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LCA STUDY OF THE INTRODUCTION OF CIRCULARITY APPROACHES WITHIN THE PRODUCTION OF LAMINATED WOOD

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Abstract: The paper presents an analysis regarding the transition from classical manufacturing to the use of recycled wood in producing laminated wood panels. These products are performing well on the market due to their price and convenience, but their production using current practices from wood scrap resulting from other types of more complex and expensive wood products manufacturing exhibits problems related to costs, lead times and sustainability. Thus, starting from the experience of a Romanian company working in this industry, we study the main differences, in terms of advantages and disadvantages of introducing circularity approaches and practices within this type of production. By using recycled wood, companies can expect a significant improvement of all the important criteria that determine market competitiveness, while at the same time, their environmental footprint will be greatly enhanced. We use life-cycle assessment (LCA), within a coherent framework of managerial improvement instruments to quantify the impact of these changes.

Keywords: life-cycle assessment, circular economy, laminated wood, manufacturing, sustainability.

1. INTRODUCTION

One of the most important paradigms shifts that has been taking place in the European economy for the better part of a decade and will continue in the foreseeable future deals with implementing the percept of circular economy into the supply chains, manufacturing processes and consumer approaches, on a large scale, that can ensure measurable environmental impact. The transformations required for this change are very diverse and complex in nature, ranging from new policies to new behaviours and to technical solutions that permit companies to retain competitiveness while working to "close the loop".

The current paper describes a circular economy transformation at the level of a wood products manufacturer in the form a case study that can serve as best practice for similar situations in other industries. The research demarche is part of a larger effort, a doctoral project, dedicated to expanding the knowledge upon how to implement circular economy approaches in the wood industry in Romania in faster, more effective, and more efficient manner.

2. STATE OF THE ART CONCERNING CIRCULAR WOOD PRODUCTION

The first step undertaken by the authors was to perform a survey of relevant scientific literature in the past few years. Since the focus of the article is upon technological developments in implementing circular economy, the scope of the review has been extended to encompass a larger number of sustainability solutions applied in the field of manufacturing. Thus, when studying the ScienceDirect and Google Scholar databases, the keywords "circular economy" have been complemented by "sustainable manufacturing", "green manufacturing" and "environmental impact", as well as their derivates and associated concepts. The resulting logical structure that supports the opportunity of further applied research in the field, with customization for the wood products area, is presented below.

According to current research, approaching the wood processing industry should be done holistically, with wood products supply chains should changing in many parts to ensure better sustainability performance: implement industry 4.0 digital technologies, rely on design for innovation to reduce consumption, stimulate recyclability, etc. [1].

The study [2] describes the main opportunities and difficulties for a developing region, at local authorities' level, to adopt the circular economy as a model for waste management and reutilization. At the same time, at organizational level [3] highlight that the implementation of the circular economy within an organization requires a cross-functional and long-term effort. The authors [1] propose an integrated framework for assessing environmental sustainability in supply chains, which constitutes a mandatory approach in order to transform entire national economies. In such a complex endeavour it is critical to recognize possible uncertainties such as [4] that discuss sources of heterogeneity for production sustainability efforts and how they can be modelled and managed using system design visualization. Many authors present the challenges of developing circular products and solutions [5], [6], [7]. The article of [8] presents the development of the technological innovations of multi-story wooden constructions, with two distinct periods of activity that have been both stimulated by government support to encourage increasing the value-added potential of the forestry sector.

The LCA (Life-Cycle Assessment) method is a common tool used to estimate the environmental impact of a product, from conception to retirement. Moreover, recert results show that comparison across sectors and the accommodation of manufacturing heterogeneity when evaluating sustainability results is possible due to LCA enhanced by Exergy Analysis [4]. Many scientists are also interested in developing new useful instruments for assisting companies to self-assess their readiness to implement circularity within their processes (e.g., MATChE platform) and then to make the necessary changes [3]. In the same direction, of weighing change and enabling the possibility to act upon its results, other teams are developing new indicators to measure the circularity degree based on the active period that wood is temporary in use, before becoming available again for another project through recycling [7].As a corollary, an article has concluded that the integration of bio-based products, life cycle assessment and social life cycle assessment are critical to achieving success in fully accomplishing the promises of the circular economy and will also be useful for the next frontier of sustainable economic development, the low carbon economy approach [5]. Furthermore, the study [5] showcases the challenges of integrating bioeconomy products in the circular economy, which can provide both very good results in terms of materials used, but also creates problems regarding end-of-life waste, as is the case for wood-based products such as the one analysed in this paper. Sustainability criteria and measures must be developed and implemented that are suitable for the sector, without simply importing the KPIs of other domains [1]. A possible model in this respect is presented by [7] which relies on material use efficiency and energy utilization yield. The research presented by [9] shows that recycling reclaimed wood can bring up to 29% improvement over business-as-usual.

In a study that compares circular and linear approaches, the authors concluded that the use of wood shavings combined with a biopolymer in creating building materials can reduce the environmental impact of using classic particleboard up to 95% [10]. Also, another research has found out that circular economy practices are being applied in the wood panel industry, but there is little work demonstrating their contribution to economic competitiveness and environmental friendliness [6]. This is in line with the aims of our current approach, as the main hypothesis that we rely upon is the fact that circularity can be adopted without negatively influencing the business model or the value proposition in this sector. In addition, the paper [10] compares the circular versus linear economy for building materials using recycled wood and biopolymer particleboard versus conventional particleboard and concludes about the viability of this technical solution. Similarly, the authors [11] assess the qualities of polymeric wood composites produced with recovered wood particles, while [12] present the implications of prolonging the life cycles of building materials on the environment and climate change mitigation efforts. The transition of this industry to circularity should be performed in a controlled manner, based on good practices and principles for manufacturing system design [13], as it has a considerable potential to contribute to a low-carbon construction sector in Europe, sustainable cities and sustainable society [14]. By analysing 61 scientific publications, the authors of [15] determine the need to adapt the circular solutions to the specific product life cycle phase, even if this requires outside support and know-how for the companies. The design stage is especially important for incorporating Design for X solutions that are geared towards ensuring the future circularity of products and projects [16]. The manufacturing stage's circularity performances is influence mostly by the knowledge of the people involved, as well as by the supply chain in which the firm operates [13].

3. RESEARCH METHODOLOGY AND RESULTS

The undertaking presented in this article is based on a structured methodology for applied research, that is described below.

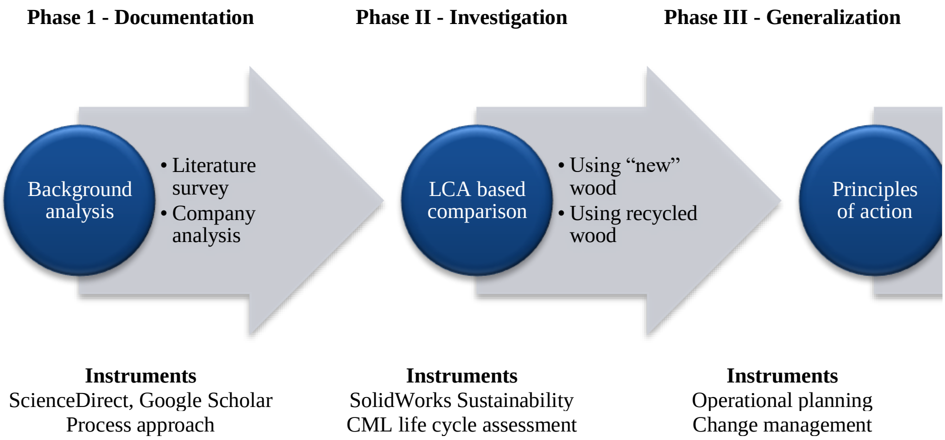

Figure 1. Research (and intervention) methodology and instruments

In the first phase, a thorough literature survey has been performed, which forms the bases of the preceding chapter of the current paper. The conclusions that can be drawn from this process and which influenced our work are that:

- Circular economy brings about significant challenges and transformations at the level of national and regional economies, but is even more important when prompting organizational transformations and requiring and redesign of the performance management approach;
- The wood product industry has a natural connection to circularity approaches and its bio-based aspects can be converted into competitive advantages, if the drawbacks are countered in time;
- The companies should have a holistic approach to becoming circular, with each process undergoing specific changes, while at the same time the relations to the suppliers and the markets are also being managed for the same type of change;
- There are significant technical and technological contributions at a high maturity level that can be applied by wood product companies to become more circular.

In parallel, a field investigation has been realized in the company that served as case study for our undertaking, to understand its characteristics and approach to market and product design and development. Silvania International is a Romanian company with over 70 years of experience in producing layered laminated wood and other wood-based products. The company industrializes natural whitewood from the forests around Lunca Ilvei, Bistrița County, and sells the products or implements construction projects in Romania or internationally. It has an integrated management system (quality-environment-OHS), performs research in forestry and uses sustainable practices. The product used for study is a triple layer laminate (a fixed format) with the following dimensions: 500 x 88 x 74 mm (length x width x depth) (see Figure 2).

Figure 2. Studied triple layer laminate. Pictures & information courtesy of the company .
(© Silvania International Prod, 2022)

The following determinations have been made, based on analysis of the firm and its bio-based products:

- The company exhibits a keen interest in solutions that have a positive environmental impact of any kind, as they can be integrated in its product design paradigm and the continuous improvement process of its integrated management system;

- The product offer is complex and is complemented by construction project implementations, which requires establishing a research baseline for a simple product, that can be extended to entire range of solutions;
- The possible cost savings potential is an important one, as the company has available a multitude of wood waste than can be used as recycled raw material for producing layered laminates.

The main investigation performed during our research was related to simulating and studying the comparison between using “new” wood or using recycled materials from previous wood-based products. The analysis was performed using the SolidWorks 2022 Sustainability software module (Figure 3), which employs the well-known CML 2001 method developed by the Institute of Environmental Sciences at Leiden University.

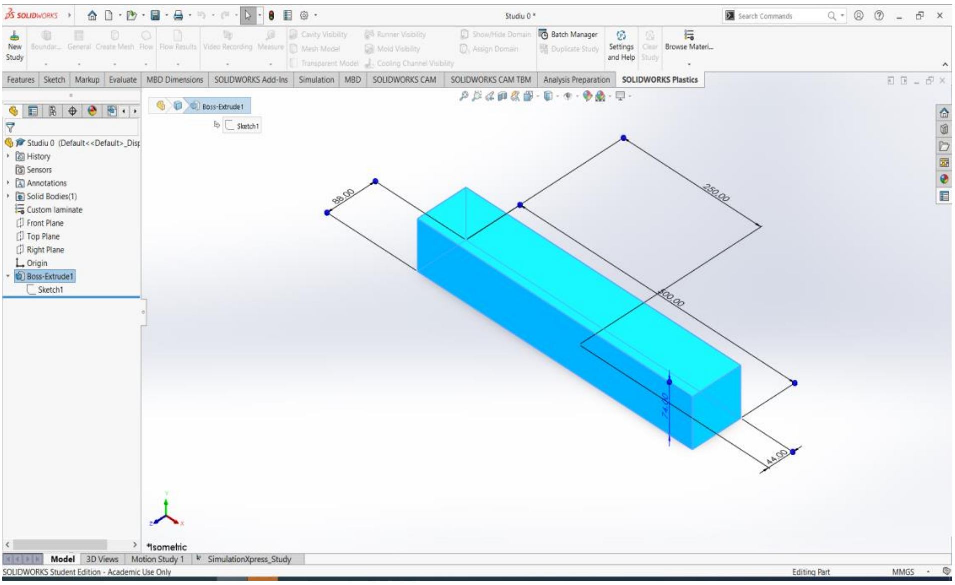

Figure 3. Simple 3D model with dimensions of the product in SolidWorks 2022

In the first version of the analysis (“new” wood - Figure 4), the product material has been chosen to closely model freshly harvested white wood, while the in the second version (recycled wood - Figure 5), the characteristics have been set to mimic the mix of wooden scraps typically available within the company’s production system as a result of manufacturing processes. As such, changes were applied to:

- raw materials (as mentioned in the paragraph before);
- energy consumption (higher for processing waste materials as some breakdown of the inputs is required, but lower for manufacturing and transportation since in-house processes have produced the scrap being used);
- production efficiency (lower for processing waste as there is an increase chance of production nonconformities) and the
- EOL distribution of outcomes (there is a proportion of 10% estimated to be lost for every circularity cycle of reusing the wood).

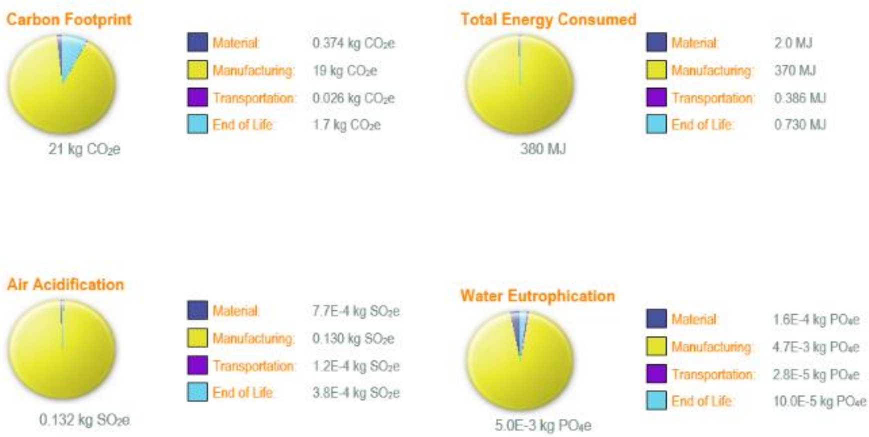

Figure 4. LCA analysis for using “new” wood - SW 2022

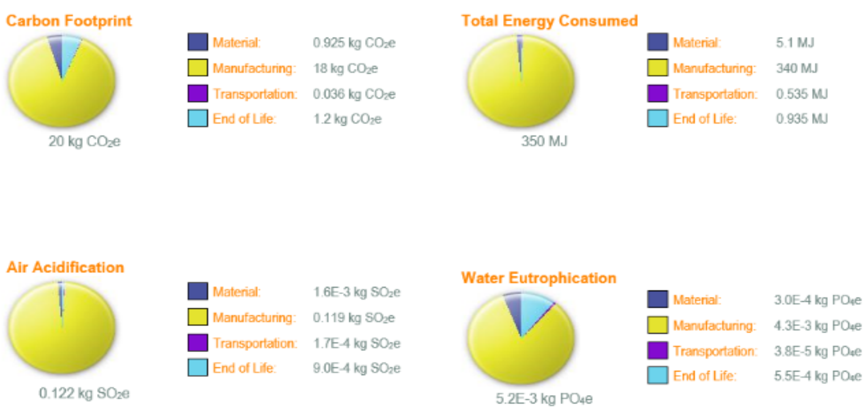

Figure 5. LCA analysis for using recycled wood - SW 2022

The main observations that can be made regarding the software comparison of the two situations can be summed up as follows (Figure 6):

- Energy consumption is decreased to due using processed materials although some of this recuperation is lost in the EOL stage, with an overall improvement of 8%;
- Carbon dioxide & air emissions are reduced by 7% and 8% respectively, as the new version of the product avoids the introduction of new biomass and requires less processing, through circularity;
- A marginal increase of water consumption is forecasted of 4%, as more water intensive technologies are necessary for processing wood scraps that contain chemical solvents and/or paint;
- Waste that ends up in the landfill (not analyzed in the graph) is also slightly increased, but after prolonging original use by 50 years, which is the projected useful life of a laminate product.

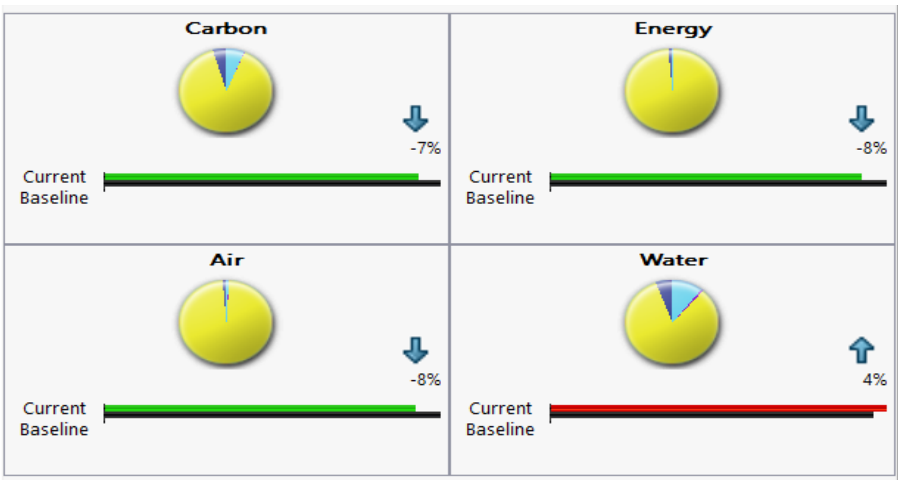

Figure 6. Comparison of environmental performance for the two product versions - SW 2022

4. DISCUSSION

The transformation proposed by the research team is in stage of feasibility study and commercial viability analysis at company level, and the arguments for it have been formulated and presented below with a 3-year perspective over the immediate gains (Table 1):

Table 1. Short- and long-term changes for adopting the circularity approach

Circularity element	Short term (current analysis)	Long term (ca. 3 years)
Wood raw material	Use of 10% recycled wood from similar products	Use of 25% recycled wood from any wood products
Chemical adhesive	Move from solvent-based to water-based adhesives	Move to bio-based adhesives (e.g., resins)
Cutting process	No change necessary, renewable energy and cogeneration of heat implemented since 2010	No change necessary, renewable energy and cogeneration of heat implemented since 2010
Assembly process	No change is necessary, low environmental impact	No change is necessary, low environmental impact
Packaging & shipping	No change to the current adhesive used, low quantity is involved	Use of recycled wood pallets, use of electrical/biofuel for transport

The analysis is structured on process level, addressing the main aspects that require improvements in terms of new technologies, new equipment, new practices, etc. In the first interval, the company's commitment to using recycled wood and moving to water-based adhesives is enough to produce detectable change in the outputs, in line with the analysis presented in the chapter before. In the second interval, the project for change should significantly increase the amount of recycled waste used, it should also implement the new resin-based adhesives which use specific techniques, and it should result in similar changes, of different nature to the logistics of the company (renewable fuels and recycled transportation aids).

A full environmental analysis of the impacts of these changes is being commissioned at the moment to address all aspects of making the company as green as possible through circularity solutions and other approaches.

5. CONCLUSIONS

Companies are becoming increasingly interested in implementing sustainable manufacturing approaches due to market and regulatory pressures, as well as due to the ongoing societal attitude change. Circularity principles are easily adoptable and implementable in the wood processing industry due to the nature of the raw material and could be complemented in the future by bio-economy approaches. The product development processes, as well as manufacturing technologies and production system configurations must be upgraded to make full use of recycled materials as raw inputs.

Although environmental investment is usually seen as antagonist to competitiveness, the authors believe this view might change if the circularity solutions will be adopted on a large scale and will result in longer use of products and materials taken from nature, and in less resource and energy intensive processing.

The presented case study highlights the need for and the benefits of adopting a circularity mindset, especially in the product creation phase, which can then propagate throughout the production system of the company. Moreover, the adoption of a circular approach on a large scale by the company can influence the relations it has with the markets, the consumers, and its suppliers, contributing to achieving the critical mass needed for a sectoral change.

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