company could consider directing more resources to this area, as calculations show that both material and cost savings can be achieved in this way. With more resource, it could be possible to repair more product groups and thus save even more.

With this conclusion, however, the author does not want to exclude other processing methods. In the case of a suitable reprocessing method, the current situation and capacity should be considered. However, despite various possibilities, it is not reasonable in any situation, to throw the usable scrap product into a scrap collection container, because it is, in the most general sense, a material misuse. To compensate the material, which is collected into the scrap collection container, more raw material must be bought in to produce the necessary products. To use the material efficiently, it is more reasonable to recycle the material than to throw it away, however associated costs should also be considered.

The processing of scrap products into packaging material could come into question if there is a greater need for these products or if for some reason the purchase price exceeds the price of own production. Otherwise, this solution is not reasonable in terms of both cost and material saving, as here also, new material must be planned to produce the end products.

In general, the process of handling scrap products in the company should be improved. Clear agreements should be made that are documented. Scrap data collection should also be implemented in all departments on a similar principle, to have a better and more accurate overview of the use of the material. Considering inaccuracies in material data, it should be reviewed where and for what reason such errors occur and how they can be prevented in the future.

SUMMARY

The master's thesis was carried out in a company that produces wooden doors and door frames. During the work, the company's products, the use of material, and the handling of scrap material were investigated. Based on the data on the production volumes and scrap amount, the further work was focused on the scrap handling methods of the largest department. In addition, the author found alternative methods for reprocessing products in addition to today's methods.

When analysing the processing methods, established requirements and technical limitations were considered. Data were also collected on the process stages, productive and labour costs of different methods to make cost calculations. Based on the collected data, a scrap recycling model was created and proposed for the company.

Regarding scrap material recycling, the principles related to the processing of wood material must be understood. The number of processes performed directly affects the final price of the product. Consequently, it is more material and cost-efficient to continue the product's initial route than to redirect it back to the original stage. In terms of costs, it is also important to define the purpose and further use of the recycled material. When throwing the material into a scrap collection container, the cost of the new material that is needed to produce the products must also be considered.

Preferring RPA as a reprocessing method, the company would have had a potential saving of 59,724 € in the year 2021 and 62,259 € in the year 2022. The conclusions have been made based on the collected scrap data of the department considering the most produced products and their average price. The savings could be even greater if this method would be fully implemented, and more resources directed.

In terms of material use and scrap products handling, the company needs to improve today's process so that the data is collected according to common principles in all departments, and is documented, so that it is possible to get a more accurate overview of material handling and therefore circulation.

Within the scope of this work the secondary costs associated with reprocessing have not been discussed, despite it, this work would be a good basis for further research and analysis, as it provides a full overview of the present wood material recycling process.

KOKKUVÕTE

Magistritöö viidi läbi ettevõttes, mis toodab puidust uksi ja ukseraame. Töö käigus uuriti ettevõtte tooteid, materjali kasutust ning praakmaterjali käsitlust. Lähtudes tootmismahtudest ja praagi kogustest, keskenduti edasises tööd suurima osakonna praak toodete ümbertöötluse meetoditele. Lisaks leidis autor lisaks tänastele meetoditele ka alternatiivseid meetodeid toodete ümbertöötlemiseks.

Töötlemismeetodite analüüsimisel võeti arvesse ettevõttes kehtestatud nõudeid ja tehnilisi piiranguid. Kuluarvutuste tegemiseks koguti andmeid ümbertöötluse meetodite protsessietappide, tootmis- ja tööjõukulude kohta. Leitud andmete põhjal loodi ja pakuti ettevõttele välja praaktoodete ümbertöötluse kulu mudel.

Praak materjali käsitlemisel tuleb mõista põhimõtteid, seoses puitmaterjali ümbertöötlemisega. Tehtavate protsesside arv mõjutab otseselt toote lõpphinda. Sellest põhimõttest lähtuvalt on materjali ja kulude säästmise seisukohalt mõistlikum jätkata toote esialgset marsruuti, kui suunata see tagasi algsesse protsessi. Kulude osas on oluline ka taaskasutatud materjali eesmärgi ja edasise kasutuse määratlemine. Materjali kogumiskonteinerisse viskamisel tuleb arvestada ka uue materjali maksumusega, mis on vajalik toodete tootmiseks.

Eelistades ümbertöötluse meetodina RPA'd, oleks ettevõte saanud potentsiaalset säästu 59,724 € aastal 2021 ning 62,259 € aastal 2022. Antud järeldused on tehtud osakonnas kogutud praagi andmete põhjal, võttes aluseks enim toodetud tooted ning nende keskmised hinnad. Kokkuhoid võiks olla veelgi suurem, kui seda meetodit täielikult rakendada ja sinna rohkem ressursse suunata.

Materjali kasutuse ja praak toodete käsitluse osas oleks ettevõttes vaja täiustada olemasolevat protsessi, et andmed oleksid kogutud ühtsetel põhimõtetel, kõikides osakondades ning oleksid dokumenteeritud. Selliselt oleks võimalik saada täpsemat ülevaadet materjali kasutuse ja seega ka materjali ringluse kohta.

Selle töö raames ei ole käsitletud ümbertöötlemisega kaasnevaid kulusid, vaatamata sellele oleks käesolev töö heaks aluseks edasistele uuringutele ja analüüsidele, kuna annab täieliku ülevaate tänasest praak materjali ringlussevõtu protsessist.

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