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SUMMARY

PhD THESIS

Applications of circular economy in leather industry

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Contained

INTRODUCTION

The leather industry is experiencing changes in production and consumption patterns due to societal concerns. It advocates a shift towards a circular economy, aiming for a more sustainable economic model where waste is minimised and resources are widely reused and recycled [1].

Leather has been of crucial importance throughout human history, since ancient times, when our ancestors used animal skins for clothing, shelter and protection. Industrialization transformed leather production from traditional vegetable-tanned hard leather to modern chrome-plated leather, now widely used in footwear, fashion, and upholstery. The leather industry has continuously advanced through innovations in chemicals, processing techniques and finished leather properties [1, 2].

Over the past century, environmental concerns have escalated, starting with water pollution and eventually leading to global environmental considerations. Strict environmental regulations in Europe, coupled with high labor costs, have caused leather production to migrate from industrialized countries to developing countries such as Latin America, India and China.

Cu toate acestea, expansiunea rapidă în aceste țări a dus la provocări de mediu, afectând agricultura și accesul la apă curată și ridicând îndoieli cu privire la durabilitatea industriei pielăriei [3]. Ca răspuns, industria a inovat la nivel global pentru a aborda preocupările legate de mediu referitoare la procesele de producție, concentrându-se pe utilizarea apei, tratarea apelor uzate, recuperarea deșeurilor și reducerea substanțelor chimice nocive [4].

Today, both society and markets demand a comprehensive approach encompassing the entire leather value chain, not just tanning processes. The focus is on traceability, ensuring ethical practices such as banning child labour and sourcing hides from animal-friendly farms. This is in line with the principles of a circular economy, where resources are used sustainably [5].

Sustainability research remains a focal point in academia and in the service and manufacturing sectors. In manufacturing, such as leather, research has played a key role in promoting the adoption of sustainable practices. Recognizing sustainability as a continuous journey rather than a destination, synthesizing existing research can guide future efforts in advancing sustainable production [17].

The main objective of the paper refers to the analysis and presentation of circular economy applications in the leather industry. Among the specific objectives of this thesis are:

- ✓ Analysis and presentation of the concept of sustainable development in the leather industry;
- ✓ Theoretical study of the leather industry in Romania and the European Union;
- ✓ Study on waste management in the leather industry;
- ✓ Studies and research on the design of sustainable footwear models (research on the realization of a shoe sole based on polymeric composite material with elastomer matrix and protein waste platterers, children's footwear design and cost efficiency).

PART I – BIBLIOGRAPHIC AND STATISTICAL ANALYSIS – INTERVIEW ON CIRCULAR ECONOMY AND THE LINK WITH THE LEATHER INDUSTRY

Chapter I. JUSTIFICATION FOR MOVING FROM LINEAR TO CIRCULAR ECONOMY

1.1. Characteristics and limitations of the linear model

„The circular economy is based on a production and consumption model involving the wider sharing, reuse, repair, renovation and recycling of existing materials and products, thus seeking to extend the life cycle of products. Thus, the circular economy is based on a system aimed at reducing, reusing and recycling, as waste is considered a valuable resource. Based on this principle, some used or defective products can be repaired and reused, others can be reused directly, and others can be recycled. By applying the circular economy principle, the aim is to minimise waste, thus enabling the materials from which it is made to be reused in the economy whenever possible when a product reaches the end of its useful life."

1.2. The concept of circular economy and its evolution

„The first ideas for the circular economy appeared in the late 19th century, and in the 1960s the need to use terms such as "spaceship Earth" was identified. In the 1970s, terms such as "Cradle-to-cradle", "Ecological design", "Industrial ecology" were increasingly countered, but also the idea of a closed-loop or regenerative economic system. Also, the practical applications of the circular economy in modern economic systems and industrial processes were encountered more and more often in the 70s. In 2009, the Ellen MacArthur Foundation was founded, which aims to inspire a generation to rethink, re-design and build a positive future in a circular economy. Subsequently, in 2013-2014, Canada and France established their own Institute of Circular Economy [19, 23]."

1.3. The correlation between production and consumption in the circular economy

„The objectives of the circular economy can be analysed from several perspectives, such as those in economic sectors, material flows and categories, business models, circular economy indicators, its long-term results. On the one hand, the strategies aim to apply circular economy solutions to economic systems and, on the other, they include global, national, industrial and consumer aspects [19]."

1.4. Correlation between material consumption and labor productivity

The Member States of the European Union have paid increasing attention to promoting the concept of circularity, which can also be seen in the following figures showing the evolution of the rate of use of circular materials. Overall, the EU (28) has made slight progress over the past 10 years, from 11.2% in 2010 to 11.7% in 2021. The years with the most significant increases were 2016 and 2019, where the circular material use rate reached 12%. Between 2010 and 2021, some of the countries made significant progress. Belgium, Croatia, Greece, Italy, Latvia, Austria and Slovenia almost doubled their circular material use rate (highlighted in Figure 1.12), while other countries such as Luxembourg, Poland and Romania regressed (highlighted in Figure 1.13) [54].

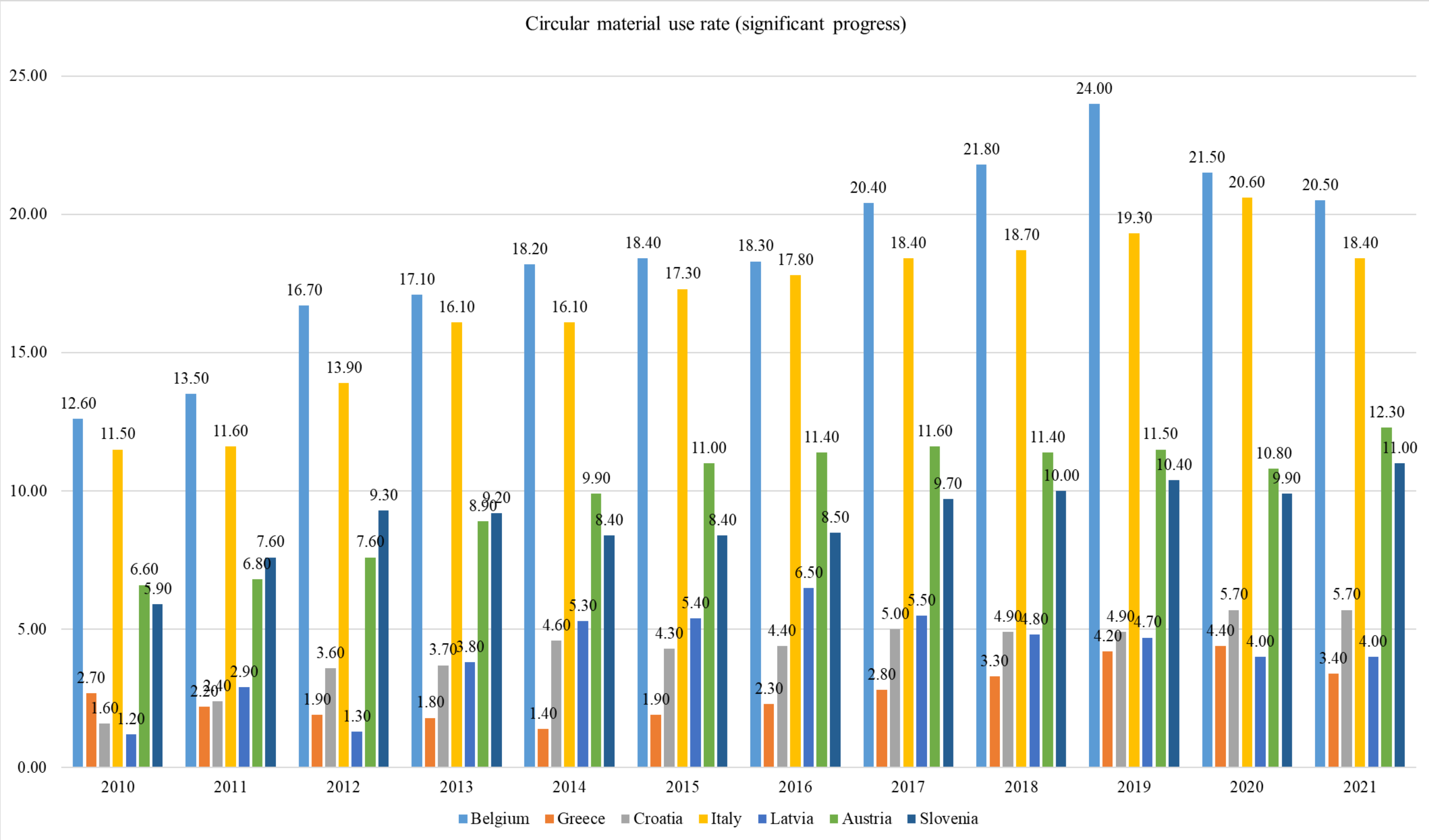

Figure 1.12 Circular material use rate for countries with significant progress

Regarding the circular material use rate in countries that have made significant progress, namely Belgium, Greece, Croatia, Italy, Latvia, Austria, Slovenia, it can be noted that Belgium recorded the highest values, increasing from 12.60% in 2010 to 24% in 2019.

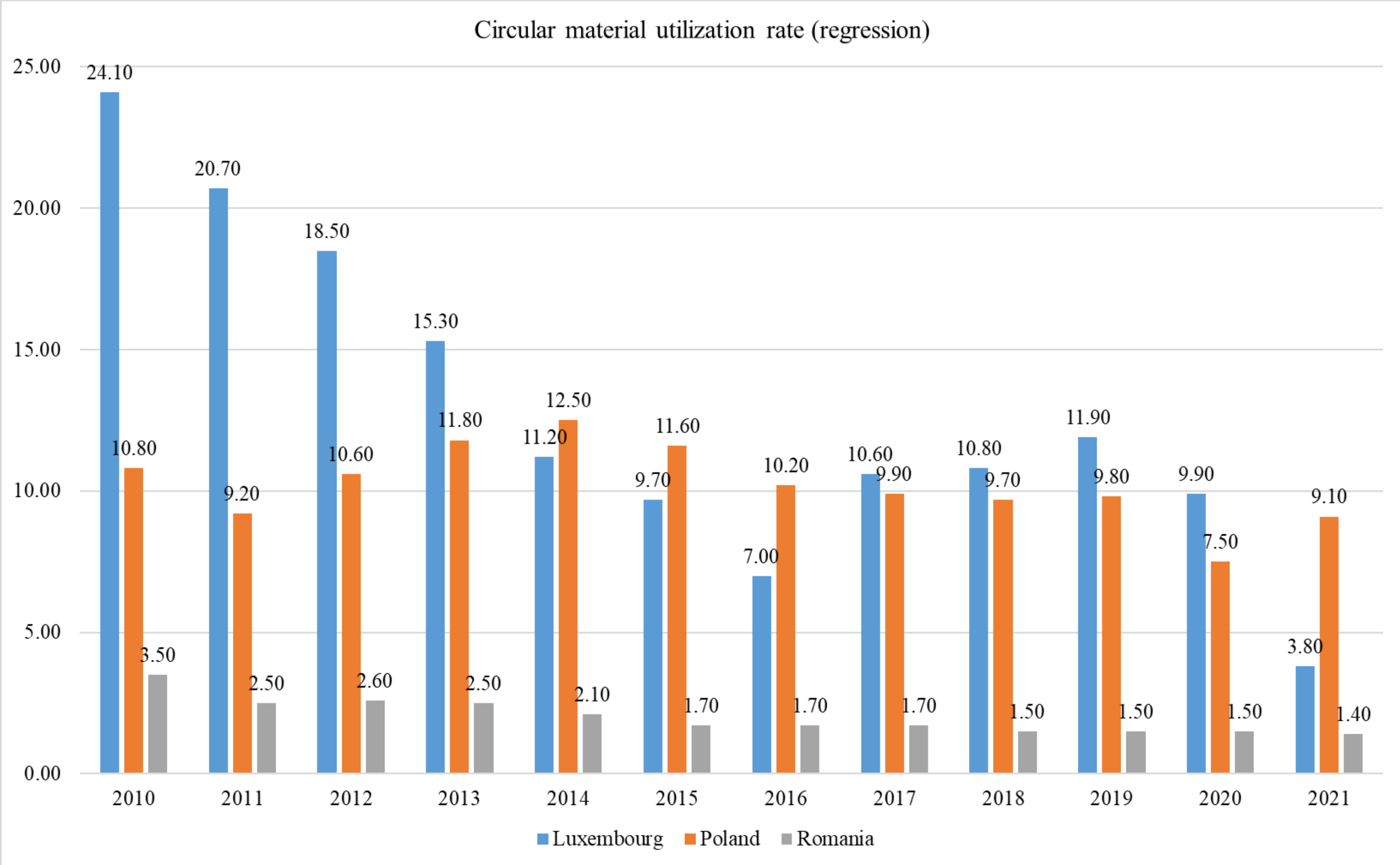

Figure 1.13 Circular material use rate for countries backsliding

From Figure 1.13 it can be seen that the countries that recorded a significant regression were Luxembourg, Poland and Romania. Of these, Romania ranks last, with the circular use rate of materials registering between 3.5% in 2010 and 1.40% in 2021, with a downward trend. The biggest decline was recorded by Luxembourg at around 90%.

1.5. Circular economy-specific indicators

The circular economy aims to separate resource use from GDP growth, while taking into account the reduction of negative environmental impacts. Economic growth in the circular economy can be observed in the following areas:

- ✓ economic impact, such as GDP growth and investment;
- ✓ environmental impact, in the sense of decreasing pollution;
- ✓ social impact, by promoting education and improving quality of life.

1.6. Conclusions on general circular economy issues

Overall, the period 2010-2020 was a significant step towards the circular economy within the EU. With a strengthened political and legislative framework and increased commitment from the various parties involved, circularity is expected to continue to rise in the coming decades, contributing to a more sustainable and responsible development of the European economy.

Chapter II. CIRCULAR ECONOMY FINANCING INSTRUMENTS

2.1. European Commission directives on generalising the concept of circular economy

La nivel european, economia circulară a fost luată în considerare de către toți factorii relevanți și este privită ca o soluție pentru problemele înregistrate recent în mediul înconjurător. Tranziția de la economia liniară actuală, caracterizată prin exploatarea intensivă a resurselor naturale și impactul negativ asupra mediului, inclusiv generarea deșeurilor, este un obiectiv important pe agenda Comisiei Europene. Prin această tranziție, se urmărește atât reducerea cantității de deșeuri, cât și menținerea valorii produselor, resurselor și materialelor în circuitul economic pe o perioadă mai îndelungată.

2.2. Structural and Investment Funds

This transition from linear to circular economy requires adequate funding, which can be provided through the Structural and Investment Funds of the European Union's financial programme.

Research and innovation projects that align with circular economy principles are encouraged under the thematic area "Connecting economic and environmental gains - the Circular Economy", which is closely linked to the European Union's Circular Economy Package.

Under this package and the Investment Plan for Europe, funding and advisory opportunities on the circular economy have been foreseen, including:

- ✓ The European Fund for Strategic Investments (EFSI);
- ✓ European Structural and Investment Funds (ESIF);
- ✓ LIFE;
- ✓ Horizon 2020;
- ✓ Just Transition Fund;
- ✓ Digital Collateral Facility (DG REGIO;
- ✓ Urban Innovative Actions (UIA).

2.3. Financial instruments

Financial instruments will play a key role in scaling up funding to new business models supporting the transition to a circular economy. Through these instruments, the development and implementation of projects and initiatives promoting resource efficiency, waste reduction and sustainable use of raw materials can be supported. In doing so, they contribute to creating an enabling environment for innovation and investment in the circular economy [73].

2.4 Conclusions on circular economy financing

The circular economy is a sustainable and innovative economic model that focuses on maximising resource value and minimising waste generation. In order to successfully implement the circular economy, different financing instruments are needed to support and stimulate this transition. The data is valid until 2020 as it is the latest moment of Eurostat information, and after this year there is no data to provide updated details.

Chapter III. BIBLIOGRAPHIC ANALYSIS AND CONCEPTUAL MODEL REGARDING THE SUSTAINABLE DEVELOPMENT OF THE LEATHER INDUSTRY

3.1. Bibliometric analysis on renewable energy in the leather industry

Environmental pollution has a serious impact on ecosystems, biological diversity and human health on a global scale. One of the largest contributors to this pollution, which is caused by a variety of economic activities, is the textile industry, with its high emissions [75].

3.1.1. Research methodology

The method of analysis selected by the authors to link renewable energy and the leather industry was bibliometric analysis. The literature research took place in May 2023 using the Web of Science database.

3.1.2. Research findings

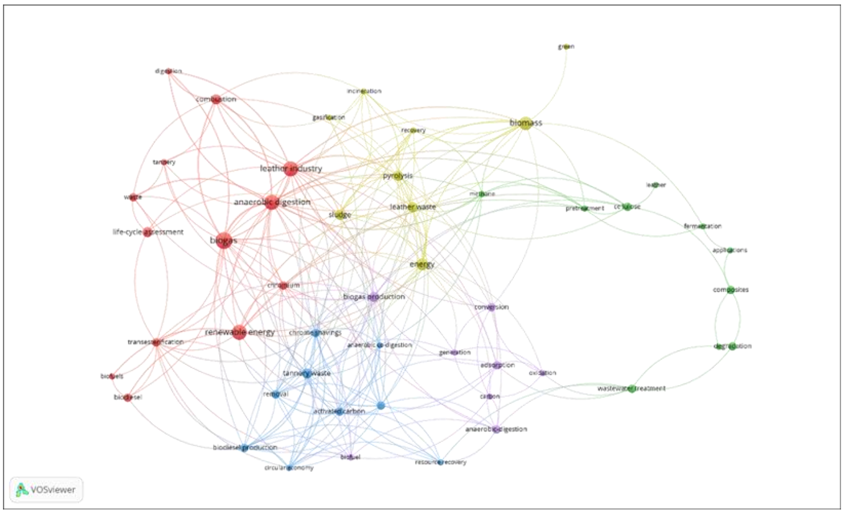

Figure 3.3 Network of occurrence of all keywords, Source: own creation

3.1.3 General conclusions from the bibliometric analysis on renewable energy in the leather industry

In conclusion, the bibliometric analysis in this paper provides researchers with a tool to invest more in the topic. Also, the evolution of technology implies that all industries will have to adapt at some point, and in the leather industry it is necessary to innovate and improve the work process, taking into account renewable energy to apply sustainability concepts.

3.2. The link between the circular economy and the leather industry – bibliometric analysis

The main purpose of this research was to conduct a bibliometric analysis of articles published in the Web of Science (WoS) database on the topic of circular economy and leather industry, with emphasis on assessing the correlation between these two fields.

3.2.1. Materials and methods

In developing this analysis, the structure of bibliometric studies, aimed at research and evaluation of a particular topic, was taken into account. To conduct this study, the literature search was conducted in July 2023 using the Web of Science database.

3.2.2.Results generated as a result of performing bibliometric analysis

Regarding the results obtained, a general search of the two terms was carried out at first and thus the bibliometric analysis could be continued. In this regard, as mentioned earlier, a total of 65 articles published in journals were identified, written by 199 authors from 133 institutions and 27 countries. As a result, basic bibliometric indicators such as year of publication, most prolific authors, journals, institutions and countries involved, as well as the link between descriptors will be presented.

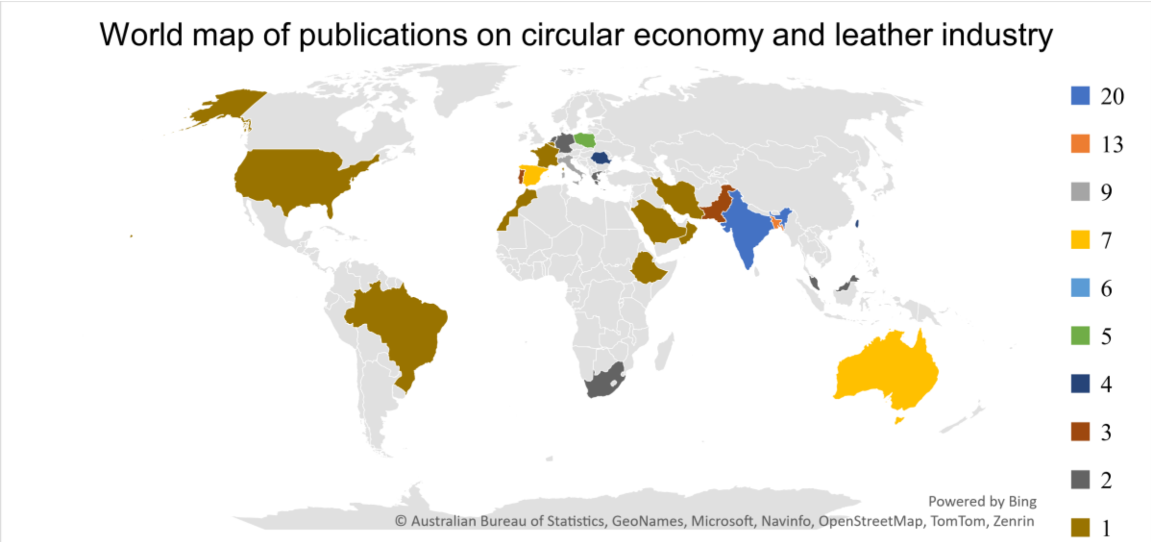

Figure 3.8 Countries with the highest number of publications with citations and impact index in circular economy and leather industry

3.2.3. Interpretation of results generated by bibliometric analysis

This research facilitates the evolution of scientific production in the field of circular economy and leather industry. The results indicate a significant increase in the number of articles published since 2018, compared to 2011-2020. The author's analysis revealed that Md. Moktadir, Abdul was the most influential author in the scientific community in the field of circular economy and leather industry.

3.2.4. Study limitations

In conclusion, there is a significant connection between the circular economy and the leather industry, especially in terms of technology. Also, maps or bibliometric networks can be extended beyond the limits of the current study to highlight relationships of co-authorship, co-words, and other relevant aspects.

3.2.5. Conclusions generated by the bibliometric analysis on the link between the circular economy and the leather industry

As the two fields of study are in full development, more research is needed to contribute to the scientific literature in this field. Also, topics such as processing industries, health, environmental protection and resource conservation require additional research to implement technologies that respond to real problems and advance these fields to a higher level.

3.3. Conceptual model of sustainable development in the leather industry from the perspective of circular economy

Here are the main components of this conceptual model:

1. ***Sustainable raw materials***
2. ***Circular design***
3. ***Sustainable production processes***
4. ***Collection and recycling system***
5. ***Collaboration and education***
6. ***Promoting the service economy***

Chapter IV. CRITICAL AND COMPARATIVE ASPECTS BETWEEN THE LEATHER INDUSTRY AND ROMANIA AND THE EUROPEAN UNION

4.1. Characterization of the leather industry in Romania and the EU

At European level, the leather industry plays an important role in various value chains, especially in the fashion, furniture and automotive sectors. The raw materials used by European tanneries come mostly from hides and skins from animals, which are mainly used for wool, milk and/or meat production. The recovery of these hides in the leather industry highlights a significant environmental role, as otherwise they would have been disposed of, and thus the focus is on recycling. In Romania, the leather industry has a particular focus on footwear production. Romanian footwear manufacturers are currently facing two major challenges. On the one hand, it has to face competition from China and Turkey, countries that produce footwear at very low prices, and on the other, with increasingly fierce competition in the fashion and elegant footwear segment. In the domestic market there is strong competition, with both domestic and foreign companies fighting for market share.

4.3. European Union case study selection

The most important tanning sectors in southern Europe, such as Italy, Spain, France and Portugal, are mainly composed of small and medium-sized enterprises and specialise in leather production for the fashion industry. On the other hand, the tannery sectors in Central and Northern Europe (Austria, Netherlands, Germany, Sweden, UK) are usually home to larger companies, which benefit from significant economies of scale in their productions.

4.4. Analysis of the attitude of the young generation towards the circular economy

„In order to obtain the results presented below, 106 questionnaires out of 150 were used. This means that the response rate was 70. 66%, the other 29.34% did not want to fill in the questionnaire, so they remained unfulfilled. The questionnaire was applied between February and May 2021. The only condition when applying the questionnaire was the age of the respondents, which had to be within the mentioned limits. As the targeted respondents were the younger generation (i.e. Generation Z) to find out their attitude/opinion on the circular economy, the conclusions of other generations are not presented here, opinions and actions that can move faster towards a circular economy. " [183]

4.5. Conclusions on Romanian and EU statistical data from the leather industry and young people's perception of the circular economy

The leather industry in Romania, France, Italy, Germany and Spain shows certain trends and characteristics in terms of number of employees, turnover and personnel cost. It is important to note that this information is based on data available until September 2021 and may be subject to further change.

Also, following the application of the circular economy questionnaire, it appears that generation Z shows an increased sensitivity and interest in this topic, highlighting their concern for sustainability and reducing environmental impact by promoting recycling and responsible consumption.

The data presented are mainly until 2020 because until this date they were provided by statistical websites such as Eurostat and Statistica.

Chapter V. EUROPEAN LEGISLATION AT NATIONAL AND REGIONAL LEVEL IN THE LEATHER INDUSTRY ON WASTE MANAGEMENT

5.1. Waste and by-products from the leather industry

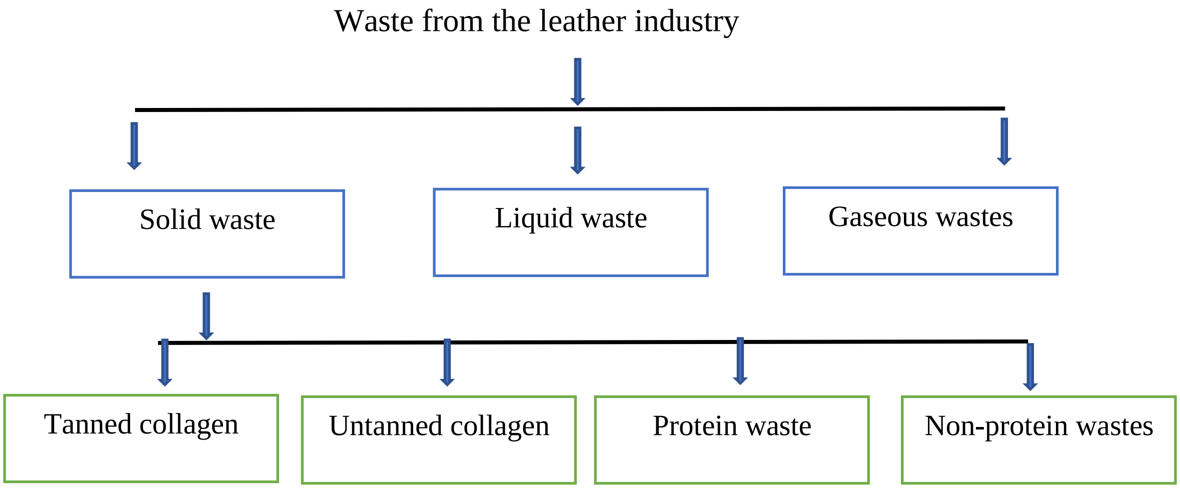

Figure 5.1 Types of waste generated from the leather industry [186]

5.2. Recovery and reintroduction of industrial waters from the leather industry

In the leather industry, water plays an essential role in tanning and painting processes, carried out in barrels and other equipment using chemical solutions. Water is also used to clean skin, machinery and workplace. It comes mainly from licensed and controlled wells, industrial and civil aqueducts, representing one of the most important environmental aspects of the leather industry.

5.4. Conclusions on European legislation on waste management in the leather industry at national and regional level

The leather industry generates a significant amount of waste and by-products in the production process. However, with the evolution of technologies and sustainability concerns, more and more initiatives are developing to recover this waste and reintroduce it into the circuit. By adopting circular economy practices, the aim is to reduce environmental impact and optimise resource use. Recovery and recovery of waste and by-products from the leather industry can bring multiple benefits. They can be transformed into raw materials for other industries, such as the production of biofuels, biofuels or surfactants for construction. In this way, the amount of waste that ends up in the environment is minimized and pressure on natural resources is reduced.

PART II STUDIES AND RESEARCH ON THE DESIGN OF SUSTAINABLE FOOTWEAR MODELS

Chapter VI. CASE STUDY - STRUCTURE AND FUNCTIONS OF LEATHER FOOTWEAR

6.1. Structure of footwear

Footwear was born in response to the need to protect the human foot from harmful environmental factors. The structure of footwear represents all its components, divided into two broad categories according to their positioning relative to the foot [215]:

- ✓ upper assembly;
- ✓ lower assembly.

Table 6.l - Attributes, functions and requirements of footwear [219]

Attributes	Footwear features	Requirements
Comfort	Physiological-hygienic function	• Thermal insulation/protection • Moisture behavior (absorption, desorption) • Air permeability, vapor •Flexibility • Non-allergenic action
	Dimensional function	• Product mass • Dimensional range • Staying within the limits of the specific dynamic effect • Dimensional stability
	Biomechanical function	• Support of the foot vault • Distribution of pressures on the support surface • Orthostatic and dynamic balance • Maintaining joint function • Staying within the limits of the specific dynamic effect
	Ergonomic function	• Shock absorption • Foot bed formation • The degree of slippage on different surfaces (ice, wet environment, tiles, parquet, etc.)

Attributes	Footwear features	Requirements
		• Ease of footwear-shoes • Dimensional foot-shoe correspondence • Tightening/fixing on the leg
Wearing performance	Reliability function (wearability characteristics)	• Resistance of joints and materials to mechanical stress • Wear resistance • Strength of finishes
	Maintenance function (maintenance features)	• Washing behavior • Behavior to the action of chemical maintenance products
	Protection function	• Foot coverage • Protection against mechanically induced traumatic actions • Protection against environmental agents
Stylistic appearance and content	Gnoseological function	• Product information (price, size, width, nature of raw materials, conditions of maintenance) • Information about the company-brand • Consumer information (personality, style)
	Stylistic-compositional function	• Stylistic conception • Constructive conception (assortment, design variant)

6.2. Attributes, functions and requirements of footwear

The term "good" in the context of a shoe product has different meanings for each user - its wearer. In essence, "good" means that the product is comfortable, lightweight, waterproof, warm, flexible, aesthetically pleasing, fits into fashion trends and is affordable. These characteristics desired by the wearer are achieved through proper design, careful execution and use of appropriate materials [218]. All these aspects contribute equally to the "success" of the product.

6.3. Upper assembly

6.3.1. Stresses of upper assembly parts in correlation with foot biomechanics and physiology

The stresses on the upper assembly vary according to its position in the system and the place it occupies in relation to the foot [222]. Since the 70s, a significant number of researchers have devoted themselves to studying the dimensional variations of the foot, including its length, width and perimeter, at different times of the day and while walking. Diebschiag, Atzler and Herbst are among those researchers who analyzed these parameters and demonstrated that foot volume varies around 4% when the foot is at rest. This variation was explained by orthostatic blood pressure and the influence of vein hemodynamics.

6.3.2. Materials for the construction of the upper assembly

6.3.2.1. Face materials

The materials used to make the uppers of the upper shoe assembly include:

- ✓ skins for faces;
- ✓ Leather substitutes for faces

6.3.2.2. Material intended for căptușelilor

The materials used to make the linings of the upper shoe assembly include:

- ✓ Liner skins: These are natural skins used to make the inner linings of shoes. They provide pleasant contact with the foot and can adapt the shape of the lining to the wearer's foot, while also having the ability to deform remanently to follow changes in foot volume under effort;
- ✓ leather substitutes intended for linings: These substitutes are produced with functionality and appearance similar to genuine leather and are used to make the inner linings of footwear;
- ✓ Smart lining textiles (shape-memory polymers): These are innovative materials that may have the ability to maintain their original shape after deformation, which contributes to the comfort and adaptability of interior linings.

6.3.3. Methods and means of assessing the characteristics of the upper assembly - Physical testing

Leather remains a reference material in the footwear industry, being considered the standard to which all synthetic and artificial products used in the manufacture of footwear uppers refer.

6.4. Lower assembly

6.4.1. Lower assembly parts load

The sole plays an extremely important role in thermal insulation and protection of the foot against external mechanical actions within the lower shoe assembly. While walking, the sole is subjected to various stresses, such as elongation, compression, repeated bending and friction. The bending radius of the sole in the area of the metatarso-phalangeal joints can vary between 4-8 cm, and the relative elongation can reach 16% for leather soles and up to 25% for rubber soles with great thickness and striations.

6.4.2. The insoles

The insoles must have the following characteristics:

- ✓ good moisture absorption and desorption capacity;
- ✓ friction resistance;
- ✓ flexibility and deformability to maintain shape while wearing;
- ✓ uniform characteristics over the entire surface, such as equal thickness and uniform concentration of substances;
- ✓ small weight;
- ✓ good joining ability by gluing or sewing.

6.4.3. Soles

Leather soles should be thick, with low flexibility, with compact and dense tissue, and their face should be smooth and glossy. These soles must have a low water absorption capacity, withstand compression, wet and dry friction, and retain their dimensions during wearing, both wet

and dry. For soles fixed by gluing, flexible skins are used, while for sewn ones, leather with reduced flexibility is preferred. The soles can be obtained from hides from pigs, bubalines and horses.
The assortments of sole skins obtained from bovine hides include: flexible bovine crope sole skins, bovine crope sole skins for sewing and bovine sole, neck and lap skins. These assortments of skins are characterized by dense, compact and homogeneous tissue with a glossy appearance.
On the other hand, rubber soles were the most used due to their versatility, durability and performance. Rubber can be used by cutting from plates or by direct vulcanization. It can be used in compact form or in the form of cellular rubber when porogenic agents are added. Frequently, two types of rubber are used to obtain soles: carbon rubber and styrene butadiene rubber, both of which are hard tires, with black carbon rubber having the highest hardness.

6.5. Shoe quality

The quality of a shoe product is determined by its attributes, functions and requirements. This refers to the extent to which the product meets consumer expectations. The concept of quality cannot be defined absolutely, but is evaluated in relation to other similar products. Thus, quality is not limited to an attribute with a single superlative value. A footwear product may respond to a greater or lesser extent to a particular quality requirement, depending on the attributes for which it was created and the extent to which it performs its functions.

Thus, the quality of a footwear product is relative and is shaped according to the needs and expectations of consumers, as well as the degree to which the product meets the established criteria.

Table 6.8 Requirements for different qualities

Quality level	Requirements
Minimum quality	• Dimensional range • Staying within the limits of the specific dynamic effect • Dimensional stability • Support of the foot vault • Distribution of pressures on the supporting surface • Orthostatic balance and dynamics • Maintaining joint function • Foot coverage • Protection against mechanically induced traumatic actions • Protection against environmental agents
Medium quality	• Global Comfort Index •Flexibility • Non-allergenic action • Product mass • Shock absorption • Foot bed formation • The degree of slippage on different surfaces (ice, wet environment, tiles, parquet, etc.) • Ease of shoes-shoes

Quality level	Requirements
	• Dimensional foot-shoe correspondence • Tightening/fixing on the leg • Resistance of joints and materials to mechanical stress • Wear resistance • Strength of finishes • Washing behavior • Behaviour to chemical maintenance products • Product information (price, size, width, nature of raw materials, conditions of maintenance) • Information about the company-brand • Consumer information (personality, style) • Stylistic conception • Constructive conception (assortment, design variant)
High quality	• Special outliers of certain parameters •Mark

6.5.1. Calculation of the quality index

The quality index (Ic) must characterize a product from multiple perspectives, including comfort (Icg), wearing performance (Ip) and appearance and design (Ie). Each attribute is given a score, and the sum of these scores determines the value of the quality index (Ic). It is important to understand that the functions contributing to each attribute can be expressed either through quantitative assessments or through subjective and objective assessments.

Ic = Icg + Ip + Ie

6.5.2. Integration of sanogenetic parameters into the quality model of footwear

The sanogenetic criterion is an essential aspect in assessing the quality of a product, as it must not affect human health in any way. Any factor contributing to the promotion, maintenance and improvement of health is considered sanogenetic. Studies reveal that about 50% of foot disorders can be attributed to or are favored by wearing non-physiological and non-hygienic footwear. The literature emphasizes the pathogenic role of some shoe models and the possibility of preventing these diseases by wearing footwear designed close to physiological parameters.

6.6. The influence of manufacturing technologies on the characteristics of footwear

A comparison will be made between two shoe systems: glued footwear (IL) and footwear made in the IJ system (direct injection on faces), which are the most commonly used worldwide.

Highlighted differences between the two systems:

- ✓ bottom construction techniques are different between the two systems, while methods for tailoring the upper assembly also differ;
- ✓ the bulkhead system used and the machines used to secure the upper assembly to the bottom are different in the two systems;
- ✓ the types of insoles used and the machines used for the upper assembly may be similar in both systems;

- ✓ the bulking process and the machines used to secure the upper assembly to the bottom may be similar in both systems;
- ✓ The material consumption for the upper assembly is different between the two systems.

<u>Upper assembly</u>

IL Shoes

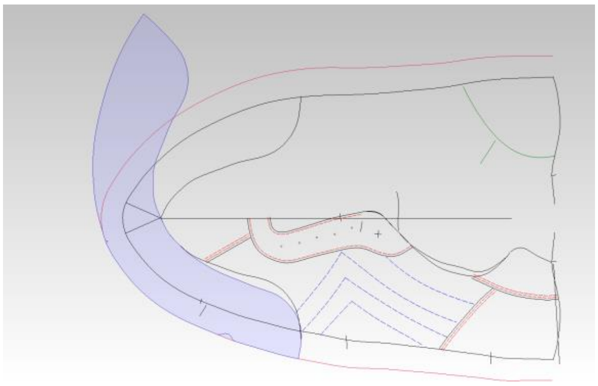

Figure 6.14 Prototype construction with drawer reserve (IL)

IJ Shoes

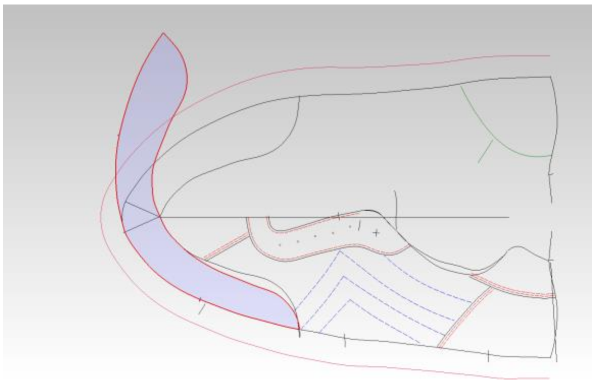

Figure 6.15 Prototype construction without drawer reserve (IJ)

<u>Reins</u>

IL Shoes

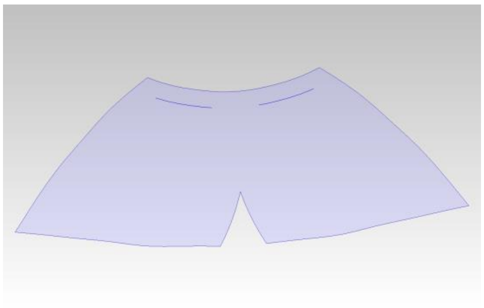

Figure 6.16 Reins on glued shoes

IJ Shoes

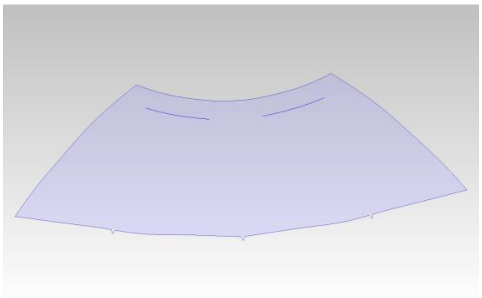

Figure 6.17 Reins on IJ shoes

<u>Special markings</u>

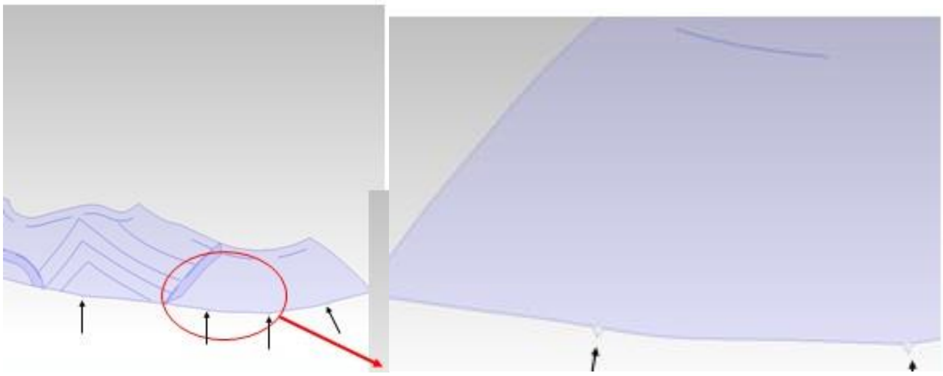

Figure 6.18 Front notches on IJ footwear

Padding – reserve to pull

IL footwear

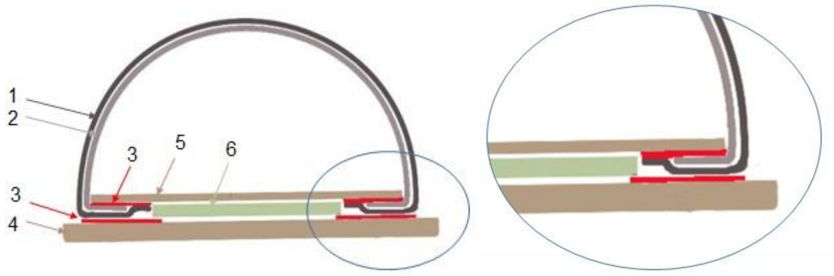

Figure 6.19 Transverse section of IL system where 1 – Face, 2 – Lining, 3 – Adhesive, 4 – Sole, 5 – Insole and 6 – Filling

Insoles

IL Shoes *IJ Shoes*

Figure 6.20 IL system insoles

Figure 6.21 IJ system insoles

6.7. Conclusions on the structure and functions of leather footwear

The recommended materials for making shoes are:

- ✓ genuine leather and natural fibre materials for the upper assembly of children's footwear;
- ✓ the insoles are made of fibrotex for the lower assembly;
- ✓ For comfort and stability, it is recommended to use thermoplastic rubber or polyurethane soles due to their physicomechanical characteristics.

The footwear will be made using the IL garment system.

In design, the following principles and restrictions will be observed:

- ✓ the shape of the last will be copied as closely as possible in the plan to obtain the desired shape in the finished product;
- ✓ the design of the lines and details of the shoe model will facilitate the assembly and obtaining a pre-spatialization of the blanks;
- ✓ the three determining factors in shoe design will be correlated and evaluated: the shape of the shoe, the garment system adopted and the characteristics of the materials used;
- ✓ the rules will be observed to obtain minimum consumption of materials and the aesthetic appearance of the footwear will be highlighted;
- ✓ the joining lines of the faces will not interfere with the functions of the foot and will not overlap the joints with functions active in its dynamics;
- ✓ the design shall take account of the deformations to which the component parts of the faces are subjected in order to avoid distortion of curvatures in the process of forming on the last.

Chapter VII. RESEARCH ON THE REALIZATION OF SHOE SOLES BASED ON POLYMER COMPOSITES WITH ELASTOMER MATRIX AND PROTEIN WASTE PLATERS (FINISHED LEATHER)

7.1. Samples and new recycled plastic parts and manufacturing procedures

As the final product of tannery, leather serves as raw material for a variety of other industries, including footwear (which accounts for about 62% of total production), clothing (which accounts for about 24%), leather goods (which accounts for about 12% of total production), and upholstery (which accounts for about 2%).

The leather manufacturing process also produces byproducts that can be used in other industries, including food protein supplies, chemicals, cosmetics, and artificial soles.

Figure 7.1 Ground protein wastes in a knife mill and sieve

Figure 7.2 Ground protein wastes in a cryogenic mill

7.2. Experiments for obtaining protein polymeric composites by extrusion-granulation

Two types of plastomers that are currently used in the manufacture of shoe soles were selected to create polymer composites with post-consumer leather fiber waste and extruding-granular vulcanized rubber:

- ✓ Thermoplastic polyurethane (TPU);
- ✓ Thermoplastic rubber styrene-butadiene-styrene (TR).

The compounding technology was used on an internal Brabender mixer with a capacity of 350 cm3 to create polymer composites with waste that were processed by extrusion-granulation in the laboratory.

Table 7.1 TR waste receipts with protein waste (finished leather)

Component	TR 0	TR 1 (5%)	TR 2 (10%)	TR 3 (20%)	TR 4 (30%)	TR 5 (50%)
TR waste	285	285	270	240	210	150
Protein waste	0	15	30	60	90	150
PS	15	0	0	0	0	0

Table 7.2 TPU waste receipts with protein waste and compatibility agent

TPU waste + protein waste + PE-g-MA

Component	TPU 0	TPU 1 (5%)	TPU 2 (10%)	TPU 3 (20%)	TPU 4 (30%)	TPU 5 (50%)
TR waste	300	285	270	240	210	150
Protein wastes	0	15	30	60	90	150
PE-g-MA	0	15	15	15	15	15

7.3. Experiments to create polymer composites processed by wavering/pressing

Four types of elastomers with functionalized protein waste (butadiene-co-acrylonitrile and EPDM - Ethylene-Propylene-Dien-Monomer) were selected to create polymer composites using functionalized protein waste processed by veiling/pressing.

Through the use of compendation technology on an internal Brabender mixer with a capacity of 350 cm³ and features such as continuous control and modification of temperature and mixing speed, polymer composites containing protein waste were produced.

According to the receptions, the ingredients were added in the correct order. The mixtures made on Brabender were supplemented by adding vulcanizing agents on a laboratory roller. In order to determine the ideal processing parameters for the laboratory press, at controlled pressure and temperatures, the processed formulations, presented in Tables 7.5 to 7.6, were examined rheologically using Monsannto's Rheometer equipment. After mixing on the roller, the composites are formed into plates by pressing at the initial stage, and from these plates, the samples are stamped for physico-chemical and physicomechanical characterization at the most efficient technological parameters achieved with the help of rheometer equipment.

Table 7.5 Butadiene-co-acrylonitrile rubber-based composites consisting of protein waste functionalised with potassium oleate

Ingredient / Symbol	UM	BO	BC1	BC2	BC3	BC4
Processed on Brabender mixer						
Butadiene-co-acrylonitrile rubber	g	190	190	190	190	190
Stearin	g	2.28	2.28	2.28	2.28	2.28
Zinc oxide	g	9.5	9.5	9.5	9.5	9.5
Silicon dioxide	g	57	38	19	0	0
Calcite	g	47.5	47.5	47.5	47.5	9.5
Protein wastes	g	0	19	38	57	95
PEG 4000	g	7.6	7.6	7.6	7.6	7.6
Mineral oil	g	19	19	19	19	19
Replenishment of mixtures with vulcanizing agents on the roller						
Antioxidant IPPD	g	5.7	5.7	5.7	5.7	5.7
Sulfur	g	2.85	2.85	2.85	2.85	2.85
Accelerator Th	g	1.14	1.14	1.14	1.14	1.14

Table 7.6 Ethylene-propylene terpolymer rubber composites - EPDM companded with protein waste, functionalized with potassium oleate

Ingredient / Symbol	**UM**	**SO**	**SC1**	**SC2**	**SC3**	**SC4**
Processed on Brabender mixer						
Ethylene-propylene terpolymer rubber - EPD	g	190	190	190	190	190
Stearin	g	2.85	2.85	2.85	2.85	2.85
Zinc oxide	g	9.5	9.5	9.5	9.5	9.5
Silicon dioxide	g	19	38	19	0	0
Calcium carbonate	g	76	47.5	47.5	47.5	9.5
Elastomeric waste	g	-	19	38	57	95
PEG 4000	g	7.6	7.6	7.6	7.6	7.6
DOF	g	19	19	19	19	19
Antioxidant IPPD	g	5.7	5.7	5.7	5.7	5.7
Replenishment of mixtures with roller vulcanizing agents						
Sulfur	g	1.9	1.9	1.9	1.9	1.9
Accelerator M	g	2.28	2.28	2.28	2.28	2.28
Accelerator Th	g	1.14	1.14	1.14	1.14	1.14

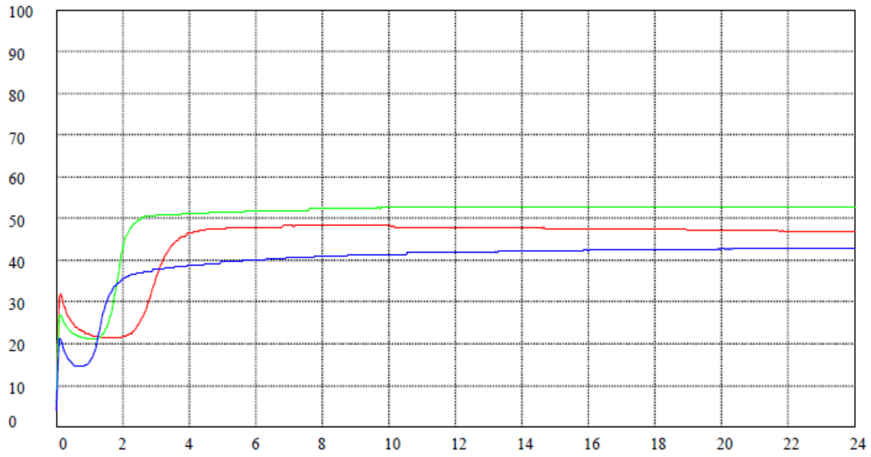

Figure 7.13 Torque variation in dNm (OY axis) over time in minutes (OX axis) for butadiene-co-acrylonitrile rubber-based mixtures mixtures: B0 (red), BC1 (green) and BC2 (blue)

7.4. Life Cycle Analysis (LCA) for obtaining a sole with protein waste composites

Waste-protein composite soles represent a significant innovation in the footwear industry, with the potential to combine the benefits of environmental performance and sustainability with the sustainable use of protein resources.

To achieve LCA (Life Cycle Analysis) for this type of product, the GaBi ts (Professional) tool and ecoinvent database were used, incorporating emission factors associated with processes and materials, together with data provided by the manufacturer and collected in the Life Cycle Inventory.

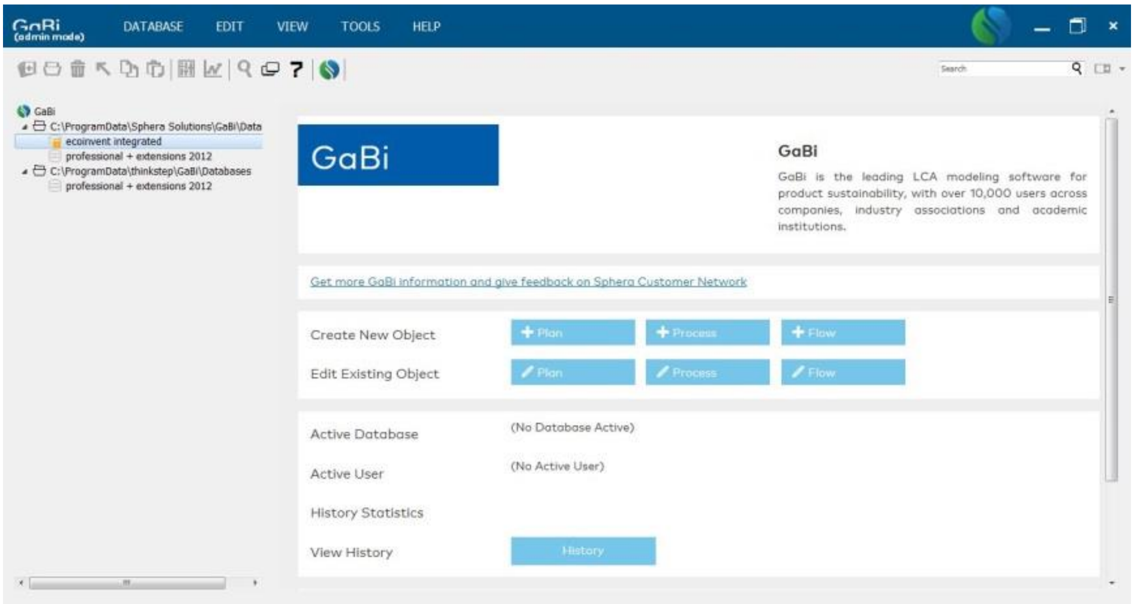

Figure 7.15 GaBi software interface

The functional unit is a very important element in the study of the carbon footprint, all inventory data (system inputs and outputs) are related to it. In addition, the results obtained shall be reported per functional unit. For this study, the functional unit is 1Kg of TR waste mixture with leather waste (I) and 1Kg of TPU waste mixture with leather waste and matching agent (II).

The Gabi program is highly advanced and has a lot of data and options to work with. For (I) and (II) respectively we created new projects and new Plans. The plans shall contain all the materials, methods and technologies necessary to obtain one kg of (I) and (II) respectively.

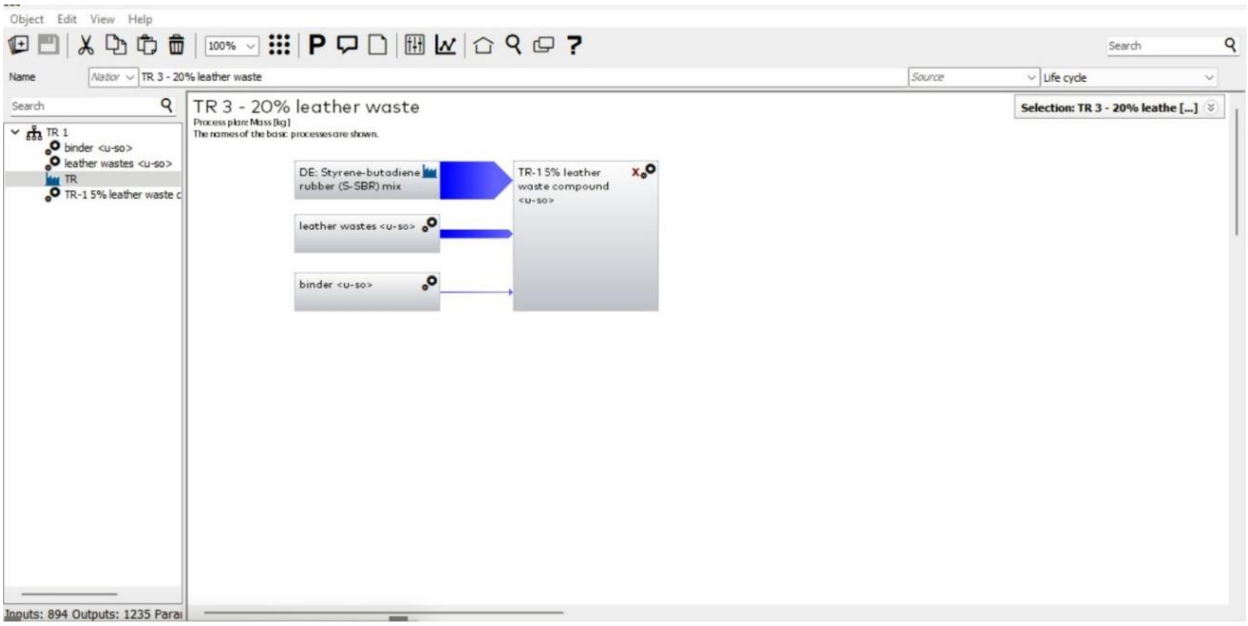

Figure 7. 16 Flow diagram of the studied system (I)

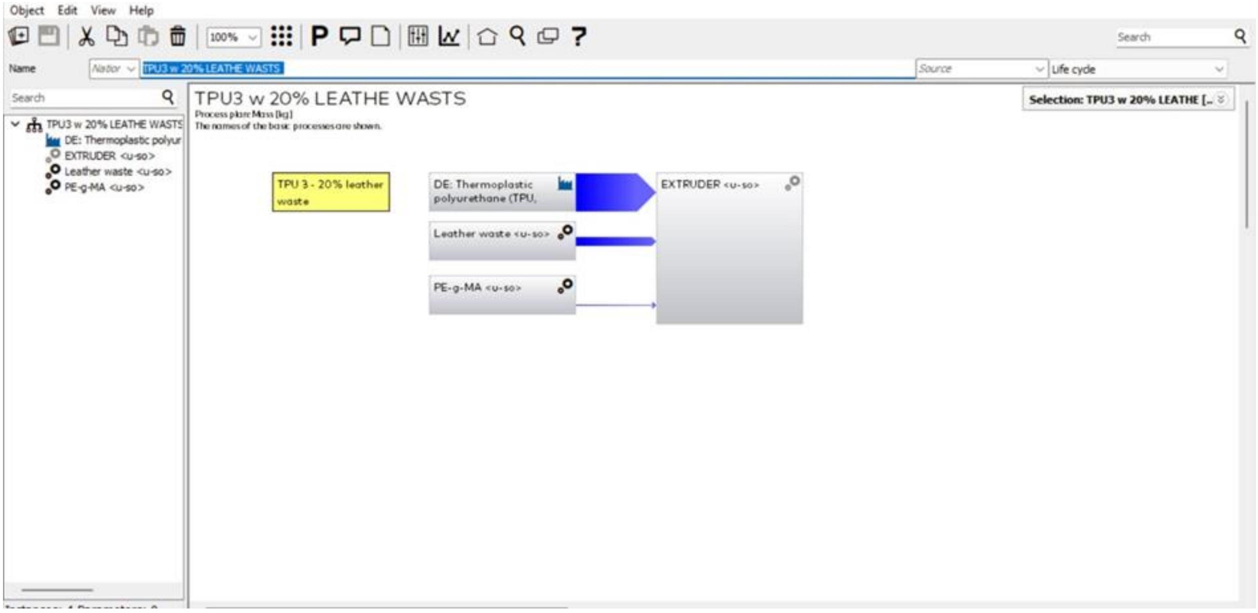

Figure 7.17 Flow diagram of the studied system (II)

7.5. Conclusions on the realization of soles with composites from protein waste

Following the research carried out for the production of shoe soles based on polymer composites with elastomer matrix and plateaers with protein waste (finished leather), the following conclusions can be drawn:

- ✓ Technical and aesthetic performance: The use of protein waste from the leather processing industry as platers in polymer composites for shoe soles has resulted in products with technical properties comparable to those obtained from traditional materials.
- ✓ Sustainability and recycling: The use of protein waste in polymer composites is a sustainable approach by harnessing secondary raw materials and reducing waste from the leather processing industry.
- ✓ Processing and compatibility: Research has highlighted the need to optimize the manufacturing process to ensure proper dispersion and homogenization of protein waste in the polymer matrix.
- ✓ Mechanical properties and durability: Polymer composites with elastomer matrix and protein waste platers exhibited a range of mechanical properties, such as tensile strength and compression, that meet the requirements for shoe soles.
- ✓ all experimental materials are 100% post-consumer and technological;
- ✓ in order to improve compatibility between the two types of waste, plastomer and protein waste, which are inert polymers incompatible with the plastomer used as a matrix, compatiting and flowing agents have been added;
- ✓ To make the waste functional, some connection points were made between the waste and the basic elastomerulus.

Chapter VIII. FINALIZING THE DESIGN OF CHILDREN'S FOOTWEAR IN ACCORDANCE WITH CIRCULAR ECONOMY PRINCIPLES

8.1. Design of children's footwear

In making children's shoes, priority criteria are comfort and safety. They are achieved through the use of appropriate materials, the shape of the blocks and the continuous improvement of the technology used. In the design of children's footwear, particular attention shall be paid to the nature of the materials used and their sanogenetic characteristics, determined by physico-mechanical and chemical analysis.

Among the materials recommended for making children's shoes are natural leather and natural fibers, which are best suited to make the component parts of the upper assembly of footwear. For the lower assembly, it is recommended to use fibrotex insoles.

In this thesis, children's footwear will be analyzed, more precisely the one made in the IL garment system (glued footwear). Through this analysis, it is intended to highlight the benefits of this manufacturing system in terms of comfort and functionality of children's footwear.

Thus, by using thermoplastic or polyurethane rubber soles and applying the optimal heel height, children's shoes made in the IL system can provide a pleasant and healthy experience while wearing, providing the little ones' feet with the comfort and stability necessary for proper and harmonious development.

Garment system: IL

The IL system (Figure 8.2) has significantly higher productivity compared to other shoe systems. This feature allowed the production of footwear with a lower consumption of raw materials and at lower costs, which led to a rapid expansion of the use of this system on a large scale.

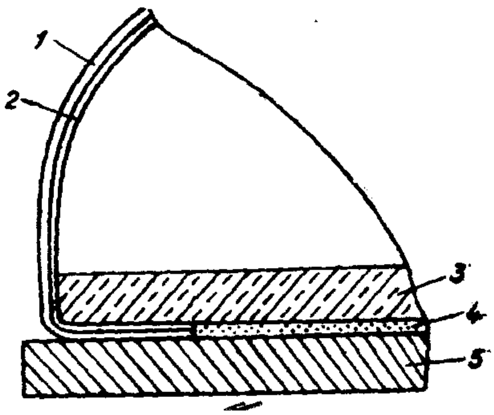

Figure 8.2 Section through IL system footwear with single sole (variant with permanent fixation of faces in texes where 1 - upper; 2 - lining; 3 - insole; 4 - filling and 5 - sole)

8.2. Children's shoe design

For children's footwear, a distinct approach to adult shoes is required, since the peculiarities of the child's foot impose special requirements. An important feature for this category of footwear is the ease of entry of the foot inside when shoes. Thus, unlike adult footwear, the lining of the children's shoe should be as short as possible, ensuring a generous opening of the tongues. This requirement is justified by the need to avoid excessive pressure on the toes when the foot is inserted into a shoe with a relatively small opening.

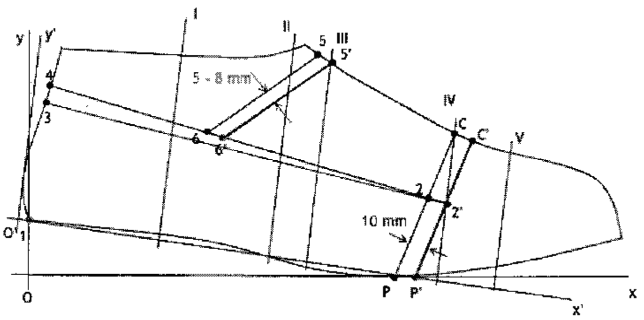

Figure 8.6 Positioning of the mean copy in the xoy reference system and drawing of baseline and auxiliary lines

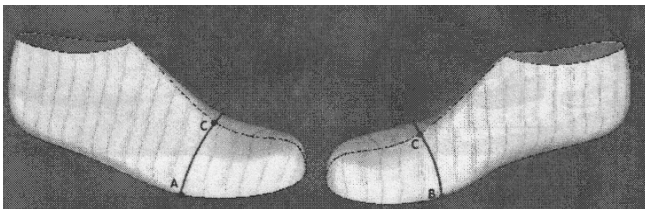

Figure 8.8 Fingerline

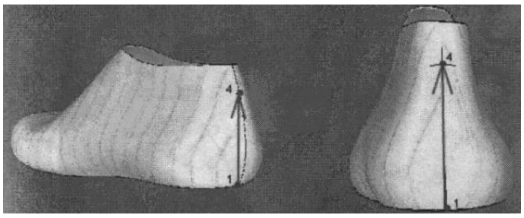

Figure 8.9 Height of bricks at the back

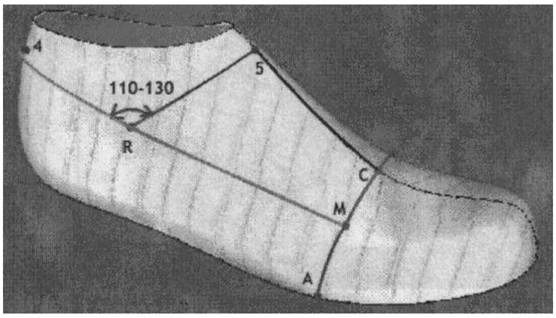

Figure 8.10 Drawing auxiliary lines

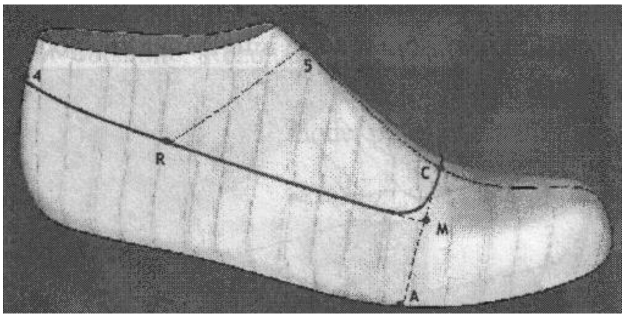

Figure 8.11 Pulling the tick opening

8.3. Design of the children's boot

The design of children's footwear, such as boots or boots, shall be based on the average copy of the shoe, which shall be entered in the reference system. A basic drawing is made, and obtaining patterns for boots is based on the average copy and a geometric construction, considering specific dimensions, such as heights and perimeters measured on the foot, taken from size tables.

For shoe types such as boots and boots, drawing the entire 3D model directly on the shoe is not possible, since the height of the bricks is greater than the height of the last. Therefore, when designing boots or boots, the average copy is started and the 2D drawing is made, using a geometric construction. The steps followed in this process include:

- ✓ obtaining the average copy;
- ✓ positioning the average copy in the coordinate system;
- ✓ making 2D basic drawing, additionally taking into account perimeters and heights;
- ✓ sectioning, modifying and obtaining final patterns for boots or boots.

8.4. Finalization of the technology used to make children's footwear

8.4.1. Frame technological process for IL footwear

Technologically, the production of children's shoes does not differ significantly from that of classic footwear. Below is described the frame technological process for the manufacture of shoes in the IL confection system (glued shoes).

The technological process for footwear in the IL system includes the following main manufacturing phases:

1. The process of reception of raw materials and materials
2. Stage of cutting parts from flexible materials
3. Stage of preparation of parts of the upper assembly of footwear (uppers)
4. Sewing assembly of shoe uppers
5. Making and preparing rigid components for final footwear
6. Modeling on the heel and making the soles
7. Completion and quality inspection of footwear

8. The Process of Marking, Packing, Storing and Shipping Shoes

8.4.2. Main operations in the process of making children's shoes

The technological process of manufacturing children's shoes consists of five distinct groups of operations, which follow a general manufacturing scheme. These groups include tailoring and stamping parts, material preparation, sewing assembly of faces, pulling and sole, and shoe finishing.

In the technological process, a wide variety of distinct operations are applied, placed in a specific order, depending on the characteristics of the product, the materials used and the processing technologies available according to the existing machine.

Figure 8.21 Folding arm stamp

Figure 8.22 Stamping with bridge

Figure 8.23 CM44CN COMELZ CUTTING MACHINE – ITALY

Figure 8.25 Chemical machine

Figure 8.26 Fitting machine

Figure 8.27 Fitted head

Figure 8.30 Thinning machine

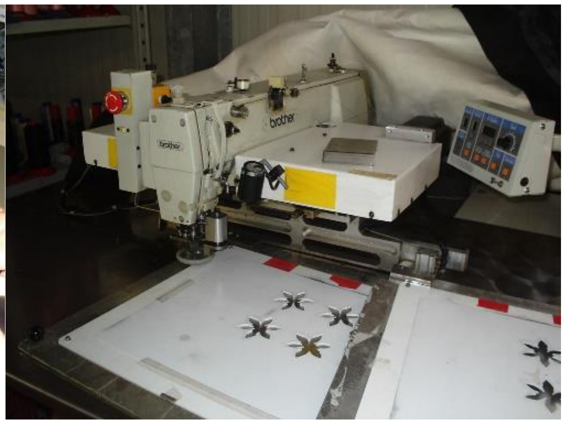

Figure 8.31 Embroidery machine

Figure 8.32 Bending machine

Figure 8.33 Smoothing machine and applied self-adhesive tape

Figure 8.34 Sewing thread measuring machine

Figure 8.35 Bomb applicator

Figura 8.36 Insoles

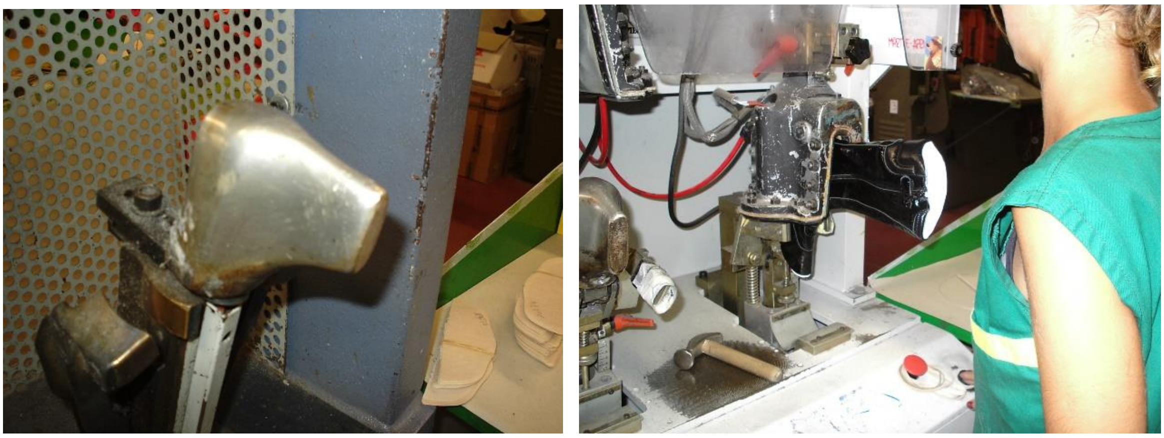

Figure 8.37 Stretching and preforming machine

Figure 8.38 Attachment of the insole to the last

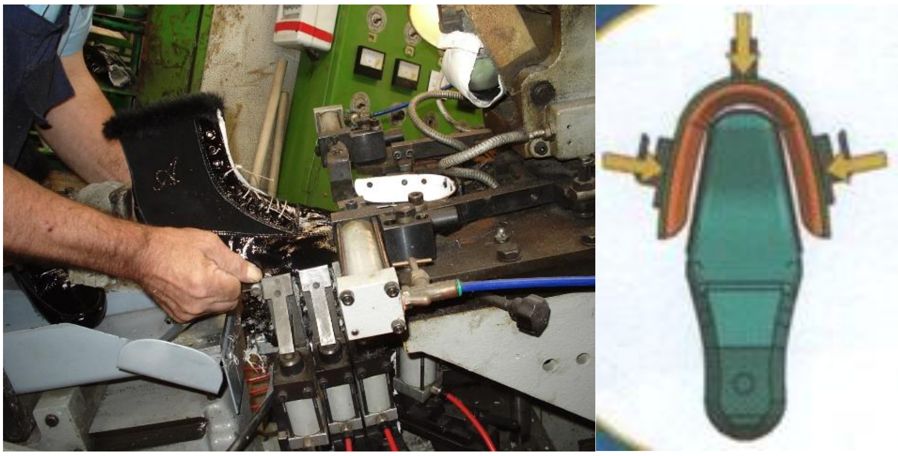

Figure 8.39 Traditional top-system drawn

Figure 8.41 Rear pulling machine

Figure 8.43 Bathing machine

Figure 8.44 Reactivator

Figure 8.45 Foot press

Figure 8.47 Sewing sole surgery

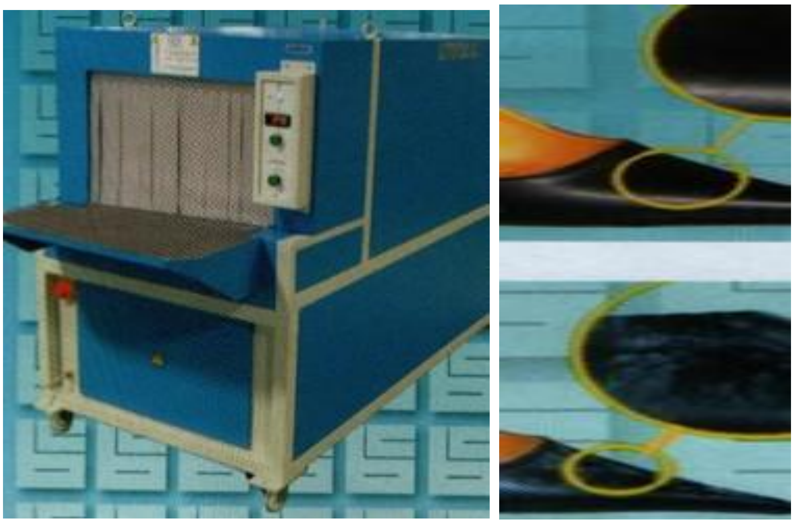

Figure 8.48 Shoe sterilization machine

8.5. Cost effectiveness of the green concept of the soles

„The global leather industry has long been an integral part of our society, offering a wide range of goods that have been prized for their durability, versatility and aesthetic appeal. However, leather manufacturing has raised concerns about its natural impact, as well as ethical issues related to animal welfare and approaches to the workforce. In recent years, there has been a growing interest in exploring eco-friendly alternatives to traditional leather, prompting a reassessment of industry approaches and elements" [241, 242].

8.5.1. General framework for the ecological concept

The literature discusses the challenges, advantages and obstacles associated with applying green concept tools. A common problem is that many tools focus on analyzing existing goods rather than creating new goods.

8.5.2. Cost effectiveness of the green concept of the soles

„The new eco-friendly sole, made from a biodegradable thermoplastic polymer consisting of a polyester derivative of Poly-Epson-Caprolactone and a copolymer (ethylene-vinyl acetate) with hydrocarbon resins, incorporates plant fibers to enhance recyclability. Unlike conventional soles, injection molding machines used for the reconverted sole require significantly lower temperatures, ranging from 60°C to 80°C, compared to 190°C to 110°C. " [241]

Tabelul 8.2 Components of cost

Cost classification	Nr.	Component of cost	Activity cost driver
Fixed Cost	1	Overhead Pre-manufacture	Overhead rate
	2	Labour cost Pre-manufacture	Work hours
	3	Machine costs	Work hours
	4	Overhead cost for manufacture	Overhead rate
	5	Labour cost for post-manufacture	Work hours
	6	Overhead cost for post-manufacture	Overhead rate
Variable Cost	7	Element costs	Nr of goods
	8	Cost of energy	Nr of goods
	9	Error risk costs	Nr of goods
	10	Packaging and shipping costs	Nr of goods
	11	Cost of consumable elements	Nr of goods

Tabel 8.3 Cost reducing actions

Main driver.	Cost reducing actions	Cost decrease vs classic manufacturing technique
Element selection and consumption	Use of natural fibres and polymers with approx.. 70% made of fossil element. Elimination of toxic elements like solvents	27%
Good construction	Reduced weight and unprocessed element consumption	43%
Energy usage	Lower temperature by 25% leads to lower energy consumption	31%
Waste management:	Scrap element can be 100% recycled and returned in manufacture	100%

Tabel 8.4 Economic feasibility

Cost category	Value €
Investment cost needed to produce 1200 pairs per day	150.400 €
Cost reduction per pair	4,52 €
Cost reduction per sole vs traditional technique	23,14%
Number of pairs needed for breakeven	33.275
Number of month needed for payback	27,7

8.6. Conclusions on the design of children's footwear in accordance with the principles of circular economy and cost-efficiency within the green concept of soles

Recommended materials for children's shoes:

- ✓ genuine leather and natural fiber materials are best suited for the upper part of children's shoes;
- ✓ insoles may be made of fibrotex for the lower assembly;
- ✓ To ensure comfort and stability, it is recommended to use thermoplastic rubber or polyurethane soles due to their physicomechanical properties such as flexibility and abrasion resistance.

1. Children's shoes will be made in the IL garment system.
2. In the design of children's shoes, the following principles and restrictions should be observed:

✓ a faithful representation of the spatial shape of the last in the plane so that the assembly process leads to the desired shape of the finished product;
✓ Design of the lines and details of the model so that the assembly leads to a pre-spatialization of the blanks before forming operations;
✓ Correlating and evaluating three key factors in shoe design: shoe shape, fabrication system and physicomechanical characteristics of materials;
✓ Optimization of material consumption;
✓ Paying attention to aesthetic aspects;
✓ Ensuring an alignment of the lines of joining the faces with the functions of the foot, avoiding their overlap over active joints;
✓ Containing the deformation of the component parts of the faces in order to avoid distortion of curvatures in the process of forming on the last;
✓ return of displacement of face lines due to the thickness of rigid intermediate parts (reel and bulge).

3. The construction parameters of the last will be according to ST 400/2004 standard, in accordance with the results of anthropometric measurements from 2003-2006.
4. The design of the insole of the last shall take into account that the angle between the tip-heel axis and the axis of the glenc is 6°.
5. The posterior area of the last on a portion of 2/3 of the total length can be typed, taking into account the results of the wearing samples and the compatibility of foot - last - footwear.
6. It is recommended to make children's shoes on width 4 for girls and 5 for boys, and boots and boots on width 5 and 6, respectively.
7. The technologies used in the manufacture of children's shoes are similar to those used in the production of footwear, generally on an industrial scale. The difference lies in the proper selection of component materials such as faces, soles, etc.

Chapter IX. CONCLUDING CONCLUSIONS, ORIGINAL CONTRIBUTIONS AND FUTURE RESEARCH DIRECTIONS

9.1. General conclusions

The general conclusions drawn from the elaborated paper refer to:

✓ Investment in research and development: To promote the circular economy, it is essential to support research and development of innovative technologies and processes that facilitate the recycling, reuse and reuse of raw materials. Public and private funds allocated for this purpose will stimulate the creation of new products and services with less impact on the environment;
✓ In Romania, the leather industry has a particular focus on footwear production;
✓ Around 99% of leather production in the EU comes from recycling animal by-products, such as residues from the meat industry;
✓ The leather industry is constantly evolving towards greener and sustainable practices, capitalizing on waste and by-products, recovering and reintroducing industrial water into

the circuit, as well as reducing energy and raw material consumption through innovative technologies;

- ✓ In the design of children's shoes, special attention is paid to the materials used and their sanogenetic characteristics.
- ✓ The use of protein waste from the leather processing industry as platers in polymer composites for shoe soles has resulted in products with technical properties comparable to those obtained from traditional materials. Also, the aesthetic appearance of the soles remained generally satisfactory, suggesting that these composites may be commercially viable;

9.2. Personal contributions

The following original contributions were made to this work:

- ✓ Documentary study on the current state of research on circular economy and correlation with the leather industry, by consulting a number of 276 specialized papers both nationally and internationally;
- ✓ Conducting two bibliometric analyses using keywords such as circular economy, leather industry, sustainable development;
- ✓ Conducting a questionnaire on young people's attitudes towards the concept of circular economy;
- ✓ Conducting experimental research on the design of children's footwear in accordance with circular economy principles;
- ✓ Conducting research on the design of shoe soles based on polymer composites with elastomer matrix and protein waste platers (fine leather);
- ✓ Conducting experiments for obtaining protein polymer composites by extrusion-granulation;
- ✓ Conducting experiments to create polymer composites processed by veiling/pressing;
- ✓ Carrying out the analysis on the framework technological process for the manufacture of footwear in the IL garment system (glued footwear);
- ✓ Presentation of the main operations in the process of making children's shoes;

9.3. Dissemination of results

Participation in International Conferences indexed ISI Web of Science

- **Claudia M Dumitra**; Razvan Dobrescu; Georgiana Moiceanu; Corina Dumitrescu; Augustin Semenescu, Leather industry and sustainable materials-Cost-Benefit Analysis, 2023 IEEE International Conference on Environment and Electrical Engineering and 2023 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), June 2023, Spain, ISBN 979-8-3503-4742-5, 1622 – 1627
- Georgiana Moiceanu, **Claudia Dumitra,** Renewable energy and leather industry – bibliometric analysis, 11th International conference on Energy and Environment 2023 (CIEM) (în evaluare)

Participation in BDI indexed international conferences

- **Claudia Monica Dumitra**, Laurentia Alexandrescu, Mirela Pantazi-Bajenaru, Dana Corina Deselnicu, Augustin Semenescu, Leather Industry in Romania - An Overview, The 9th International Conference on Advanced Materials and Systems, Bucharest (2022)
- **Claudia Monica Dumitra**, Georgiana Moiceanu, Youngs generation attitudes towards circular economy, The 10th International Conference of Management and Industrial Engineering, ICMIE 2021, ISSN 2344-0937

- Georgiana Moiceanu, Andreea Barbu, Mirona Popescu, Olivia Negoiță, **Claudia Monica Dumitra**, Waste management facts overview: wastes and recycling, The 10th International Conference of Management and Industrial Engineering, ICMIE 2021, ISSN 2344-0937

Articles published in BDI indexed journals

- **Claudia Monica Dumitra**, Dana Corina Deselnicu and Augustin Semenescu, Waste from the leather industry – a research in current context, Nonconventional Technologies Review, Vol 27 No 1 (2023), ISSN codes are: Print: ISSN 2359-8646; On-line: ISSN 2359-8654, Editura POLITEHNICA, Romania, 18 – 26
- **Claudia Monica Dumitra**, Augustin Semenescu and Corina Ionela Dumitrescu, European leather industry – a research in current context, Nonconventional Technologies Review, Vol 27 No 1 (2023), ISSN codes are: Print: ISSN 2359-8646; On-line: ISSN 2359-8654, Editura POLITEHNICA, Romania, 10 – 17
- **Claudia Monica Dumitra**, Georgiana Moiceanu, Corina Ionela Dumitrescu, The Circular Economy Approach, Faima Business & Management Journal, Volume 10, Issue 1, pp. 43-59 (2022)
- Andreea BARBU, Georgiana MOICEANU, Ştefan-Alexandru CATANĂ, **Monica Claudia DUMITRA** and Claudiu Adrian PURDESCU, „Analysis Of the Romanian Educational Offer Regarding the Existing Situation at The Level of Specialization: Engineering and Management, And Business Administration," Proceedings of the 38th International Business Information Management Association (IBIMA), ISBN: 978-0-9998551-7-1, ISSN: 2767-9640, 23-24 November 2021, Seville, Spain, p 1032-1039
- **Monica DUMITRA**, Corina Ionela DUMITRESCU, Vlad Alexandru SANDU, Cătălina Georgiana DÎLBEA and Răzvan Mihai Dobrescu, "Healthcare Organizations – Analysis of Systems, Entrepreneurial Approach and Management of the COVID-19 Pandemic," Proceedings of the 36th International Business Information Management Association (IBIMA), ISBN: 978-0-9998551-5-7, 4-5 November 2020, Granada, Spain, p 3880-3893

9.4. Future research directions

The results obtained from the studies and researches carried out were capitalized by elaborating and publishing scientific papers in specialized journals, in the volumes of national and international conferences and their preparation within national and international scientific events.

Among the future research directions are pursued:

✓ Continuing research on the design process of children's footwear from waste resulting from the processing process in the leather industry;

✓ Continuing and expanding research on the behavior of designed and realized products;

✓ Making 3D models of the designed footwear and subjecting them to quality tests to establish accurate quality indices;

✓ Performing a numerical analysis of the technological process of making children's footwear, establishing energy consumption and correlating data with the costs involved.