Ekonomia

The importance of social innovations in the knowledge-based economy in the context of footwear sector solutions

edited by Katarzyna Ławińska, Małgorzata Jabłońska

WYDAWNICTWO UNIWERSYTETU ŁÓDZKIEGO

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SCIENCE FOR THE SOCIETY

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Introductory Notes

The analysis of social relations between science, innovation, and the economy is an interesting issue, more and more widely referred to in the related literature. In the Polish scientific space, however, this topic is still new and not fully recognised, even though the genesis of the above subject matter derives from the conceptual framework that dates back to the 1960s. The social dimension of innovation is more and more elaborated upon in the strategic documents of the European Union, being an important component of the development strategy of the EU and the Member States. The essence of social innovation is the creation, development, and dissemination of ideas to effectively address crucial social concerns at the level of society, a specific social group or an individual. It is therefore worth attempting to further exemplify this concept by identifying the true links between a social need and a specific good, service, method or process.

Social innovation, similarly to technological innovation needs a stimulator of growth, which mainly manifests itself in the form of a market niche or a specific need and a requirement. Hence, it is often difficult to clearly separate social innovation from technological innovation. As a matter of fact social innovation is supposed to contribute to the improvement of society's life, thus appropriate actions should be taken to intensify the innovative processes, as they constitute a prerequisite for the progress of civilisation. The new EU perspective 2021–2027 provides the development opportunities for social innovation. All of the cohesion policy programmes put forward by Poland in its capacity as the Member State have been approved by the European Commission, which means that investments worth almost EUR 76 billion will be implemented in the coming years. In the new EU perspective, projects implemented to the extent of digital transformation, education, culture, social innovation, entrepreneurship, the health care system, energy efficiency, climate, transport, tourism and post-Covid-19 recovery and resilience or mitigating the effects of the Ukrainian crisis will be awarded the EU financial assistance.

This study constitutes the deliverable arising from the implementation of the Project financed by the Ministry of Education and Science under the „Science for Society" Programme. It is the Project No NdS/539367/2021/2021 entitled „*The impact of footwear design, materials and proper fit on the health of children and adolescents*". In effect of the Project the monograph was developed in cooperation with the Lukasiewicz – Lodz Institute of Technology and the Faculty of Economics

and Sociology of the University of Lodz. The study focuses on presenting and discussing various types of interrelations amongst theoretical issues related to social innovation and economic practice. An interesting and unusual combination is the presentation of social innovation in the context of solutions used in the footwear industry, which is developing more and more dynamically in Poland (especially in the area of e-commerce). Poland is also one of the leading European footwear manufacturers, occupying the 7th position in terms of production volume in the EU, with the market share of 2.5%, following Italy, Spain, Portugal, Germany, Romania and France. In addition, there is a fierce competition in the industry, which is conducive to the emergence of new types of innovation but it is also susceptible to various types of social needs as well.

The monograph consists of five theoretical and empirical chapters.

The first Chapter entitled '*The Importance of Social Innovation in the Knowledge-based Economy*' addresses the concept and taxonomy of social innovation. This part of the study draws attention to the issue of innovation funding sources in the new EU financial perspective.

The second Chapter '*Footwear Innovation to Improve the Comfort of Use*' contains theoretical and practical references to innovation in the footwear industry. The authors of the Chapter give examples of modifications of footwear materials that have been used in economic practice, and the improvement of the health conditions of footwear users becomes the related measurable output.

The third Chapter of the study entitled '*Waste Management Methods and Unit Processes in the Tanning Sector*' refers to the environmental aspects of social innovation in the footwear industry. The Chapter deals with the issue of utilisation of production residues or their re-use.

The fourth Chapter entitled '*Lower limbs. Ontogenesis, anatomy, deformations*' presents the most common complications occurring in children and adolescents in the field of incorrect use of footwear or the lack of adaptation of footwear to the needs of a demanding society in this respect. The Chapter draws attention to the essence of making innovative technological arrangements in the area of improving the comfort of footwear use.

The fifth Chapter entitled '*Social and Economic Benefits Assessment in Terms of Social Innovation*' displays the results of the research surveys aimed to recognise awareness and perception of benefits arising from innovation implemented into economic practice. In the study 408 respondents took part in the period from October till December 2022. On the grounds of the research output and the analysis of the related statistical figures, the attempt was taken to outline the social innovation development prospects in the footwear industry by 2050.

The topics addressed in the monograph may contribute to the development of the further scientific research on the footwear industry and its significance for the development of social innovation in Poland and in the world.

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Chapter 1

The Importance of Social Innovation in the Knowledge-based Economy

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1.1. The Importance of Social Innovation in the Innovation Ecosystem

Innovation is one of the determinants of economic development. Thanks to the implementation of new products, services and organisational changes into business practice, enterprises are able to compete effectively or satisfy various types of needs. Innovativeness, from the perspective of a single enterprise, is also perceived in financial terms. The implementation of innovative solutions should contribute to the improvement of business performance. The innovativeness of an enterprise is assumed to expresses the willingness and ability to implement new solutions, both of a technological and non-technological nature.[1] The attempt to define social innovation for the purpose of this study makes it impossible to omit issues related to the environment of innovation.

Innovation is considered the driving force of every economy, while in the micro scale, it correlates with development, competitiveness, learning process and change. The dynamics of changes taking place in the environment of each organisation forces the need for constant adaptation to new operating conditions, which directly accounts for the requirement to implement a new product, service or to restructure a company. Given the analysis of the literature on the subject in the field of innovation, it is plausible to state that there is terminological ambiguity in this regard. Researchers have still failed to develop a uniform definition of innovation, which often leads to misinterpretation. This is partly due to the fact

1 T. Kraśnicka, (2013), *Innowacyjność przedsiębiorstw – uwarunkowania organizacyjne*, Studia Ekonomiczne nr 136, Wydawnictwo Uniwersytetu Ekonomicznego w Katowicach, Katowice, p. 168.

that the study of innovation is a relatively new research area to the extent of social sciences.

One of the most common definitions of innovation is developed by innovation pioneer JA Schumpeter who was the first to have introduced this conceptual framework to economic sciences. According to him, innovation should be understood as: introducing new products into the production or improving the existing ones, introducing a new or improved production method, opening a new market, using a new way of selling or purchasing, using new raw materials or semi-finished products, introducing a new organisation of production, a new organisational structure, e.g. creating a monopoly or breaking it up.[2] Among the current definitions of innovation, the one developed by the OECD bears noting since it takes into account a number of key features of innovation. In terms of economic practice, innovation means the implementation of a new or significantly improved product, service or process,[3] which has an impact on the development of entrepreneurship,[4] which, apart from competitiveness and innovation, has in recent years become one of the most important issues related to the economic growth of regions.[5] The innovativeness of a company is also defined as the search for solutions derived from science[6] or social need[7] for commercial purpose.

Due to the fact that innovation is a complex category and represents a multi-dimensional meaning, several classification types of innovation may be found in the related literature. One of the most important is its division into product-based, process-based, and organisational innovation. Product-based innovation means new or improved products, process-based innovation relates to new or improved production processes, while organisational innovation translates into changes in the management system.[8] This nomenclature is used by the OSLO Manual, hence its widespread use. In fact, however, there are still other classification types that are related to such criteria as: the functional area of the organisation, the degree of novelty, originality of changes or the mechanism of stimulating innovation.

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2 W. Furmanek, (2017), *Innovations as the Category of Contemporaneity*, "Labor et Educatio", no. 5, Kraków, p. 17.

3 OECD, Eurostat 2008.

4 G. Avram, E. Hysa, (2022), *Education, Knowledge and Data in the Context of the Sharing Economy,* "The Sharing Economy in Europe"*,* Cham: Palgrave Macmillan, pp. 181–206.

5 M. Jabłońska, R. Dziuba, I. Hurak, (2018), *Czynniki rozwoju przedsiębiorczości w Polsce Wschodniej*, „Wiadomości Statystyczne", GUS, Warszawa, p. 57.

6 W. Furmanek, (2017), *Innovations as…*, p. 19.

7 A. Markowicz, (2019), *Innowacje społeczne jako determinanty rozwoju społeczności lokalnych,* "*Ekonomia Społeczna. Innowacje społeczne*", vol. 1, Uniwersytet Ekonomiczny w Krakowie, Kraków, pp. 32–40.

8 J. Tutaj, (2019), *Innowacje – próba pomiaru*, [in:] Z. Malar, J. Tutaj (eds), *Innowacje a dobrostan społeczeństwa, gospodarki i przedsiębiorstw:próba pomiaru*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław, p. 12.

Table 1.1. Innovation – Classification Types

1.	**Strategic, tactical**	**They** are put under consideration from the macro and micro point of view. Strategic innovation accounts for long-term projects with significant potential, priority for the company or the state. Tactical innovation comes forward with changes in products, technology, etc.
2.	**Creative, imitative**	They are put under consideration from the point of view of importance for the company and the economy. Creative innovation is called pioneering innovation and imitative innovation, i.e. adapted ones.
3.	**Radical, recombinant, modification**	Radical innovation gives rise only to new products, technologies and methods of management. Recombinant innovation is the use of existing technical solutions to create new solutions. Modification innovation consists in slight changes in already existing solutions. Such modification will not change the function of the product but the related characteristic feature is the response to the customers' needs and requirements in order to satisfy them.
4.	**Purposeful, instrumental**	Purposeful innovation consists brings about a completely new solution. Instrumental innovation constitutes a change in the system of production or management leading to a new goal.
5.	**Demand, supply**	Demand innovation arise from market needs (satisfying a market niche). Supply innovation comes from scientific and research outcome, often as a result of theoretical research, without any influence upon the market and consumer needs.
6.	**Single, synergistic**	Individual innovation is implemented and affects only one sphere of the company's business operations. Synergistic innovation impacts many areas of the company's business operations.
7.	**Employee, participatory**	Employee innovation comes forward with solutions initiated by employees as it arises from their creativity and the need for change. Participatory innovation brings about top-down solutions.
8.	**Technical, biotic, anthropocentric, social**	Technical innovation consists in modifications in the field of production technology. Biotic innovation means innovation in the field of nature. Anthropocentric innovation influences various aspects of human life. Social innovation impacts the organisation of interpersonal relations.

Source: own study based on: J. Tutaj, (2019), *Innowacje – próba pomiaru*…, p. 12.

The analysis of the definitional extent of the topical issue in question for the purpose of this study has underlain the decision to distinguish two models of innovation: social and economic. Economic innovation, that is a broader term, is associated with the implementation of improved products, a new product or the use of more efficient production methods as well as a new and more effective organisational framework that is tantamount to reorganising or restructuring a company in terms of a micro innovation as opposite to a macro one within the entire economy.[9] The table below displays a few of the most important definitions of economic innovation (covering the broad meaning of innovation) and concurrently presenting various aspects.

Table 1.2. Economic Innovation – A Variety of Definitions

Author	Definition of Economic Innovation
1	2
Skubiak B.	– consists in addressing major social concerns, based on entrepreneurial initiatives that emphasise philanthropy, individual responsibility and a limited role of the state. Social innovation is not only a response to specific needs, but also creates social changes, a new vision, a new way of perceiving and defining problems as well as solutions to those problems;
Gomulka S.	– seen as long-term investments;
Olejniczuk-Merta A.	– can be unpredictable, can be a by-product of solving other social problems; – it is also recognised as experimental social activities aimed at improving the quality of life of individuals, nations and entire communities; – contributes to improvement of the living standards; – it is the relationship between business, society and development;
NCBiR	– it is a solution which at the same time does not respond to social needs, and also causes a permanent change in given social groups. Those solutions may be related to innovative products, services or processes that provide for diverse solutions to typical social problems;
OECD	– a new or improved product is introduced to the market or a new or improved process is used in production;
Skonieczny J.	– a response to such social challenges as: ageing of the society, economic crisis, increase in unemployment among university graduates;
Praszkier R. and Nowak A.	– it is a precondition for the emergence of social entrepreneurship in the economic sphere;

9 S. Żero, (2018), *Różnice w interpretacji pojęć innowacji oraz imitacji*, [in:] E. Gruszewska, A. Matel, E. Kuzionko-Ochrymiuk (eds), *Współczesne problemy ekonomiczne w badaniach młodych naukowców*. T. 2, Zarządzanie organizacją, finanse i inwestycje, Polskie Towarzystwo Ekonomiczne, Białystok, p. 41.

1	2
Bannet E.	– the creation and implementation of new processes, products, services and delivery methods that result in significant improvements in results, efficiency, effectiveness or quality;
Popplow M.	– successful introduction of new services, products, processes, business models and ways of working;
Parker J.	– a process that includes all activities that bring a new product or manufacturing method to practical use;
Pomykalski	– a process covering all activities related to the creation of an idea, the creation of an invention as well as the implementation of the invention;
Lange O.	– these are changes in the production functions that allow the company to increase the profit that may be earned under given market conditions;
Johnston R.	– it is not only the first use of a product or manufacturing method, but also the subsequent use by other companies, industry sectors or countries;
Cossack M.W.	– a source of economic growth;
Poll E. and Ville S.	– intended to improve the company's performance and is usually protected by intellectual property rights; – economic innovation consists of technological innovation (new or improved products or processes) or organisational innovation.

Source: own elaboration based on: B. Skubiak, (2016), *Innowacje społeczne w teorii i praktyce*, Barometr Regionalny tom 14, nr 1, Wyższa Szkoła Zarządzania i Administracji w Zamościu, Zamość, pp. 29–30; A. Olejniczuk – Merta, (2013), *Innowacje społeczne*, Konsumpcja i Rozwój nr 1/2013, Warszawa, pp. 23–26; R. Praszkier, A. Nowak, (2012), *Przedsiębiorczość społeczna. Teoria i praktyka*, Oficyna a Wolters Kluwer business, Warszawa; J. Skonieczny, (2022), *Innowacja Społeczna*, „Zeszyty Naukowe Uniwersytetu Ekonomicznego w Poznaniu", nr (246), Poznań, p. 99; E. Bannet, (2007), *Quixotes, Imitations and Transatlantic Genres. Eighteenth Century Studies*, The Johns Hopkins University Press, Baltimowe, pp. 553–569; M. Popplow, (1998), *Protection and Promotion: Privileges for Inventions and Books for Machines in the Early Modern Period. History of Technology*, No 20, Bloomsbury, Londyn, pp. 103–124; *Oslo Manual – OECD Proposed Guidelines for Collecting and Interpreting Technological Innovation Data*, OECD/EC/Eurostat 2005; J. Parker, (1974), *The Economics of Innovation*, London; A. Pomykalski, (2001), *Zarządzanie innowacjami*, PWN, Warszawa, p. 56; O. Lange, (1961), *Uwaga o innowacjach*, [in:] *Pisma ekonomiczne i społeczne 1930–1960*, PWN, Warszawa, p. 160; S. Gomułka, (1998), *Teoria innowacji i wzrostu gospodarczego*, CASE, Warszawa, p. 17; R. Johnston, (1966), *Technical Progress and Innovation,* "Oxford Economic Papers" 1966, vol. 18, iss. 2, pp. 158–176, za: P. Drucker, (1992), *Innowacja i przedsiębiorczość. Praktyka i zasady*, PWE, Warszawa, pp. 39–42; M.W. Kozak, (2008), *Czynniki determinujące możliwości wykorzystania polityki strukturalnej na potrzeby rozwoju polskich regionów*, [in:] K. Bondyra, M.S. Szczepański, P. Śliwa (red.), *WieloPolska Regionalna. Regionalizm w Polsce a polityka strukturalna Unii Europejskiej,* Wydawnictwo Wyższej Szkoły Bankowej w Poznaniu, Poznań, p. 33; E. Pol, S. Ville, (2009). *Socialinnovation: Buzz word or enduring term?*, "The Journal of Socio-Economics", Vol *38*(6), pp. 878–885.

P. Drucker was one of the first researchers whatsoever when it comes to organisation and management processes in corporations and non-profit organisations, who defined social innovation. In his works, he emphasised the importance of social innovation and entrepreneurship. According to the researcher, the stimulus for innovation does not have to be any technical factor since market observations, demographic processes or social attitudes are often enough.[10] P. Drucker's indication of social aspects contributed to the search for links between innovation and social conditions of their development. He pointed out that innovation is a result caused in the economy by society.[11] Currently, the related literature is increasingly abundant as far as various types of references and examples of research on the social aspects of innovation are concerned. Having examined the related diverse literature, it may be concluded that the term "social innovation" has developed on the basis of such concepts as: institutional changes, social goals and public good.[12] The table below displays diversified approach to the definition of social innovation.

Table 1.3. Social Innovation – A Variety of Definitions

Author	Definition of social innovation
1	2
Skubiak B.	All types of scientific and technological innovation has an ex-ante or ex-post social component;
Olejniczuk-Marta A.	Any deliberate and conscious change into a new one that: – takes place in specific spatial and temporal conditions, – is expressed in material form or not, – is achieved thanks to activities different from routine, – involves additional effort and risk, – by nature and at least indirectly, it refers to the human being and society as the ultimate addressee of innovation;
Wiktorska-Święcka A., Klimowicz M. and Moroń D.	– the subject of social innovation is therefore a special type of change resulting from human dreams, desires and needs and efforts generated in the social environment;
European Union	– a response to social needs, especially those that are not traditionally met by the private sector or public institutions and are targeted at vulnerable groups in society; – social innovation is based on the ingenuity of citizens, civil society organisations, local communities, entrepreneurs and public officials;

10 W. Kwaśnicki, (2013), *Innowacje społeczne – nowy paradygmat czy kolejny etap w rozwoju kreatywności człowieka?*, [in:] W. Kwaśnicki (ed.), *Innowacyjność a samoorganizacja społeczna,* Uniwersytet Wrocławski, Wrocław, p. 9.

11 P. Drucker, (1992), *Innowacja i przedsiębiorczość. Praktyka i zasady*, PWE, Warsaw, p. 153.

12 E. Pol, S. Ville, (2009), *Socialinnovation: Buzz word or enduring term?*, "The Journal of Socio-Economics", vol. 38, no. 6, pp. 878–885.

1	2
Huczek M. and Smolarek M.	– is any intentional and conscious change into the new one, which takes place in specific spatial and temporal conditions, is expressed in a tangible or intangible form and refers to the human individual and society as the final recipient of innovation; – therefore, it has no limits, no time frames: is as useful and effective as it is useful to users in satisfying their needs: ranging from intangible to tangible ones;
Raufflet E.	– provide new knowledge to satisfy social needs;
Praszkier R. and Nowak A.	– creating and implementing new ideas for organizing activities or social relations in order to achieve common goals;
Edwards-Schachter M. and Wallace M.L.	– innovation that underlies the process of social change.

Source: B. Skubiak, (2016), *Innowacje społeczne w teorii i praktyce*, Barometr Regionalny tom 14, nr 1, Wyższa Szkoła Zarządzania i Administracji w Zamościu, Zamość, pp. 29–30; A. Olejniczuk – Merta, (2013), *Innowacje społeczne*, „Konsumpcja i Rozwój", nr 1/2013, Warszawa, pp. 23–26; A. Wiktorska-Święcka, M. Klimowicz, D. Moroń, (2015), *Zarządzanie innowacjami społecznymi,* Difin, Warszawa, p. 11; M. Huczek, M. Smolarek, (2018), *Innowacje społeczne w procesie zarządzania organizacjami*, „Zeszyty Naukowe Wyższej Szkoły Humanitas. Zarządzanie", Sosnowiec, p. 10; E. Raufflet, (2009), *Mobilizing business for post-secondary education*: CIDA university, South Africa, "Journal of Business Ethics", Vol. 89, pp. 191–202; M. Edwards-Schachter, M. L. Wallace, (2017), *Shaken, but not stirred: Sixty years of defining social innovation*, "Technological Forecasting and Social Change", 119(4), pp. 64–79.

The scientific literature distinguishes three different ways of defining social innovation:

- focusing on non-technical innovation in an organisational context,
- social innovation is combined with technological innovation,
- social innovation is considered to be independent and new social practices.[13]

So, what is the difference between social innovation and economic innovation? Social innovation, in addition to the above-mentioned features, is characterised by the fact that the benefits of this innovation accrue primarily to society as a whole, and not to private individuals.[14] In the case of social innovation, the goal of creating innovation is important, it is about satisfying new social needs, particularly in such areas as: education, health care, environmental protection, public finance or public and social services. Social innovation is the solution that contributes to solving social problems, in particular when all previous methods of solving those problems have turned out to be unreliable. As pointed out by Bukowski A. and others:

13 M. Huczek, M. Smolarek, (2018), *Innowacje społeczne w procesie zarządzania organizacjami*, Zeszyty Naukowe Wyższej Szkoły Humanitas, Sosnowiec, p. 11.

14 M. Wronka-Pośpiech, (2015), *Innowacje społeczne – pojęcie i znaczenie,* "Studia Ekonomiczne", Scientific Journals of the University of Economics in Katowice, No 212, Katowice, p. 127.

in the case of social innovation, what is important is the final goal it serves […], after implementation, the "social invention" is supposed to introduce a change consisting in increasing human well-being […], therefore social innovation should – in order to be recognised as such – positively affect the quality of life or increase key quantitative indicators related to human life. In this perspective, a social innovation can be both the Internet (which is also a technological innovation), a new medicine (which is also a business innovation), and a program to activate local communities. However, it cannot be those innovations that bring negative social effects or serve only business purposes without reference to a wider context […].[15] A similar approach to social innovation is also promoted by researchers Pol and Ville, according to whom economic innovation is profit-oriented innovation, which means creating new ideas with the intention of earning money. This does not mean, however, that social innovation does not generate revenues for the company because the vast majority of social innovation constitutes business innovation.[16] The Guide to Social Innovation indicates that social innovation includes:

- innovation that addresses the social needs of groups at risk of exclusion, traditionally not satisfied by the market and other institutions,
- innovation focused on sustainable development,
- innovation focused on organisational changes in relations between various institutions and their stakeholder groups.[17]

Given the above, although short and synthetic, it allows to define social innovation by means of the following criteria:

- new or improved solutions, the implementation of which results from a social need,
- usefulness does not result from a sudden market need, but from a social need, that so far could not be satisfied for various reasons;
- the implementation of this type of innovation is not massive;
- the goal is to create added value for society as a whole.

1.2. Innovation Booster in the Enterprise

Innovation involves a sequence of events, that generally begins with the emergence of an idea and ends with the introduction of a ready-made solution to the market through various commercialisation models. Due to the fact that innovation has

15 A. Bukowski, S. Rudnicki, J. Strycharz, (2012), *Społeczny wymiar innowacji*, "Zarządzanie Publiczne" No 2(20), Uniwersytet Ekoniiczny w Krakowie, Kraków, pp. 14–15.

16 E. Pol, S. Ville, (2009), *Socialinnovation: Buzz…*, pp. 878–885.

17 European Commission, *Guide to Social Innovation 2013,* pp. 6–7.

a very strong impact on economic and social development, it is worth looking at the process of boosting innovation in a company and the evolution of this phenomenon. Innovation has a real impact on the level of competitiveness.[18]

Innovation booster in the enterprise has undergone a significant evolution in connection with the scientific and technical development taking place over the centuries. Technical progress, i.e. the process of development changes manifesting itself through the introduction of new, improved machines, devices, tools, and new technologies to the production process, and through the use of existing resources in a more efficient way, was an important element of Schumpeter's theory of innovation and this approach is still valid today. Innovation is associated with change, and this in turn is the domain of the passage of time, and related progress in various areas of the economy. Technical progress consists of several basic stages which include: basic research, applied research, development and implementation. Importantly, does this classification apply to all four institutional sectors: the enterprise sector, the higher education sector, the government sector and the sector of private non-commercial institutions.

Table 1.4. Stages of the Technological Process

Definition	Technology Readiness Level
1	2
Basic Research – Experimental or theoretical work undertaken primarily to gain new knowledge of the underlying foundations of phenomena and observable facts without any particular application or use in mind. Basic research consists in the analysis of properties, structures and relationships, and the related goal is to formulate and test hypotheses, theories or laws. It is divided into clean and focused basic research. „Pure" basic research is conducted with the aim at developing background knowledge, with no purpose of achieving long-term economic benefits. „Targeted" basic research is conducted with the aim of creating foreground knowledge that may serve the purpose of solving problems or exploiting opportunities, both existing and anticipated.	Level I – the basic principles of a given phenomenon have been observed and described – the lowest level of technology readiness, meaning the start of scientific research in order to use the related outcome in future applications. Those may include, among others, the research into the basic properties of technology.

18 R. Dziuba, (2014), *Rola innowacyjności i konkurencyjności w rozwoju regionu Bałkanów Zachodnich na przykładzie Czarnogóry*, „Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania" 37/2, Wydawnictwo uniwersytetu Szczecińskiego, Szczecin 2014, p. 225.

1	2
Applied (Industrial) Research – Original research work undertaken to gain foreground knowledge. It is focused primarily on specific, practical goals (OECD def.); this is work aimed at acquiring foreground knowledge and new skills, developing new products, processes or services, or introducing significant improvements to them (def. Law on Higher Education and Science).	Level II – the concept of the technology or its future application has been defined. This means starting the process of searching for the potential application of the technology. From the moment of observing the basic principles describing the new technology, one can postulate its practical application, which is based on predictions. There is as yet no evidence or detailed analysis to support the assumptions made. Level III – critical functions or concepts of the technology have been confirmed analytically and experimentally. This means conducting analytical and laboratory tests to confirm the predictions of scientific research on selected elements of technology. Those may include components that are not yet incorporated into an integral whole or are not any representative of the entire technology, either. Level IV – components of the technology or its basic subsystems have been verified through laboratory testing procedures. That process means that the basic components of the technology have been incorporated. Those may include integrated 'ad hoc' models in the lab. A general mapping of the target system is performed through laboratory testing procedures. Level V – components or basic subsystems of the technology have been verified in an environment close to the real one. The core components of the technology are incorporated into real supporting elements. The technology may be tested under simulated operating conditions. Level VI – a prototype or model of a system or subsystem of technology is demonstrated in conditions close to real. This means that a representative model or prototype of the system, that is much more advanced, is tested at level V, in conditions close to real. Tests at this level include the prototype-based laboratory testing procedure imitating real conditions with high fidelity or in simulated operating conditions.

1	2
Development work – Work undertaken in a methodical manner, based on knowledge gained through research and practical experience and the foreground knowledge, aimed at developing new products or processes or improving existing products or processes (OECD def.). Activities involving the acquisition, combination, shaping and use of background knowledge and skills, including those in the field of IT tools or software, for planning production and designing and creating changed, improved or new products, processes or services, excluding activities involving routine and periodic changes introduced to them, even if such changes are improvements (def. Law on Higher Education and Science).	Level VII – a prototype of the technology is demonstrated in operating conditions. The prototype is almost at the operating system level. This tier represents a significant advance over Tier VI and requires demonstrating that the technology under development is operationally applicable. Research at this level includes testing prototypes on the so-called research platforms. Tier VIII – research and demonstration of the final form of the technology has been completed. This means that it has been confirmed that the target level of technology has been achieved and the technology may be used in the conditions envisaged for it. Practically, this level represents the end of the demonstration. Examples include testing and evaluating systems to validate design objectives, including those relating to logistics support and training. Level IX – checking the technology in real conditions proves the intended effect. This indicates that the demonstrated technology is already in its final form and may be implemented in the target system. Among other things, this is related to the use of developed systems in real conditions.
Implementation works – Works undertaken on the basis of the company's decision to use the results of research and development works, including the use of inventive projects, both own and acquired in the form of a license, related to the launch of production of new products or modernization of manufactured products and the introduction of new manufacturing methods, which precede the start of production on an industrial scale.	

Source: file:///C:/Users/user/Downloads/Poziomy_gotowosci_technologiczna.pdf (accessed: 12.02.2023; ustawa z dnia 20 lipca 2018 r. – Prawo o szkolnictwie wyższym i nauce (Dz.U. 2022 poz. 574, z późn. zm.); https://stat.gov.pl/metainformacje/slownik-pojec/pojecia-stosowane-w-statystyce-publicznej/10,pojecie.html (accessed: 12.02.2023); Podręcznik Frascati 2015, OECD; https://stat.gov.pl/metainformacje/slownik-pojec/pojecia-stosowane-w-statystyce-publicznej/340,pojecie.html (accessed: 12.02.2023).

Taking into account the definitional extent of basic, applied and development research, we have a broad definition of research and development (R&D), which is to be found in many EU strategic documents, national and international legal acts, etc. The order in which those three types of research and development activities appear should not imply that basic research leads to applied research and then to development. It has long been known that in the system of R&D activities there are many flows of information and knowledge, and the direction of transmission of those flows is also diverse. According to the authors of the Frascati handbook, development work may inspire basic research, and there is no reason to believe that basic research cannot lead directly to new products or processes.[19] Therefore, it should be recognised that the phase of basic research, applied research, development, implementation and diffusion overlaps one another, which is the result of the existence of links between each of them.[20]

Scheme 1.1. Linear Model of Innovation
Source: A. Kędzierska Szczepaniak, K. Szopik-Depczyńska, K. Łazorko, (2016), *Innowacje w organizacjach,* Texter, Warszawa, pp. 11, 16.

The Organisation for Economic Co-operation and Development (OECD) plays a key role in the correct interpretation of R&D activities. According to the OECD, "*R&D includes creative work undertaken in a methodical manner to increase the body of knowledge – including knowledge of humankind, culture and society – and to create new applications for existing knowledge*".[21] The key criterion for classifying R&D by type presented in the table below is the expected use of the related outcome.[22]

In order for a given activity to be classified as research and development activity, it is necessary to meet five basic criteria that determine the separation of this type of activity from other activities carried out in a given unit.

19 OECD, *Podręcznik Frascati 2015*, Główny Urząd Statystyczny, Warszawa 2015, pp. 47.
20 A. Kędzierska Szczepaniak, K. Szopik-Depczyńska, K. Łazorko, (2016), *Innowacje w organizacjach,* Texter, Warszawa, pp. 11, 16.
21 OECD, *Podręcznik Frascati…*, p. 48.
22 Ibidem, p. 56.

Table 1.5. R&D Classification Criteria

Criterion	Description
Focusing on new discoveries	Universities and research institutes – R&D activities are expected to generate completely new foreground knowledge and advanced background knowledge; Enterprises – as part of R&D activities, achievements, that are new to the enterprise and are not yet used in a given industry, are expected;
Relying on original, non-obvious concepts and hypotheses	R&D must aim at new concepts or ideas that add up to the background knowledge. Routine activities are excluded from the scope of R&D, and new methods developed for the purpose of performing are included in common tasks.
Uncertainty about the final result	R&D involves uncertainty because at the beginning of an R&D project, the type of result and the cost (including time spent) cannot be precisely identified in relation to its objectives. There is uncertainty about the cost or time needed to achieve the expected results.
Planning and budgeting	Research and development activities are formal activities carried out in a methodical manner. This means that R&D is carried out in a planned manner, with both the course of the process and its outcome being recorded. In order to verify this, it is necessary to specify the purpose of the R&D project and the sources of funding for research and development work. The availability of such documentation is consistent with an R&D project that is aimed at meeting specific needs and for which own human and financial resources are available.
Leading to results that can be played (possible to transfer or restoration)	An R&D project should result in the potential to transfer foreground knowledge, ensuring its exploitation and allowing other researchers to replicate the results as part of their own R&D. Since the purpose of R&D is to develop the background knowledge, the results must not remain muted (i.e. they cannot remain only in the minds of researchers), as there is a risk of losing both those results and the knowledge associated with them.

Source: own study based on: OECD, *Podręcznik Frascati 2015*, Główny Urząd Statystyczny, Warszawa 2015, pp. 49–50.

In consideration of the above, it should be pointed out that the inception of the innovation booster should begin with the correct definition of phenomena or events that are likely to occur in the course of developing innovation. As mentioned earlier, models of innovation booster processes have evolved from Schumpeter's time until the present day. Currently, the most known classification of innovation booster is proposed by R. Rothwell in the early 1990s. He systematised innovation booster processes in an enterprise and distinguished five generations of models of innovation booster processes.[23]

Table 1.6. Models of Innovation Booster Process, according to R. Rothwell

Booster Model	Properties
1	2
Technology-driven innovation model (supply-driven model) From the 1950s to the mid-1960s	– is based on the concept developed by JA Schumpeter; – innovation is limited to research and development (R&D); – the initiator of innovation booster activity is the R&D staff; – assumes that the supply of innovation is determined by the state of knowledge and the tendency of independent explorers to constantly search for new solutions; – innovation booster activity stems from the current development of basic research and an appropriate R&D potential; – Entrepreneurs incur a certain risk through innovation, expecting future benefits. The implementation of innovation will change the structure of the market, giving a temporary monopolistic position and extraordinary profits to innovators. This will result in the emergence of imitators (diffusion) and will adversely impact the privileged position of enterprises by increasing market competition; – the form of the supply model according to the sequence of events: research – design and engineering – production – sale; – the model has worked well in absorptive economies where the entrepreneur does not have to solicit customers (the so-called first-generation model); – shows the features of a linear model;

23 K. Kozioł, (1992), *Modele procesu innowacyjnego w przedsiębiorstwie*, „Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania" No 6, 2008, p. 523, [in:] R. Rothwell, (1992), *Successful Industrial Innovation: Critical Factors for the 1990's*, "R and D Management", no 22.

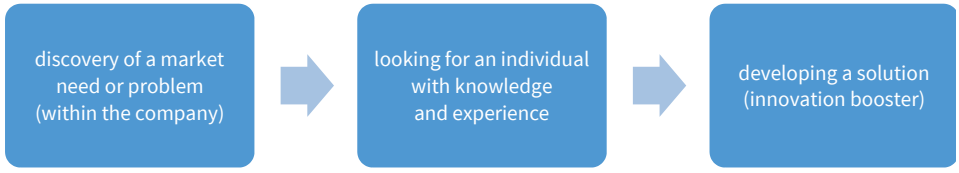
1	2
Model of innovation pulled by the market (demand model) From the mid-1960s to the early 1970s	– the market is the main source of ideas and inspiration for R&D activities, which is why this model works well in economies where the market decides which product will be accepted by the customer and which will be rejected; – the most important, from the point of view of the company's business operations, is the staff dealing with marketing, i.e. recognising market needs; – the success of the company is based on the ability to anticipate short-term changes and needs in the market and to capture potential opportunities for new products among them; – innovation is treated as a response to new, economic opportunities to maximise the company's profit; – the level of innovation booster activity is determined by the expectation of a higher market value of a new or improved good, which depends on the current size and the expected growth rate of the market capacity in which new products will be sold; – the form of the demand model according to the sequence of events: market need – product development – production – sale (the so-called second generation model); – shows the features of a linear model;
Feedback model From the early 1970s to the mid-1980s	– innovation treated as a logically sequential process that consists of functionally separate but coupled and interdependent phases. The birth of a new idea may take place both after a new need in the market has been recognised and as a result of R&D activity. What is important in this model is the mutual penetration and interaction of market needs and R&D activities (the so-called third generation model); – it is a non-linear model;
Integrated/parallel model From the early 1980s to the early 1990s	– the model has been implemented in economic practice as a result of rapid technological development; – the creation of new products is based on design teams combining various functions. Under this concept, features are introduced into the new product development process from the very beginning (the so-called fourth generation network model);

Table 1.6 (cont.)

1	2
Network model From the mid-1990s	– companies increasingly rely on external innovation resources in the booster innovation process; – shift from own core business and R&D in favour of, for example, selected aspects of R&D in favour of buying ready-made outcome; – enterprises assume the role of an integrator, handling the innovation booster process and development activities carried out by partners (the so-called fifth generation model);

Source: own study based on: M. Zastępowski, (2017), *Model procesu innowacyjnego Polskich małych i średnich Przedsiębiorstw*, „Organizacja i Kierowanie", nr 2, SGH, Warszawa, p. 372; R. Ciborowski, (2012), *Modele rozwoju innowacyjnego*, [in:] *Ekonomika i zarządzanie innowacjami w warunkach zrównoważonego rozwoju*, edited by Andrzej H. Jasiński and Robert Ciborowski, Białystok 2012, pp. 49–50.

The models of the innovation booster process presented above, from the supply model to the integrated model, are closed models, which means that individual enterprises use only their own internal resources to pursue innovation. Often is such an innovation booster procedure based on the know-how of employees who, through their own experience and knowledge, are able to penetrate the market need, create a theoretical outline of the solution to a given problem or market need, and then, with the involvement of other resources within the company, develop a prototype. Currently, innovation is created most often in connection with "assignment from the outside". This trend was started in 2003 by H. Chesbrought who observed that more and more companies used external sources to conduct innovation booster activities. He described such events as open to innovate.[24] In other words, they are network models, self-learning systems that generate knowledge and initiate the learning process, aimed at connecting internal and external ideas, as well as internal and external innovation paths to the market, which accelerates the development of new technologies. The open innovation model emerged in the early 2000s and continues until now.



Scheme 1.2. Open Innovation Booster (sixth generation innovation)
Source: own study.

24 M. Zastępowski, (2017), *Model procesu innowacyjnego Polskich małych i średnich Przedsiębiorstw*, „Organizacja i Kierowanie", nr 2, Szkoła Główna Handlowa, Warszawa, p. 374.

The effective implementation of innovation when it comes to business operations and the range of its impact have a fundamental significance as far as the social effectiveness of science and the pace of economic development are concerned. Both from the point of view of business practice and the related literature, the implementation of innovation is considered to be the weakest element of the innovation process. It often turns out that innovators lack managerial tools or skills, and managers, in turn, lack knowledge in the field of commercialisation know-how. The innovation implementation procedure itself is different, depending on the type of innovation, which may be as follows:

- product – introduction of a product or service that is new or significantly improved;
- process – implementation of a new or significantly improved method of production or delivery;
- marketing – implementation of a new marketing method involving significant changes in product design/construction or packaging, distribution, promotion or pricing strategy;
- organisational – implementation of a new organisational framework in the operating principles adopted by the company.[25, 26]

The above also applies to social innovation that may include products, services, processes, technologies, organisational frameworks, business models, social movements, etc. Examples of social innovation are presented in the table below.

Table 1.7. Social Innovation Types

Social Innovation	Examples
product	technologies that assist people with disabilities
service	microcredit, mobile banking
process	peer-to-peer cooperation model, crowdsourcing
market	Fair Trade, time banks
organizational	social enterprises
new business models	social franchise, the use of JIT (just-in-time) strategies for social challenges
new platforms	new models of care for people with intellectual disabilities and those in „social isolation"

Source: M. Wronka-Pośpiech, (2015), *Innowacje społeczne – pojęcie i znaczenie*, Studia Ekonomiczne. „Zeszyty Naukowe Uniwersytetu Ekonomicznego w Katowicach", nr 212, Katowice, p. 129.

25 OECD, (2005), *Oslo Manual, Guidelines For Collecting And Interpreting Innovation Data, Third Edition*, European Commission, pp. 50–53.

26 A. Kędzierska Szczepaniak, K. Szopik-Depczyńska, K. Łazorko, (2016), *Innowacje…*, p. 11.

The process of creating and implementing social innovation in economic practice does not differ significantly from a typical innovation process. In the related literature, however, the process of delivering social innovation is treated separately, which is why six stages of the innovation booster process in this case are distinguished:

- inspiration;
- proposal;
- prototype;
- maintenance;
- scaling;
- systemic change.[27]

The "inspiration" stage is associated with a social need that arises suddenly and unexpectedly, e.g. as a result of a natural disaster, contributing to the occurrence of a social need that has not been satisfied so far. Inspiration may also refer to a social need that has not been satisfied despite the fact that a market need actually exists, e.g. the problems of an ageing society. This "non-satisfaction" of the social need may have occurred because the implementation of this type of innovation is unprofitable for a typical enterprise. It means that the identification of a social need, regardless of the circumstances of its occurrence, is parallel to the achievement of the sowing phase of an innovative idea.

The second stage, "proposal", comes forward the development of a preliminary concept to address a social problem. It is responsible for conceiving ideas brought forward by citizens and consumers of services, the local community, employees of organisations or members of social organisations. This is a time-consuming step. Due to the fact that the purpose of social innovation is to satisfy specific social needs, it is necessary to reach the social group most interested in a given innovation.

The "prototype" stage includes pilot studies aimed at checking whether the proposed solution to a social problem is acceptable to users. From the point of view of the organiser of the innovation booster process, this is the most difficult stage. It covers time-consuming and cost-intensive conceptual work (corrections to the prototype, substantive consultations) as well as activities related to, for example, searching for funding sources for subsequent stages of the prototype development.

The "maintenance" stage means the popularisation and implementation of innovation, which ends with the development of a prototype that meets social expectations. At this stage, the owners of the innovative conceptual framework should develop a business model based on which its commercialisation will take place.

The "scaling" stage consists in the diffusion of innovation among groups and communities interested in changing, purchasing, implementing the proposed innovative conceptual framework (e.g. through franchise or licensing).

27 http://www.socialinnovator.info/process-social-innovation (accessed: 12.02.2023).

The last stage, i.e. "systemic change", consists in implementing new ways of thinking and acting that relate to various areas of social life. At this stage, the social changes that have taken place after the implementation of innovation are often assessed. Systemic changes make up social innovation that has contributed to changes in the existing education, health and information systems and has brought about new and better behaviour of people.

1.3. Social Innovation Booster Pre-conditions and Implementation Prospects

Social innovation addresses the challenges emerging in the social system. The onset of each innovation of this type should be seen in the ongoing change, starting from a change of thinking and ending with a change related to technical and economic progress. Social innovation refers to many areas of social life, e.g. education, management or culture. However, the undoubted ally and cause of social innovation in each of the above-mentioned areas is knowledge, which is a key value of social life. As it has already been emphasised in the previous part of the study, for an innovation to be considered socially innovative, it should have the following attributes:

- novelty,
- dissemination of the effect,
- effectiveness,
- addressing a social need,
- boosting social activity to action.

Social innovation promotes the competitiveness of the EU and its regions that are well-positioned to play a leading role to this end. Regional authorities can arrange for this process. They can take the lead in promoting social innovation, provide funding, bring together diverse stakeholders, introduce strategic thinking, and support the generation of fresh ideas to address societal and societal challenges. In order for social innovation to develop, there is a real need to support the related development at the central level, so one of the most important pre-conditions for the development of this type of innovation is to create a favourable environment. A special role in this respect is played by governments and the policy of central authorities at various levels. The United States has good practices in this regard. In 2009 the Office for Social Innovation was established and $50 million was allocated for its operation. The following year, upon the initiative of the then President, the Office of Social Innovation and Civic Activity was launched, the mission of which

was to improve opportunities, equality and justice by helping to create a social sector. The Social Innovation team is working to identify and scale better, more effective social solutions to deliver on the priorities of the President of the United States that strengthen communities and provide for economic advancement.[28] In 2014 the Social Innovation Found was established. The fund combined public and private funds to develop solutions based on societal needs. Social needs financed under the Fund included activities in the field of: generating new economic opportunities, healthy future and youth development.[29] Through the efforts of this Fund, $350 million of private and non-federal commitments have been raised to fund social innovation activities.[30] The European Union has similar experience in supporting the idea of social innovation at the central level. Social innovation is incorporated into numerous policy initiatives of the European Commission, which translates into regulations governing the Structural Funds. In each previous and current programming period, specific measures are accessible for the development of social innovation. Within the financial perspective 2014–2020, the Horizon 2020 Programme has been the largest instrument in terms of allocation of funds aimed at financing the development of research and innovation. The Programme deliverables include the achievement of 3% of the GDP for financing research and development in the Community by 2020. It has consisted of three mutually complementary priority areas: an excellent scientific base, a leading position in industry, and social challenges (it has emphasised the need for social innovation to the greatest extent).

The vast majority of social innovation stems from the initiative of a single citizen or various types of organisations, the core business of which is to deal with the identification of social needs. It is the output of a process that consists of:

- identification of social needs,
- creating new solutions,
- evaluation of the effectiveness of those solutions,
- monitoring effectiveness in practice.[31]

The development and implementation of social innovation, like any other type of innovation, requires the delivery of a model that would mark the most important milestones throughout the process. The model developed by the European Commission includes the ten most important steps to be taken when implementing social innovation.

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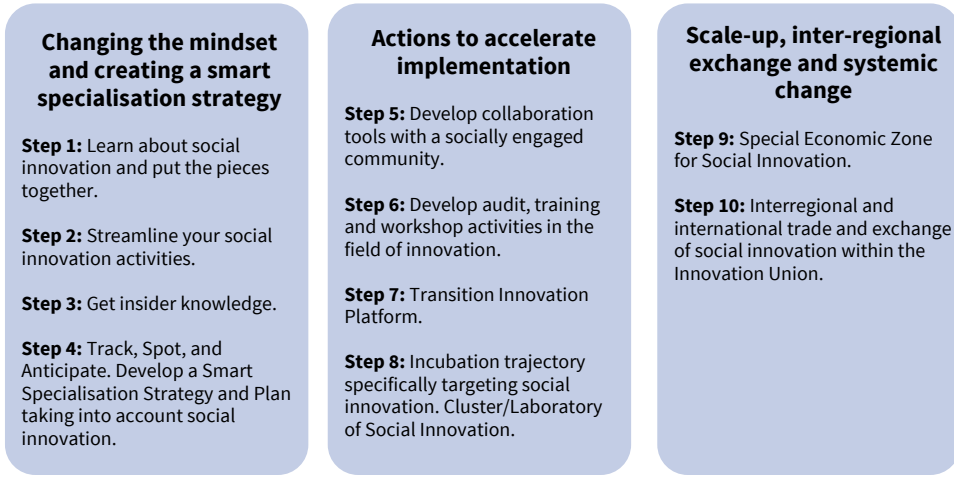
28 https://obamawhitehouse.archives.gov/administration/eop/sicp/about (accessed: 18.03.2023).

29 https://obamawhitehouse.archives.gov/administration/eop/sicp/initiatives/social-innovation-fund (accessed: 18.03.2023).

30 W. Kwaśnicki, (2014), *Jak wspierać rozwój innowacji społecznych?*, [in:] A. Olejniczuk-Merta (ed.), *Innowacje społeczne od idei do upowszechniania efektu*, Instytut Badań Rynku, Konsumpcji i Koniunktur, Warszawa, p. 29.

31 K. Zajda, (2014), *Uwarunkowania innowacji społecznych w społecznościach wiejskich i metody ich stymulowania*, [in:] E. Psyk-Piotrowska (eds), *Nowe mechanizmy rozwoju obszarów wiejskich*, Uniwersytet Łódzki, Łódź, p. 145.



Scheme 1.3. Milestones in the process of developing and implementing social innovation
Source: *Guide to Social Innovation 2013*, European Commission, p. 60.

Implementation of social innovation is carried out through the performance of activities within three basic areas: changing the way of thinking, leading to implementation and accelerating implementation, and increasing access to social innovation. The European Commission indicates that social innovation should be implemented in areas such as:

- preparation of a strategy and action plan for social innovation in connection with the region's smart specialisation strategy;
- building capacity for social innovation by supporting new organisations and adapting existing ones;
- strengthening the social innovation market and encouraging cross-sectoral cooperation by using the power of public procurement to encourage innovative and cross-sectoral approach;
- supporting innovators to start and grow through business support measures and encouraging innovation in the workplace;
- investing in new financing models at every stage of the innovation process, specifically in financing pilots, implementation and scaling;
- establishing better structures for social innovation performance measurement, evaluation, benchmarking and comparison of existing and proposed policies and projects;
- promoting exchange and learning on social innovation approach across Europe.[32]

32 European Commission, *Guide to Social…*, p. 72.

1.4. The Role of Social Innovation in Ensuring the Societal Security

The introduction of new, significantly improved products or processes is crucial for increasing efficiency and improving the societal security. The cause of innovation is often the change in products or services from the point of view of improving the safety of their users. Innovation is essential to thrive in today's competitive and dynamic global economy. For this reason, innovation has become the focus of attention of the European Commission, which, both in the previous and in the current financial perspective, are one of the most important areas of supporting the development of European regions.

The safety of innovation may be considered from two perspectives: a single use of innovation and an enterprise that implements innovation due to the desire to improve the economic standing. Both spheres are governed by law. A relevant part of the statutory law and related regulations entail executive regulations to be enforced by the public administration and authorities in order to influence market activity and the behaviour of private entities in the economy. A wide range of regulations may affect the innovation booster activity of both enterprises and even the entire economy because they directly cover such areas as: trade and customs, financial issues, corporate governance, accounting and bankruptcy, intellectual property law, health and security issues, employment and labour market, immigration, environment and energy.[33] The effects of implementing social innovation, that have an impact on the economy, society or the environment, result from the goals set in the field of innovation, aimed at external outputs, such as reducing the environmental impact of activities or improving health and security. Other headings cover the contribution of innovation to broader societal goals such as social inclusion, public safety and gender equality.[34]

Social innovation in the area of safety to a great extent addresses the improvement of the safety of inhabitants in inhabited areas, safety of products, and safety at work. As far as the first of the above-mentioned areas is concerned, in recent years, activities based on cooperation with progressive municipalities and activation of local communities to the extent of the safety of residents have been successfully completed. As an example of such activities the city of Poznań may serve, where in 2018 the process of building and increasing the safety of city residents was launched through the following initiatives:[35]

33 https://stat.gov.pl/files/gfx/portalinformacyjny/pl/defaultaktualnosci/5496/18/1/1/podrecznik_oslo_2018_internet.pdf (accessed: 02.04.2023).

34 https://stat.gov.pl/files/gfx/portalinformacyjny/pl/defaultaktualnosci/5496/18/1/1/podrecznik_oslo_2018_internet.pdf (accessed: 02.04.2023).

35 https://badam.poznan.pl/2018/ii_nasza-przestrzen/08_bezpieczenstwo/programy-w-zakresie-zwiekszenia-bezpieczenstwa-mieszkancow-poznania/ (accessed: 02.04.2023).

- "Seniors – personal safety" – the programme aimed at raising awareness among seniors about safety, experience exchange, and promotion of safety in everyday life. As part of the project, meetings were organised in housing estate clubs, senior clubs, and day care centres, during which the risks to which seniors may be exposed in everyday life were discussed. It was also indicated how to proceed in emergency cases and how to avoid them;
- "Safe district – safe resident" – under this initiative, 60 meetings were organised at police stations. The topics of the meetings covered security and public order, problems and concerns of local communities and analyses of possible actions and implementation of action plans set out by the councils of housing estates to successfully address the immediate problems;
- "Cheer safely" – the goal was to prevent problems and teenage behaviour concerns, as well as to promote correct social attitudes of young people, eliminating aggressive behaviour and promoting the principle of fair play, and thus teaching cultural participation in mass sports events;
- "School free from drugs and violence" – the aim was to introduce and implement uniform forms of cooperation among school, parents, and students as well as the police and municipal guards aimed at counteracting addiction, and in particular preventing phenomena related to drugs and violence among minors;
- "Ensuring safety in water areas" – Preventive and educational activities were carried out in cooperation with the Police, the City Guard of the City of Poznań, namely surveillance of dangerous places, including places usually used for swimming, bathing and practising water sports, and raising awareness of the risks associated with use of water areas;
- "I know how to save lives" – the aim was to expand the education and training of children and the youth through acquisition of knowledge and practical skills in the field of first aid, including particularly cardiopulmonary resuscitation;
- "Detector in every home" – the aim was to promote fire safety by running a campaign to raise awareness of the desirability of installing smoke and carbon monoxide detectors as well as gas and LPG detectors that save health and life.

Improving work safety is an increasingly conscious choice of entrepreneurs, especially in the context of improving their efficiency, economic indicators or social benefits, because a modern enterprise must meet the growing requirements, both economic and social. Occupational safety may be defined as a state of work consisting in work performance in conditions that are not hazardous to the health and life of employees. Employers' activities in the field of safety are aimed at preventing accidents at work and improving working conditions so that they do not become harmful to health.[36] Examples of solutions to increase work safety are:

36 A., Kreml, (2014), *Innowacyjność w sferze bezpieczeństwa i higieny pracy jako czynnik rozwoju biznesu*, "Państwo i Społeczeństwo Państwo i Społeczeństwo", vol. 14, no. 3, Kraków, pp. 87.

- new or significantly improved methods of creating and providing services to improve work safety;
- significant changes in hardware and software to improve work safety;
- changes in the procedures and techniques used to provide services;
- new or significantly improved techniques, devices and software in support activities;
- innovation in the organisation of the workplace – they consist in the implementation of new methods of division of tasks and decision-making powers;
- new organisational methods in the field of relations with the environment consisting in the implementation of new ways of organising relations with the environment.[37]

1.5. Possible Funding Sources for Social Innovation in the Programming Period 2021–2027

The role of innovation in the new programming period is increasing as its cross-sectoral and international nature is also emphasised. The European Commission expects national authorities to prepare research and innovation strategies to use funds more efficiently and to increase synergies between the EU and national policies and public and private investments. Smart Specialisation Strategy is the tool of the Innovation Union Initiative. It is a new concept aimed at identifying competitive advantages of regions. This strategy is to direct the development of innovation through the transfer of funds to regions where entrepreneurship is developed in accordance with the established directions of development.

Social innovation is integrated into many policy programmes and projects of the European Commission. They are implemented in particular to combat poverty and social exclusion, to stimulate entrepreneurship and social entrepreneurship, to promote employment, and to improve the well-being of the elderly.[38]

Poland is a beneficiary of the fourth perspective of the EU funds in the programming period 2021–2027. In the current financial perspective, EUR 72.2 billion will be allocated to the cohesion policy, while EUR 3.8 billion will be available from the Just Transition Fund.[39] The target measures co-funded with those funds are

37 Ibidem, pp. 90–91.

38 https://s3platform.jrc.ec.europa.eu/documents/20182/84453/Guide_to_Social_Innovation.pdf (accessed: 12.02.2023).

39 https://poland.representation.ec.europa.eu/strategies-and-priorytety/key-dzialania-eu-for-polskie/polityka-spojnosci_pl (accessed: 09.03.2023).

specified in the Partnership Agreement that defines strategic priority areas from the point of view of effective use of the EU Funds. Those priority areas include: social, economic, environmental and territorial.[40] The document in question defines 6 objectives of the cohesion policy for the programming period 2021–2027:

Goal 1: A more competitive and smarter Europe.
Goal 2: A greener, low-carbon Europe.
Objective 3: A better connected Europe.
Objective 4: A more social Europe.
Objective 5: Europe closer to citizens.
Goal 6: Mitigating the effects of the transition towards a climate-neutral economy.[41]

From the point of view of the goals met by social innovation, projects that could contribute to social development may be found in any of the above-mentioned areas. However, it should be borne in mind that each of the listed goals has a specific system of challenges that defines the strategic, common goal of all projects that will be implemented in a given area. In addition, the intended measures are specified in detail as they are to contribute to the achievement of the objective set out in the Partnership Agreement and the results that should be the effect of the actions taken in order to deliver on the strategic objectives.

The European Funds for Modern Economy Programme (FENG) constitutes one of the Programmes under which the objectives of the cohesion policy will be implemented in the years 2021–2027. The FENG is the successor to the Smart Growth Programme implemented in the previous financial perspective as the innovation booster programme dedicated to entrepreneurs. The Programme places great emphasis on research and development (R&D). Under the Programme it will be possible to finance projects responding to the greatest civilisation challenges. The support is intended for enterprises that want to develop research and development infrastructure, finance high-risk projects or support the "green" and digital transformation of enterprises. The FENG also supports joint research projects for entrepreneurs and research organisations to enable them to develop innovative ideas. The strategic objective of the FENG Programme is to increase the potential in the field of research and innovation and the use of advanced technologies, increase the competitiveness of SMEs, develop skills for smart specialisation, industrial transformation and entrepreneurship, and transform the economy towards Industry 4.0 and green technologies. The FENG priority areas cover:

- National Smart Specialisations (KIS);
- cooperation between science and business;
- support for entrepreneurs at every stage of development;
- support for the entire R&D&I process.

40 https://www.fundusze Europejskie.gov.pl/media/109449/umowa_partnerstwa_broszura_210x210_nowa_3-small.pdf (accessed: 09.03.2023).
41 Ibidem.

Table 1.8. Cohesion Policy Objectives for 2021–2027

The Goal of the Cohesion Policy	Strategic Objectives	Challenges	Planned Activities	Results
1	2	3	4	5
Goal 1: A more competitive and smarter Europe	– Increased importance of research and innovation and the use of advanced technologies; – Strengthening the potential of enterprises and public administration for a modern economy; – digitisation;	– Technological progress in all sectors of the economy; – The use of digital technologies and new business models in enterprises; – Internet speed of at least 100 Mb/s for everyone;	– Support for all stages of creating innovation in enterprises; – Digitisation of enterprises and the public sector; – Construction of an ultra-fast broadband network for all households (in rural and urban areas);	– Expansion of research, development and innovation activities of enterprises; – Increasing the automation and robotisation of enterprises; – Providing access to broadband Internet to as many households and businesses as possible.

1	2	3	4	5
Goal 2: A greener, low-carbon Europe	– Energy efficiency and reduction of greenhouse gases; – Support for the production of energy from renewable sources; – Support for energy infrastructure and smart solutions; – Adaptation to climate change; – Sustainable water and sewage management; – Circular economy and resource efficiency; – Protection of natural heritage and biodiversity; – Low-emission transport and urban mobility;	– Reducing greenhouse gas emissions; – Reduction of CO2 emissions; – Reliability and stability of energy supply; – Extreme weather phenomena; – Appropriate treatment of municipal wastewater; – Reducing the amount of waste generated; – Unsatisfactory conservation status of endangered species and natural habitats – Ensuring better access to public transport for inhabitants of urban areas;	– Improvement of energy efficiency of enterprises, residential buildings and public utility buildings; – Construction or reconstruction of the grid into smart grids that enable the receipt of energy from RES; – Investments in energy infrastructure; – Support for management and improvement of nature protection systems; – Development of infrastructure for cyclists and pedestrians as well as public transport;	– Decrease in energy consumption in the housing and business sectors; – Increase in the share of RES in final energy consumption; – Improvement of the quality and security of the functioning of the power grid; – Increase in retention capacity (also natural), including small retention; – Improving the efficiency of drinking water and municipal sewage management; – Improving the efficiency of municipal waste management; – Strengthening the protection of biodiversity and natural ecosystems; – Better organisation of collective transport in cities and improvement of its accessibility.

Table 1.8 (cont.)

1	2	3	4	5
Objective 3: A better connected Europe	– Transport;	– Reduction of deficits in the infrastructure of the transport network; – Introduction of an integrated approach to transport planning and organization; – Ensuring the availability of transport; – Reducing the number of casualties and injured people, especially in road accidents; – Reducing CO_2 emissions and the environmental impact of transport;	– Development of land and water transport infrastructure (in the Trans-European Transport Network and beyond) with priority for the development of railways; – Integration of different modes of passenger and freight transport; – Implementation of investment and educational activities in the field of security; – Implementation of investment activities in the field of charging or refuelling infrastructure for alternative fuels for zero-emission vehicles;	– Creation of a multimodal (combining different modes of transport) transport system with a high level of safety and lower environmental impact; – Reducing disproportions in the transport accessibility of Polish voivodeships; – intermodal passenger and freight transport; – Increasing the accessibility of transport points/hubs for people with reduced mobility and disabilities.

1	2	3	4	5
Objective 4: A more social Europe	– Labor market, human resources; – Education, training, skills; – Social inclusion and integration; – Healthcare; – Culture and tourism;	– Strengthening the adaptability of enterprises and employees in response to dynamic changes on the labor market; – Raising the level of skills and qualifications of the society; – Reducing poverty and social exclusion; – Greater access to health services, taking into account the differences between regions; – Strengthening the role of culture and tourism for economic; development and social cohesion;	– Activation of unused labor resources; – Disseminating and improving the quality of pre-school education; – Supporting people at risk of poverty or social exclusion; – Improving the quality of health services; – Maintenance and modernisation of cultural heritage sites;	– Higher level of employment of people in a difficult situation on the labor market; – Development of „soft" and pro-innovative competences of students; – Increasing access to services related to taking up a job or changing a profession for people at risk of poverty or social exclusion; – Increase in the quality and accessibility of health services; – Increasing the tourist attractiveness of regions and the country.

Table 1.8 (cont.)

1	2	3	4	5
Objective 5: Europe closer to citizens	– Europe closer to citizens;	– Rebuilding local economies, especially in the face of the epidemic crisis; – Little influence of local communities on the development of boroughs and districts; – Accelerating the development of areas in the most difficult socio-economic situation; – Development of competences of local authorities (planning and implementation of development policy); – Strengthening social capital; – Inverting the pyramid of health benefits;	– Actions addressed to less developed areas – strategic areas; – interventions, including medium-sized cities losing their socio-economic functions; – and areas at risk of permanent marginalization; – Supporting local governments and bottom-up initiatives in the preparation of territorial strategies; – Implementation of integrated projects; – Use of territorial instruments such as ITI, CLLD and IIT;	– Transformation of local economies; – Strengthening functional links between rural areas and cities; – Participation of local stakeholders in planning socio-economic development.

1	2	3	4	5
Objective 6: Mitigating the effects of the transition towards a climate-neutral economy	– Europe on the way to a climate-neutral economy.	– Mitigating the effects (on society, employment, the economy and the environment) of the transition to a climate-neutral economy; – Increasing the investment attractiveness of „coal" regions; – Reducing greenhouse gas emissions and increasing energy efficiency.	– Assistance for small and medium-sized enterprises in developing their activities, especially in innovative industries; – Support in the „green energy" sector and the reduction of low emissions; – Change and improvement of employees' qualifications; – Revitalisation and decontamination (decontamination) of post-mining and post-industrial areas; – Increasing the availability of selected public services.	– Modernization of labor markets in the areas of „mining transformation" understood as creating jobs in sectors unrelated to mining and conventional energy; – Preparation of investment areas in areas with mining and conventional energy; – Maintaining (or increasing) the level of professional activity of the inhabitants of the areas of „mining transformation" and limiting the phenomenon of depopulation of these regions.

Source: own study based on: https: //www.fundusze Europejskie.gov.pl/media/109449/umowa_partnerstwa_broszura_210x210_nowa_3-small.pdf (accessed: 09.03.2023).

The programme consists of four priority areas. The most important information for entrepreneurs on funding sources for innovation to be successfully implemented into the economic reality is described below.

Priority I – Support for entrepreneurs.

Specific objective: RSO1.1. Developing and strengthening research and innovation capacity and the use of advanced technologies (ERDF).

Measures designed to be financed under the specific objective cover the support provided directly to entrepreneurs (the so-called tailor-made support) as part of the possibility of implementing comprehensive projects consisting of the following modules:

- Module – R&D – The applicant may obtain funding for all or selected elements of the research process – from industrial research, through development work, including the creation of a demonstrator/prototype, testing it to the extent provided for in the GBER. Multiple stages of research and development work may be carried out under the project if it is necessary to achieve commercialisable effects. The result of the R&D module should be the development of innovation that is feasible to be implemented in business. The level of co-financing under this module is: 70% of expenditure on fixed assets, materials and construction works as well as intangible assets (the level of support results from the Regional Aid Map), 50% of expenditure on consulting services, including those supporting innovation, and 100% of expenditure on the establishment of security for the co-financing agreement.
- Module – Implementation of Innovation – under this module it is possible to finance the implementation of R&D results in the company's business operations, in the form of innovative solutions, consistent with the areas of national smart specialisations, as well as other costs directly related to the innovation implementation. R&D work may be co-financed under the "R&D" module, financed from other funds or purchased by the Applicant;
- Module – R&D Infrastructure – under this module the Applicant may obtain funding for investments in infrastructure necessary to implement the research agenda for the creation of innovative products or services consistent with the areas of national smart specialisations. The infrastructure must be used for industrial or experimental development purposes as defined in the GBER. The research agenda may be co-financed under the "R&D" module or implemented and financed entirely with other funds. As part of the implementation of projects under this module, one can receive co-financing to cover up to 70% of expenditure on fixed assets, materials and construction works, as well as intangible assets (the level of support results from the Regional Aid Map).
- Module – Competence – the support provided in this module provides for the improvement of competencies of employees and managers (related to R&D work), their acquisition of new skills and qualifications, including

qualifications included in the Integrated Qualifications System (ZSK) understood as a formal confirmation competencies held by an authorised entity or qualifications and competencies recommended by the Sectoral Competence Councils, in particular in the field of: R&D, smart specialisations, industry transformation towards the 4.0 economy, technology transfer, innovation management, commercialisation of R& D results R, competences in the field of internationalisation, protection of industrial property, digitisation, climate policy, eco-design, circular economy, low-carbon economy, as well as competences necessary to operate research infrastructure financed under a comprehensive project. As part of the implementation of projects under this module, one can receive co-financing to cover up to 70% of training expenses.

- Module – Greening of Enterprises – the aim of the support is the transformation of enterprises towards sustainable development and the circular economy, including the development of new business models. The implementation of the module is intended to change the way enterprises think about the entirety of their business operations, taking into account its environmental aspects and switching it to a circular model: from the selection of contractors and resources, through product and service design, to sustainable production and management of waste and product life cycle. The module includes support for eco-design, environmental and product life cycle assessments (Product Environmental Footprint (PEF), Life-Cycle Assessment (LCA), Environmental Technology Verification (ETV) and implementation of the related recommendations and investment support under greening enterprises.
- Module – Digitisation – the support is intended to finance investments to the extent of application of solutions aimed at digitisation in the enterprise: production, processes, products, services and business model. The support will also be used in order to increase the level of cybersecurity in enterprises. The level of co-financing in the companies of this module is: 70% of expenditure on fixed assets, materials and construction works as well as intangible assets (the level of support results from the Regional Aid Map), 50% of expenditure on consulting services, including those supporting innovation, and 80% of expenditure on with environmental protection.
- Module – Internationalisation – the purpose of the support offered under the module is the promotion of the company's products or services abroad. Support in this area may inter alia include: commercialisation of R&D results abroad, participation in international supply chains, promotion of products or services on foreign markets, obtaining protection of industrial property rights outside Poland or defending them. The support is addressed primarily to SMEs that conduct R&D&I activities. The support will also cover small mid-caps, mid-caps and other large companies. Enterprises other than SMEs

and small mid-caps may successfully obtain financial support for production investments under the condition that they cooperate with SMEs. The level of co-financing under this module is a maximum of 50% of expenses on participation in trade fairs and conferences and economic missions, a maximum of 50% of expenses covering consulting services, including those supporting innovation, and a maximum of 50% of expenses on protection/defence of industrial property rights.[42]

Priority II – Innovation-friendly environment;

Specific objective: RSO1.1. Developing and strengthening research and innovation capacity and the use of advanced technologies (ERDF).

The funds planned to finance projects under the above specific objective will address such problem areas as: increasing the ability of the science sector to cooperate, technology transfer, support for initiatives selected at the European Union level, alternative methods of financing R&D, pilot and monitoring projects, activation, networking, development of enterprises by supporting clusters, development of enterprises by supporting innovation centres and development of enterprises starting innovative activities.

Implementation of projects conducive to increasing the ability of the science sector to cooperate is aimed at supporting the mobilisation of people and institutions in the science sector to cooperate with business, as well as to international cooperation in order to increase the number of commercialised research results, improve the competence of research teams in the field of technology transfer, increase the mobility of R&B staff. The above will be implemented through the following modules:

- International Research Agendas – support for the creation and development of world-leading organisations and research teams, cooperation with a foreign partner and application of the best global practices. The support will be a systemic instrument of stabilisation. The initial allocation of funds is EUR 100 million for the years 2022–2029.
- Team projects – support for R&D work carried out by teams led by scientists from around the world in Poland (or partially abroad), carried out in partnership with a foreign laboratory (run by academic units or companies) and an entrepreneur from Poland.
- Cooperation of the best research teams in the form of consortia in selected strategic areas – support for the implementation of research agendas in areas indicated on the basis of social and economic challenges.
- Supporting the infrastructure of research organisations for the economy: the use of the existing infrastructure will be a priority; the support for projects from the Polish Map of Research Infrastructure and projects that meet i.a. criteria

42 https://www.nowoczesnagospodarka.gov.pl/media/111296/FENG_zatwiertowani_przed_KE.pdf (accessed: 09.03.2023).

indicated in the Partnership Agreement; implementation of the research agenda in line with the KIS, taking into account in particular the areas of cooperation with enterprises. As part of the investment, it is possible to launch the so-called "learning factories": educating staff/testing new solutions by entrepreneurs. Development of the competencies of the scientific and research staff, e.g. in the field of commercialisation of R&D, technology transfer, and innovation management, is an obligatory element of the projects.

Within the framework of the objective to support technology, the following measures have been programmed to be implemented:

- support aimed at preparation for the commercialisation of technological solutions (including those developed at universities and research organisations), e.g. R&D and pre-implementation work; strengthening cooperation with enterprises, also through e.g. cooperation with Sectoral Competence Councils, innovation centres, KIS working groups, long-term development of services of technology transfer centres and special purpose vehicles, and raising awareness on the importance of commercialisation among people managing a research organisation;
- improvement of business competencies of research teams at universities, verification of their compliance with market needs, also through cooperation with Sectoral Competence Councils, innovation centres, KIS working groups;
- measures to develop spin-offs, also through participation of private investors as well as to support commercialisation of solutions developed by individual innovators. Teams and companies benefiting from commercialisation-related funding source can then seek further support through development programmes and equity instruments.

Support for initiatives selected at the European Union level: The support will be awarded to the best projects selected through assessment procedures as part of calls for proposals conducted at the EU level:

- Funding projects awarded the Seal of Excellence under the HE or other EU programmes.
- Support for IPCEI projects
- Funding projects implemented by Polish partners in the areas of KIS as part of S 3 transnational partnerships.

Alternative methods of financing R&D work intended under the objective include:

- Joint research projects – support for R&D projects of enterprises and research organisations, implemented together with partners;
- Grants for Eurogrants for research organisations and entrepreneurs in order to for them to be prepared to successfully apply for funding within the framework of the EU programmes under the direct management mode;
- Innovative public procurement – new ways of financing R&D projects in the problem-driven research formula. Funding will cover R&D and technology

demonstrators, in particular related to the European Green Deal. Apart from that, Grand Challenges open to interested innovators is intended to be arranged for.

Pilot and monitoring projects, activation, networking are implemented under the objective:

- Inno_LAB – designing and testing new forms of support for broadly understood innovation, R&D and pro-innovation competencies. As part of the project, including activation activities, recommendations resulting from the work output of Sectoral Competence Councils, NSS working groups are followed;
- Project on the National Smart Specialisation – includes the process of entrepreneurial discovery as well as monitoring and evaluation of activities in the area of smart specialisations. It is also intended to undertake activities in the field of coordination and cooperation at the national and regional level, aimed at increasing the involvement of Polish entities in the international cooperation in the areas of KIS and RIS;
- Inno_Regio_lab Project: support for regions to build R&D&I capacity through knowledge exchange and networking; analysis on the development of entrepreneurship, innovation and effectiveness of regional development policy, development of assumptions for support tools in regional policy. The project may follow recommendations resulting from the work of Sectoral Competence Councils and NSS working groups.

The development of enterprises through support for clusters includes, above all, actions to support clusters (National Key Clusters and supra-regional growth clusters). It is primarily planned to strengthen human and infrastructural resources, test new services, build platforms and internationalise. The support is tailored to the level of cluster development and covers implementation of new services by clusters for companies, taking into account the recommendations of the Sectoral Competence Councils as well as the effects of the work of KIS working groups.

Development of enterprises through support for innovation centres constitutes the measure undertaken for the benefit of Innovation Centres (OI) based on a new model of the IO accreditation system to the extent of specific functionalities and consortia of technological specialisations with the participation of IO, i.e.:

- support for the development potential of entities accredited at the central level, in connection with the testing and implementation of new/improved services for entrepreneurs in the field of accredited functionality or technological specialisation;
- support for the provision of high-quality pro-innovation services by accredited consortia, including support for digital and green innovation hubs (DIH, GIH).

The development of enterprises launching innovation booster activity constitutes the measure dedicated to enterprises that do not have experience in

the implementation of R&D projects financed with the EU funds. As part of the Innovation Coach information service, development goals of potential beneficiaries of the Programme in the area of innovation will be set out and their innovative potential will be diagnosed. Then, as part of the INNOSTART Project, Innovation Coach graduates will be able to take advantage of:

- specialist consultancy in the field of concept development and preparation of the first R&D project;
- financial support for the implementation of the first R&D project for START.

2.1.1.1. Specific objective: RSO1.2. Reaping the benefits of digitisation for citizens, businesses, research organisations and public institutions (ERDF).

Measures under the specific objective include the need to increase the benefits of digitisation for businesses. An important part of the support available under the objective is to support the digital transformation of SMEs. The models indicated in this part of the programme also take into account the challenges related to the digital transformation of the economy. In this way, they contribute to the implementation of the EU Digital Strategy and other EU and national strategies in this area. In particular, this applies to the European Digital Innovation Hubs (EDIH) ecosystems and the Testing and Experimentation Facilities (TEF AI) dedicated to those issues.

2.1.1.1. Specific objective: RSO1.3. Strengthening sustainable growth and competitiveness of SMEs and creating jobs in SMEs, including through productive investment (ERDF).

Measures carried out under the above objective address i.a. the need to support SMEs to internationalise. At the same time, support for the development of innovative start-up/scale-up companies is an important part of the financial assistance available under the objective. Supporting this type of enterprises requires a variety of measures – from instruments supporting the creation of startups (popularisation and preparation to run your own enterprise, seed financing) through specialised support for the development and scaling of a selected group of startups (development programmes of an acceleration nature) to financial capital allocated to innovative companies. The implementation of models under SO1.3 thus contributes to the implementation of the EC challenge set out in the CSRs for Poland 2019 and 2020 as far as improvement of competitiveness and internationalisation of small and medium-sized enterprises is concerned.[43]

Priority III – Greening of enterprises;

2.1.1.1. Specific objective: RSO2.1. Supporting energy efficiency and reducing greenhouse gas emissions (ERDF).

Under the specific objective, measures are intended to contribute to increasing energy efficiency and reducing greenhouse gas emissions, and thus contributing to

43 https://www.nowoczesnagospodarka.gov.pl/media/111296/FENG_zatwiertowani_przed_KE.pdf (accessed: 09.03.2023).

the achievement of the objectives of the European Green Deal as well as national strategic documents.

2.1.1.1. Specific objective: RSO2.3. Development of smart energy systems and grids and energy storage systems outside the Trans-European Energy Network (TEN-E) (ERDF).

Under the objective, support will be provided for IPCEI projects – financing projects of Polish enterprises participating in the implementation of Important Projects of Common European Interest (the so-called IPCEI projects) in accordance with Art. 107 sec. 3 lit. (b) of the Treaty on the Functioning of the European Union (TFEU), as IPCEI projects are clearly innovative in light of the latest developments in the sector. Financing will cover projects that fit into the specific objective related to the development of smart energy systems and grids as well as energy storage systems, in particular projects related to hydrogen technologies. The thematic and material extent of support will be consistent with the scope of projects included in the EC decision on the IPCEI in the area of hydrogen.[44]

Priority IV – Technical Assistance.

The implementation of Priority 4 is aimed at ensuring an effective management and implementation system of the Programme. Three areas of support have been identified:

- efficient programme implementation system;
- ensuring the potential of beneficiaries, potential beneficiaries and partners;
- effective information and promotion of the Programme.[45]

On January 19, 2023 the calendar for the call for projects under the European Funds for Modern Economy (FENG) programme was approved. The amount of funds allocated is EUR 4.7 billion. In 2023, 27 competitive and 16 non-competitive calls are expected to be launched.[46] Calls for Projects will be carried out within the framework of three measures:

- Action 1.1 The SMART path
- Action 2.1 International Research Agendas
- Action 2.2 First Team
- Measure 2.4 Research Infrastructure of the Modern Economy
- Action 2.7 Proof of Concept
- Action 2.9 Seal of excellence
- Action 2.10 IPCEI
- Measure 2.12 Grants for Eurogrants

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44 https://www.nowoczesnagospodarka.gov.pl/media/111296/FENG_zatwiertowani_przed_KE.pdf (accessed: 09.03.2023).

45 Ibidem.

46 https://www.poir.gov.pl/strony/about-the-program/fe-dla-nowoczesnaj-gospodarki/aktualnosci/schedule-naborow-realizatorch-w-ramach-programu-fundusze-european-dla-nowoczesnaj-gospodarki- na-2023-r/ (accessed: 18.03.2023).

- Measure 2.25 Promotion of the brand of innovative SMEs
- Measure 2.32 Technological credit
- Measure 3.1 Ecological credit
- Operation 3.3 Hydrogen IPCEI.[47]

The FENG calls addressed to consortia of SMEs and research organisations or non-governmental organisations are:

- SMART path – i.e. developing and strengthening the research and innovation capabilities of enterprises;
- Joint Research Undertakings – i.e. measures aimed at the operations of entrepreneurs and scientific and research consortia for the purposes of implementation of R&D work to the extent of technological solutions, the need for which will be defined by the partners;
- IPCEI – a model that supports Polish entrepreneurs participating in the implementation of Important Projects of Common European Interest.

The institutions that will organise calls for proposals under respective measures are: the Polish Agency for Enterprise Development (PARP), the National Centre for Research and Development (NCBiR), the Foundation for Polish Science, Bank Gospodarstwa Krajowego (BGK). The first Calls for Projects started in the first quarter of 2023.

47 https://www.poir.gov.pl/media/113708/harmonogram_naboru_świadcz_FENG_11012023.pdf (accessed: 18.03.2023).

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Chapter 2

Footwear Innovation to Improve the Comfort of Use

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2.1. Definition of the Comfort of Footwear Users and Improvement Prospects

Footwear satisfies diverse and constantly changing human needs, and it may significantly shape the development and efficiency of the foot in both positive and negative terms. According to orthopaedic doctors, non-physiological footwear becomes the cause of many diseases and deformities of the feet, which are often irreversible. Footwear should provide for certain functions:

- Protective;
- Hygiene and comfort;
- Social and aesthetic.

The protective function is the basic function that footwear must fulfil:

- protection of the foot against mechanical factors (mechanical injuries, pressure), unevenness of the ground;
- protection of the foot against climatic factors (temperature, precipitation);
- protection against liquid agents (water, acids, alkalis, fats, salt solutions);
- protection against radiation, variability of electromagnetic fields, electrostatic impact, which are harmful to human health.

Hygiene and comfort are the properties of footwear that ensure the well-being of the wearer and the healthy condition of the foot. Footwear should also allow the feet to develop and function naturally:

- Maintenance of an optimum microclimate at foot level through ventilation and oxidation of the foot skin, permeation of water vapour from the inside to the outside, absorption and desorption of liquids and vapour, mechanical vapour transmission, internal heat dissipation;
- Antimicrobial protection;
- Providing biomechanical support and movement through internal volume and dimensions corresponding to correct static and dynamic dimensions, ensuring preservation of natural posture, anti-slip and shock absorption;
- Maintaining the health of the body through correct and anatomical design;
- Influencing the reflex points of the presopuncture.

It would be good if the footwear also fulfilled social and aesthetic functions:

- Compatibility with the current fashion;
- Retention of original aesthetic appearance as long as possible throughout the use of footwear;
- Price.

Nowadays, with the changing environment and conditions of human life, technological advancement, and especially with widespread manufacture chemicalisation, the problem of comfort and safety in the use of products, including footwear for general use, is most relevant.

The comfort of footwear use is a subjective feeling of each user and is therefore difficult to define and evaluate. The comfort of use is also called physiological comfort because it should primarily satisfy the physiological needs of the foot.[1]

Comfortable footwear should ensure the well-being of the wearer, the healthy condition of the feet and allow the feet to develop naturally and function in accordance with their physiology and working functions. Comfort is the function that applies to all types of footwear (casual, safety, work, sports). Aspects of comfort relate to the appropriate shape, size of the footwear, as well as the properties of the raw material in combination with the anthropometric characteristics that are individual for each user.[2]

Comfortable footwear is important from the point of view of psychology and overall health, as it prevents foot deformation, corns, calluses and even varicose veins. As footwear comfort is a subjective perception of the user, there are few reports on its global improvement in the related literature. The overall wearer

1 I. Duda, (2005), *Comfort and safety issues in footwear,* "Scientific Journals of the Cracow University of Economics", vol. 685, Kraków, pp. 5–18.

2 W. Serweta, J. Wójcik, M. Matusiak, K. Ławińska, B. Szałek, (2020), *Research on the Possibilities of Polymer Textile Applications as Footwear Packages to Improve Health Properties.* "Fibres & Textiles in Eastern Europe", vol. 4, no. 142, Łódź, pp. 89–94.

comfort rating scale is, among others, assessed by the Kruskal-Wallis test. In this test, patients rate shoe comfort features by means of nine categories (overall shoe comfort, heel cushioning, side-to-side support, arch height, heel fit, ball of the foot width, heel width, ball of the foot cushioning, length).[3]

In the related literature, optimal thermal conditions, an optimal microclimate inside the footwear, which is related to the selection of suitable materials (high quality, moisture absorption and wicking) constitute frequently mentioned categories of comfort improvement. A study published in the International Journal of Fashion Design assessed the footwear preferences and microclimates of footwear made of leather and mesh spacer fabric. Subjective feelings when wearing both types of footwear were investigated. Out of the 80 respondents, the majority preferred sports shoes made of mesh fabric, as leather sports shoes retained more heat and moisture on the feet. The perception of temperature, moisture, and overall comfort of the footwear is influenced by the test subjects' criteria such as gender, age, and the type of activity.[4]

The materials used for manufacturing both the shoe upper and lining as well as the innersole have the greatest impact upon the footwear thermal comfort. Diverse arrangements of materials were tested for absorption and permeability, which was closely related to the footwear comfort.[5] The authors, based on literature sources,[6, 7] assumed that the humidity inside the footwear in the range of 70–85% is partial discomfort, and above 85% it is full comfort. They defined the generalised discomfort index DI = TRH>70% • DIRH>70%, where DI was the generalised discomfort index, TRH>70% was the time during exercise when the relative humidity was higher than 70%, and DIRH>70% was the discomfort index for relative humidity higher than 70%. They carried out a statistical analysis that allowed to distinguish materials used for the shoe uppers and lining, that may minimise the perceived discomfort associated with humidity inside the footwear. They tested a variety of materials and their different combinations (Table 2.1., 2.2. and 2.3.).

3 B. Hurst, H. Branthwaite, A. Greenhalgh et al., (2017), *Medical-grade footwear: the impact of fit and comfort,* "Journal of Foot and Ankle Research", vol. 10, no. 2.

4 K. Yick, A. Yu, P. Li, (2019), *Insights into footwear preferences and insole design to improve thermal environment of footwear*, "International Journal of Fashion Design, Technology and Education", vol. 12, no. 3, pp. 325–334.

5 W. Serweta, Z. Olejniczak, M. Matusiak, (2019), *Improve of Footwear Comfort Sensation with Material Packages and Knitted Fabrics*, "FIBRES & TEXTILES in Eastern Europe", vol. 27, no. 3(135), Łódź, pp. 85–90.

6 F. Langmaier, M. Mladek, (1973), *Studie mikroklimatu obuvi*, „Kozarstvi", vol. 4, pp. 96–101.

7 F. Langmaier, (1990), *Hygiena a komfort obutenohy*, „Kozarstvi", vol. 12, pp. 345–349.

Table 2.1. Types of lining fabrics used in the study

Type of lining fabrics	Symbol	Water vapour permeability [mg/cm² h]	Water vapour coefficient, [mg/cm²]
3D knitted fabric with PA fibre	MP1	30.5 ± 4.2	245.0 ± 17.5
3D knitted 'a-jours' fabric with PA	MP2	45.8 ± 0.9	367.4 ± 6.1
Trevira	MP8	21.5 ± 1.7	173.3 ± 11.5
Knitted fabric PE (small loop)	MP39	37.7 ± 2.2	301.3 ± 3.2
Microfibre PE	MP41	21.3 ± 3.2	170.7 ± 7.1
Knitted fabric PE (bigger loop)	MP42	42.6 ± 5.2	341.7 ± 8.2

Source: W. Serweta, Z. Olejniczak, M. Matusiak, (2019), *Improve of Footwear Comfort Sensation with Material Packages and Knitted Fabrics*, "FIBRES & TEXTILES in Eastern Europe", vol.27, no. 3(135), Łódź, pp. 85–90.

Table 2.2. Types of leather lining used in the study

Type of leather lining	Symbol	Water vapour permeability [mg/cm² h]	Water vapour coefficient, [mg/cm²]
Cow split grinded leather	SP1	15.8 ± 0.8	136.0 ± 4.5
Cow leather	SP2	13.6 ± 1.1	128.3 ± 8.2
Pig grain leather	SP3	15.3 ± 0.6	113.6 ± 1.8

Source: W. Serweta, Z. Olejniczak, M. Matusiak, (2019), *Improve of Footwear Comfort Sensation with Material Packages and Knitted Fabrics*, "FIBRES & TEXTILES in Eastern Europe", vol. 27, no. 3(135), Łódź, pp. 85–90.

Table 2.3. The set of materials analysed

Group I (materials compiled with MP41)	Group II (materials compiled with MP39)	Group III (leather lining)
MP8 + MP41	MP8 + MP39	SP1
MP42 + MP41	MP42 + MP39	SP2
MP2 + MP41	MP2 + MP39	SP3
MP1 + MP41	MP1 + MP39	

Source: W. Serweta, Z. Olejniczak, M. Matusiak, (2019), *Improve of Footwear Comfort Sensation with Material Packages and Knitted Fabrics*, "FIBRES & TEXTILES in Eastern Europe", vol.27, no. 3(135), Łódź, pp. 85–90.

The best materials are given as follows: MP2 – MP41 – SW1 and MP2 – MP39 – SW1 (given above) and for components corresponding with the SW4 upper: MP2 – MP41 – SW4 (DI = 0.09) and MP2 – MP39 – SW4 (DI fluctuating around 0.10). It is worth noting that only the MP41 and MP39 materials were selected because for the other materials, that had accounted for changes in the discomfort indexes recorded after a longer time of use, namely 30-minute exertion, the changes were insignificant.

According to the minimised discomfort index, the best materials out of those tested were: SP1 (DI = 0.24), SP2 (DI = 0.36) and SP3 (DI = 0.29). SP1 regarded as the best leather lining.

The analysis of the relationship between combinations of the lining and upper materials and discomfort index values obtained on the basis of exertion simulation confirmed that differences existed and were statistically significant. The optimal choice of footwear materials may substantially minimise the footwear discomfort. It is a very important factor.

The effect of comfort on running economy and injury risk was also assessed in relation to oxygen consumption (economic perspective) and biomechanical parameters (injury perspective) during walking and running. However, this study found that an increase in comfort did not lead to a reduction in oxygen consumption and significant changes in biomechanical parameters.[8]

The primary footwear components of interest to improve performance include midsole material, weight, longitudinal bending stiffness,[9] shock absorption.[10]

Technically, shoe comfort may be defined by means of the conjugation of several factors, namely, fitting, in-shoe thermal and humidity, plantar pressure distribution and ground impact forces. Among those parameters, ground impact force is one of the most significant aspects to take into consideration in the development of comfortable shoes since it contributes to discomfort but may also induce injuries and in some cases pain.[11]

However, the definition of shock absorption is not completely consensual and the range of its acceptable values is not clear. Shock absorption properties are related to the capability of cushioning the impact of ground forces that affect human locomotion. When walking, human gait involves repeated loading (nearly 60% of

8 J. Jindorfer, J. Kröll, H. Schwameder, (2020), *Does enhanced footwear comfort affect oxygen consumption and running biomechanics?*, "European Journal of Sport Science", vol. 20, no. 4, pp. 468–476.

9 E. Day, M. Hahn, (2020), *Optimal footwear longitudinal bending stiffness to improve running economy is speed dependent*, "Footwear Science", vol. 12, no. 1, pp. 3–13.

10 R.M. Silva, J.L. Rodrigues, V.V. Pinto, M.J. Ferreira, R. Russo, C.M. Pereira, (2009), *Evaluation of shock absorption properties of rubber materials regarding footwear applications*, "Polymer Testing", vol. 28, no. 6, pp. 642–647.

11 M.W. Whittle, (1999), *Generation and attenuation of transient impulsive forces beneath the foot: a review*, "Gait Posture", vol. 10, no. 3, p. 264–275.

one's body weight is loaded abruptly, in less than 20 ms, onto the ipsilateral limb) each time the foot hits the ground in the early stance phase of the gait cycle.[12] This results in a transient force transmitted up to the skeleton, as a shock wave that runs through the human body from feet toward the upper extremities. Impact ground forces present values that may reach up to 120 and 250 percent of the person's body weight in walking and running conditions, respectively.[13] Impact loads generated during gait have been implicated in several injuries and health problems, such as stress fractures, Type 1 shin splints, cartilage breakdown, osteoarthritis, knee injuries and low back pain.[14] Proper cushioning will attenuate those impact forces and protect the musculoskeletal system from potential injury.

The heel-pad is the natural mechanism to attenuate the generated shock wave. Several studies[15, 16, 17] have been conducted in order to understand the mechanical properties of the heel pad linked to the impact force attenuation during locomotion, however the published results are still under some controversy.[18] Moreover, the common use of footwear since birth has decreased the attenuating capability of the heel-pad mechanism in absorbing the impact of ground forces.[19]

The foot-ground interface depends both on the shoe and floor material and their interaction, therefore those interfaces play an important role in providing suitable biomechanical characteristics, injury prevention and reducing discomfort.

Cellular materials (e.g. foams, ethyl-vinyl-acetate, polyurethane, etc.) are commonly accepted as materials that prove good cushioning properties, however those soft materials show lower tear strength, higher abrasion and tend to deform gradually, leading to an uncomfortable situation, and in some cases may contribute significantly to back pain, musculoskeletal disorders and injuries. Nevertheless, in

12 R. Bogey, *Gait analysis*, updated 23.02.2023, Gait Analysis: Fundamentals, Methods of Analysis, Normal Gait (medscape.com).

13 B.M. Nigg, D. Stefanyshyn, G. Cole, P. Stergiou, J. Miller, (2003), *The effect of material characteristics of shoe soles on muscle activation and energy aspects during running*, "Journal of Biomechanics", vol. 36, no. 4, p. 569.

14 R.S. Goonetilleke, (1999), *Footwear cushioning: relating objective and subjective measurements*, "Human Factors", vol. 41, no. 2, pp. 241–256.

15 P. Aerts, R.F. Ker, D. De Clercq, D.W. Ilsley, R.M. Alexander, (1995), *The mechanical properties of the human heel pad: a paradox resolved*, "Journal of Biomechanics", vol. 28, no. 11, pp. 1299–1308.

16 A. Gefen, M. Megido-Ravid, Y. Itzchak, (2001), *In vivo biomechanical behavior of the human heel pad during the stance phase of gait*, "Journal of Biomechanics ", vol. 34, no. 12, pp. 1661–1665.

17 K-J. Chi, D. Schmitt, (2005), *Mechanical energy and effective foot mass during impact loading of walking and running*, "Journal of Biomechanics", vol. 38, no. 7, pp. 1387–1395.

18 R.E. Weijers, A.G. Kessels, G.J. Kemerink, (2005), *The damping properties of the venous plexus of the heel region of the foot during simulated heelstrike*, "Journal of Biomechanics", vol. 38, no. 12, pp. 2423–2430.

19 U. Jorgensen, F. Bojsenmoller, (1986), *Joint forces in extension of the knee: Analysis of a mechanical model*, "Acta Orthopaedica Scandinavica", vol. 57, no. 1, pp. 41–46.

order for a good shock absorption behaviour in footwear, a compromise between the shock absorption properties of a material and its elasticity and resistance to fatigue has to be reached. For this reason, rubber materials are still preferred for outsole manufacture, due to their particular physical properties such as high tear and tensile strength, lower abrasion, resistance to oils and durability.[20]

Methodologies for evaluation of a material's shock absorption properties are limited in number, and none of them is completely accepted by all of the economic operators in the footwear market. Standardised methodologies can be found in the procedure A of ASTM F1614-06 (dynamic analysis)[21] and EN ISO 20344:2004-5.14 (static analysis).[22] The former one evaluates the impact response properties of athletic shoes using an impact test and the latter one is a test method for safety footwear, that evaluates the energy absorption of the seat region.

Other methodologies use a similar approach to assess the shock absorption properties of the contact surfaces. For example, the European standard EN 14808:2005[23] (based on the Berlin Artificial Athlete) defines a method of determining the shock absorption characteristics of sports surfaces by means applying a 20 kg weight that falls onto a spring placed on the tested item. In the European standard EN 1177:2008[24] and equivalent ASTM 1292:2004[25] the test methods of determining the critical fall height are defined, based on impact attenuation of surfacing playground materials.

There are also other non-standardised methodologies such as the SATRA PM 142 Shock Absorption Test Method,[26] and the IBV shock absorption testing methodology.[27] The SATRA PM 142 differs from the standardised procedure A of ASTM F1614-06 to the extent of small details in terms of the fixed anvil assembly. As far as the first method is concerned, the fixed anvil consists of a single block weighing 8.5 kg while in the case of the second one the total 8.5 kg mass includes a 200 g detachable tup. Another important difference is the geometry of the tup: the SATRA PM 142 test method uses a spherical tup while the ASTM F1614-06 test makes use of a flat tup with rounded edges. The IBV test method is a completely different approach in which a drop test machine is used for simulating the effect

20 R.M. Silva, J.L. Rodrigues, V.V. Pinto, M.J. Ferreira, R. Russo, C.M. Pereira, (2009), *Evaluation…*

21 ASTM F1614-06, *Shock Attenuation Properties of Materials Systems for Athletic Footwear*, American Society for Testing and Materials, 2006.

22 EN ISO 20344, *Personal Protective Equipment – Test Methods for Footwear* (2004).

23 EN 14808, *Surfaces for Sports Areas – Determination of Shock Absorption* (2005).

24 EN 1177*, Impact Attenuating Playground Surfacing – Determination of Critical Fall Height* (2008).

25 ASTM F1292-04, *Standard Specification for Impact Attenuation of Surfacing Materials within the Use Zone of Playground Equipment* (2004).

26 S. Tailby, (2003), *Falling mass shock absorption test "SATRA Bulletin*", October, p. 17.

27 J.V. Durá, A.C. García, J. Solaz, (2002), *Testing shock absorbing materials: the application of viscoelastic linear model*, "Sports Engineering", vol. 5, no. 1, pp. 9–14.

of the first stage of walking on materials. This method is intended to evaluate the dynamic stiffness and dissipated energy ratio.

Verdejo and Mills[28] also proposed an impact machine to analyse the changes in the mechanical response of shoe midsole foams. In their work they analysed the changes in stress-strain responses of foams under repeated impacts that simulated heel strikes. The key design parameters of the impact machine identified included the impact frequency and the peak pressure. A different approach was made by Goonetilleke and Ravinda, these authors used a 20-participant panel to evaluate the perceived levels of cushioning (PLC), which in turn was correlated with the footwear impact test results. They reported that, during walking, the magnitude of the peak deceleration on the impact tester appeared to be a good prediction of the PLC. Moreover, they concluded that impact characterisations could reveal important differences between materials and how they were perceived during activity.[29]

2.2. Antimicrobial Protection

Antimicrobial protection is one of the hygiene and comfort functions that footwear should fulfil. Bacterial and/or fungal colonisation of footwear causes detrimental effects such as user discomfort, reduced mechanical resistance of footwear materials (e.g. leather, textiles) or persistent odour from isovaleric acid that takes its origin when Staphylococcus epidermidis, the resident species of the normal bacterial flora of the skin, breaks down leucine present in sweat.[30] Therefore, functional materials with antimicrobial properties may prolong the economic life of footwear, thereby reducing costs and improving overall user comfort.[31]

A way to eliminate or inhibit the growth of microorganisms on footwear materials is, in addition to foot care and hygiene, the use of antimicrobial agents.[32] Chemical antimicrobial agents such as silver, copper oxides, zinc oxides, quaternary ammonium

28 R. Verdejo, N.J. Mills, (2004), *Simulating the effects of long distance running on shoe midsole foam*, "Polymer Testing", vol. 23 no. 4, pp. 567–574.

29 R.S. Goonetilleke, (1999), *Footwear cushioning…*

30 M.M. Sánchez-Navarro, M.Á. Pérez-Limiñana, F. Arán-Ais, C. Orgilés-Barceló, (2015), *Scent properties by natural fragrance microencapsulation for footwear applications*, "Polymer International", vol. 64, no. 10, pp. 1458–1464.

31 K. Ara, M. Hama, S. Akiba, K. Koike, K. Okisaka, T. Hagura, T. Kamiya, F. Tomita, (2006), *Foot Odour Due to Microbial Metabolism and its Control*, "Canadian Journal of Microbiology", vol. 52, no. 4, pp. 357–364.

32 M.M. Sánchez-Navarro, M.Á. Pérez-Limiñana, F. Arán-Ais, C. Orgilés-Barceló, (2015), *Scent properties…*

salts, borates, 3-iodo-2-propynyl butylcarbamate (IPBC), zinc pyrithione, etc., are used in the footwear industry. However, some of those are hazardous to the normal microflora of the foot skin and have irritant, harmful and toxic properties for the natural environment and human health. An alternative may arise from natural antimicrobial agents such as essential oils since their action against bacteria and fungi has been confirmed by numerous scientific studies.[33, 34, 35, 36, 37, 38, 39, 40]

Essential oils are extracted from plants such as cinnamon, mint, thyme, sage, clove, basil and rosemary. They are volatile substances, so when applied to materials, they have a short-lived effect, besides being chemically unstable and prone to oxidative degradation and loss of volatile compounds, especially when exposed to oxygen, light, moisture and temperature. Encapsulation of the essential oil eliminates those disadvantages with regard to the functionalisation of footwear materials, and furthermore provides controlled release properties expected by the footwear market.

Several scientific studies have shown that the encapsulation process increases the stability of essential oils by protecting them from external factors: oxygen, light radiation and reduces their volatility, giving materials a long-lasting effect. Microencapsulation plays an important role in obtaining smart textile and leather coatings.

33 Ibidem.

34 C. Chirilă, V. Deselnicu, M.D. Berechet, (2017), *Footwear Protection against Fungi Using Thyme Essential Oil*, "Leather and Footwear Journal", vol. 17, no. 3, pp. 173–178.

35 C. Chirilă, M. Crudu, V. Deselnicu, (2014), *Comparative Study regarding Resistance of Wet-White and Wet-Blue Leather to the Growth of Fungi*, "Leather and Footwear Journal", vol. 14, no. 2, pp. 107–120.

36 D.C. Deselnicu, A.M. Vasilescu, A.A. Purcarea, G. Militaru, (2014), *Sustainable Consumption and Production in the Footwear Sector*, "Leather and Footwear Journal", vol. 14, no. 3, pp. 159–180.

37 I.A. Radwan, A.H. Abed, M.R. Abeer, R.A. Ibrahim, A.S. Abdallah, (2014), *Effect of Thyme, Clove and Cinnamon Essential Oils on Candida albicans and Moulds Isolated from Different Sources*, "American Journal of Animal and Veterinary Sciences", vol. 9, no. 4, pp. 303–314.

38 T. Steviæ, T. Beriæ, K. Šavikin, M. Sokoviæ, D. Goðevac, I. Dimkiæ, S. Stankoviæ, (2014), *Antifungal Activity of Selected Essential Oils against Fungi Isolated from Medicinal Plant*, "Industrial Crops and Products", vol. 55, pp. 116–122.

39 O. Niculescu, M. Leca, Z. Moldovan, D.C. Deselnicu, (2015), *Obtaining and Characterizing of a Product with Antifungal Properties Based on Essential Oils and Natural Waxes for Finishing Natural Leathers*, "Revista de Chimie – Bucharest", vol. 66, no. 11, pp. 1733–1736.

40 E.E. Bayramoðlu, G. Gülümser, I. Karaboz, (2008), *The Investigation of Antibacterial Activities of Some Essential Oils in Wet Blue Leather*, "International Journal of Natural and Engineering Sciences", vol. 2, no. 1, pp. 33–36.

2.3. Modification of Footwear Materials By Means of Natural and Safe Substances of Antibacterial and Antifungal Properties

Essential oils have become an integral part of everyday life. They are used in a great variety of ways: as food flavouring, as feed additives, as flavouring agents in the tobacco industry, and in the compounding in cosmetics and perfumes. Furthermore, they are used in air fresheners and deodorisers as well as in all branches of medicine such as in pharmacy, balneology, massage, and homeopathy. Aromatherapy and aromachology represent a more specialised area. In recent years, the importance of essential oils as biocides and insect repellents has led to a more detailed study of their antimicrobial potential. Essential oils are also good natural sources of substances proving commercial potential as input materials for chemical synthesis.[41]

2.3.1. Safety of cinnamon, peppermint and oregano essential oils in the context of toxic effects on human health and the natural environment. Comparison with commercial preparations

A quantitative and qualitative analysis of the essential oils oregano (Bamer), cinnamon bark, peppermint (Essence) was carried out. In order to demonstrate the safety of the essential oils, it was checked whether their ingredients were classified as hazardous under the CLP (classification, labelling, packaging) Regulation, i.e. REGULATION (EC) No 1272/2008 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/200. The regulation aims to protect human health and the natural environment. For comparison, the ingredients of commercially available preparations for the preservation of leather, textiles and polymeric materials were analysed in the same way. The results are shown in Tables 2.4 to 2.6.

41 E. Schmidt, (2020), *Production of essential oils*, [in:] K. Hüsnü Can Başer, G. Buchbauer (eds), *Handbook of Essential Oils*, CRC Press, Boca Raton, p. 36.

Table 2.4. Composition and toxicity of oregano oil (Bamer) hazardous for health and the natural environment (in compliance with the CLP Regulation)

Substance/ Ingredient of the oil	Quantity [weight %]	Human Toxicity	Environmental Toxicity
pinene	0,25		
camphene	0,47		
β-pinene	1,29		
1-octen-3-ol	–		
p-cymene	4,10		
limonene	0,25	Flam. Liq. 3 Skin Irrit. 2 Skin Sens. 1 H226 H315 H317	Aquatic Acute 1 Aquatic Chronic 1 H400 H410
eucalyptol	3,87		
γ-terpinene	3,71		
linalool	4,74	Skin Sens. 1B H317	
camphor	2,49		
borneol	2,43		
4-terpineol	1,06		
α-terpineol	1,26		
thymoquinone	–		
thymol	1,11	Acute Tox. 4 * Skin Corr. 1B H302 H314	Aquatic Chronic 2 H411
carvacrol	59,41		
caryophyllene	9,91		
humulene	1,66		
unidentified	1,99		

Source: own elaboration.

Table 2.5. Composition and toxicity of cinnamon bark oil (Essence, Turkey) hazardous for health and the natural environment (in compliance with the CLP Regulation)

Substance/ Ingredient of the oil	Quantity [weight %] Cinnamon Essence (bark)	Quantity [weight %] Cinnamon Turkey (bark)	Human Toxicity	Environmental Toxicity
1	2	3	4	5
pinene	2,98	0,69		
camphene	–	0,33		

Table 2.5 (cont.)

1	2	3	4	5
benzaldehyde (almond oil)	0,71	–	Acute Tox. 4 H302	
β-pinene	1,40	0,30		
felandren	–	0,82		
cymene	2,86	1,31	Flam. Liq. 3 Skin Irrit. 2 Skin Sens. 1 H226 H315 H317	Aquatic Acute 1 Aquatic Chronic 1 H400 H410
eucalyptol	4,63	1,85		
γ-terpinene	1,09	–		
linalool	9,04	10,77	Skin Sens. 1B H317	
isoborneol	–	–		
4-terpineol	0,51	–		
α-terpineol	3,23	0,18		
cinnamaldehyde	49,42	61,07		
isosafrole	–	–		
safrole*	–	–	Carc. 1B Muta. 2 Acute Tox. 4 H350 H341 H302	
carvacrol	–	–		
p-eugenol	–	–		
α-terpinyl acetate	1,70	–		
eugenol*	1,80	5,32		
dimethyl acetal of cinnamaldehyde	0,79	–		
caryophyllene	11,52	11,27		
cinamyl acetate	0,69	2,94		
benzyl benzoate	0,04	–	Acute Tox. 4 H302	Aquatic Chronic 2 H411
unidentified	7,59	3,15		

Source: own elaboration.

Table 2.6. Composition and toxicity of peppermint oil (Essence) hazardous for health and the natural environment (in compliance with the CLP Regulation)

Substance/ Ingredient of the oil	Quantity [weight %] Mint (Essence)	Quantity [weight %] Mint (Turkey)	Human Toxicity	Environmental Toxicity
1	2	3	4	5
pinene	0,01	0,57		
β-pinene	0,02	0,89		
myrcene	–	–		
3-octanol	0,05	0,05		
limonene	0,23	–	Flam. Liq. 3 Skin Irrit. 2 Skin Sens. 1 H226 H315	Aquatic Acute 1 Aquatic Chronic 1 H317 H400 H
linalool	0,10	–	Skin Sens. 1B H317	
trans-p-mentha-2,8-dien-1-ol	0,04	–		
isopulegol	0,15	–		
isomentone	0,40	0,21		
menthone	23,59	8,38		
levomenthol	1,98	15,58		
trans-1,3-cis-1,4-menthol	19,56	11,51		
menthol	42,57	36,29		
terpinen-4-ol	–	–		
α-terpineol	1,26	0,75		
cis-dihydrocarvone	–	–		
trans-dihydrocarvone	–	–		
trans-carvone	–	–		
pulegone*	0,30	0,43		
carvone	–	–	Skin Sens. 1 H317	
piperitone	1,40	0,82		
menthol acetate	0,66	7,29		
element	0,18	0,10		
bourbonene	0,54	0,30		
longifolene	0,10	0,06		

Table 2.6 (cont.)

1	2	3	4	5
copaene	0,47	0,08		
isogermacrene	0,49	–		
germakren	0,13	0,21		
γ-cadinene	0,04	0,03		
δ-cadinene	0,11	0,08		
unidentified	5,90	16,69		

Source: own elaboration.

In Tables 2.7 to 2.9 the abbreviations used are explained in accordance with the CLP Regulation.

Table 2.7. Hazard Class and Category Code (human)

Hazard Class and Category Code (Human)	
Acute Tox. 4	Acute toxicity
Carc. 1B	Carcinogenicity
Flam. Liq. 3	Flammable liquid
Muta. 2	Germ cell mutagenicity
Skin Corr. 1B	Skin corrosion/irritation
Skin Irrit. 2	Skin corrosion/irritation
Skin Sens. 1	Respiratory/skin sensitisation
Skin Sens. 1B	Respiratory/skin sensitisation

Source: own elaboration according to the CLP Regulation.

Table 2.8. Hazard Class and Category Code (Natural Environment)

Hazard Class and Category Code (Natural Environment)	
Aquatic Acute 1	Posing a risk to the aquatic environment
Aquatic Chronic 1	
Aquatic Chronic 2	

Source: own elaboration according to the CLP Regulation.

Table 2.9. Physical, Health and Environmental Hazard Statements

Physical Hazard Statements	
H226	Flammable Liquid and Vapour
Health Hazard Statements	
H302	Harmful if swallowed.
H314	Causes severe skin burns and eye damage.
H315	Irritates the skin.
H317	May cause an allergic skin reaction.
H341	Suspected of causing genetic defects <state the route of exposure if it is definitively proven that no other route of exposure causes risk>.
H350	May cause cancer <state the route of exposure if it has been definitively proven that no other route of exposure causes the hazard>.
Environment Hazard Statements	
H400	Very toxic to aquatic organisms.
H410	Very toxic to aquatic organisms with long-lasting effects.
H411	Very toxic to aquatic organisms with long-lasting effects.

Source: own elaboration according to the CLP Regulation.

Essential oils are natural substances with multidirectional effects. There are numerous compounds in their composition, including unidentified ones. As it can be seen from the list above, most of them are completely safe and have no adverse impact on either human health or the natural environment. A few can affect human health (causing mainly skin irritation) and the natural environment, but are found in essential oils in very small quantities (tables above), which means that essential oils have no adverse impact on health and the natural environment and are completely safe.

Tables 2.10.–2.40. exhibit the composition and human and environmental toxicity of commercial preparations for the modification of leather, textiles and polymers to impart antimicrobial properties.

Table 2.10. Composition and toxicity of Sanitized T 27-22 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Silver chloride	2	–	–

Source: Safety data sheet for Sanitized T 27-22.

Table 2.11. Composition and toxicity of Sanitized T 28-28M hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Silver chloride	1,35	–	–

Source: Safety data sheet for Sanitized T 28-28M.

Table 2.12. Composition and toxicity of Sanitized TH 22-27 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
zinc pyrithione CAS:13463-41-7	15	Repr. 1B, H360D, Acute Tox. 2, H330, Acute Tox. 3, H301, STOT RE 1, H301, Eye Dam. 1, H318	Aquatic Acute 1, H400, Aquatic Chronic 1, H410

Source: Safety data sheet for Sanitized TH 22-27.

Table 2.13. Composition and toxicity of Sanitized T 99-19 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Dimethyltetradecyl [3-(trimethoxysilyl)-propyl]ammonium chloride CAS: 27668-52-6	50	–	–

Source: Safety data sheet for Sanitized T 99-19.

Table 2.14. Composition and toxicity of Ultra-Fresh DW-30 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Tiabendazole (2-(4-Thiazolyl)-1H-benzimidazole) CAS:148-79-8	15	–	Aquatic Acute 1, H400, Aquatic Chronic 1, H410
zinc pyrithione (Bis(1-hydroxy-2(1H)-pyridinethionato-O,S)-(T-4) zinc) CAS:13463-41-7	15	Repr. 1B, H360D, Acute Tox. 2, H330, Acute Tox. 3, H301, STOT RE 1, H301, Eye Dam. 1, H318	Aquatic Acute 1, H400, Aquatic Chronic 1, H410

Source: Safety data sheet for Ultra-Fresh DW-30.

Table 2.15. Composition and toxicity of Ionpure hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Silver-zinc-aluminium-boron phosphate glass/ silver-zinc oxide glass	100	–	–

Source: Safety data sheet for Ultra-Fresh DW-30.

Table 2.16. Composition and toxicity of Dezyntol [*antifungal and antibacterial agent*] hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Quaternary ammonium compounds, benzyl-C8-18-alkyldimethyl, chlorides 2 of the quaternary ammonium compounds (benzylalkyldimethyl (alkyl from C8-C22 saturated and unsaturated, tallow alkyl, coco alkyl and soya alkyl), chlorides, bromides, or hydroxides CAS:63449-41-2	5	Acute Tox. 4, H312 Acute Tox. 4, H302, Skin Corr. 1B, H314	Aquatic Acute 1, H400

Source: Safety data sheet for Dezyntol.

Table 2.17. Composition and toxicity of Acticide SR2405 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
2-Octyl-2H-isothiazole-3-one CAS:26530-20-1	6 g/100 g	Acute Tox. 2, H330, Acute Tox. 3, H311, Acute Tox., H313, Skin Corr. 1, H314, Eye Dam. 1, H318, Skin Sens. 1 A, H317	Aquatic Acute 1, H400, Aquatic Chronic 1, H410

Source: Safety data sheet for Acticide SR2405.

Table 2.18. Composition and toxicity of Acticide WB 300 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
2(Thiocyanomethylthio) benzothiazole CAS:2156-17-0	> 25%	Acute Tox. H330, Acute Tox. 4 H302, Acute Tox. 4 H312, Skin Irrit.2 H315, Eye Irrit 2 H319, Skin Sens 1 H317	Aquatic Acute 1 H400, Aquatic Chronic 1 H410
Benzenesulfonic acid, 4-C10-14-alkyl derivs, calcium salts	1–3%	Eye Dam. 1 H318, Skin Irrit.2 H315	Aquatic Chronic 3, H412

Source: Safety data sheet for Acticide WB 300.

Table 2.19. Composition and toxicity of Acticide WB 920 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
2-octyl-2H-isothiazol-3-one CAS:26530-20-1	20%	Acute Tox.3 H311, Acute Tox. 3 H331, Skin Corr. 1B H314, Eye Dam. 1 H318, Acute Tox.4 H302, Skin Sens. 1A H317	Aquatic Acute 1 H400, Aquatic Chronic 1 H410
Ethoxylated fatty alcohol	< 2,5%	Eye Dam. 1 H318	

Source: Safety data sheet for Acticide WB 920.

Table 2.20. Composition and toxicity of Busan 85 hazardous for health and the natural environment Busan 85 (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Potassium dimethyldithiocarbamate CAS:128-03-0	50 g/100 g	–	–

Source: Safety data sheet for Busan 85.

Table 2.21. Composition and toxicity of N-Silveria Quattro hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Silver CAS:7440-22-4	12%	–	–

Source: Safety data sheet for N-Silveria Quattro.

Table 2.22. Composition and toxicity of Ultracide FFOB hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
2-octyl-2H-isothiazol-3-on CAS: 26530-20-1	45	Acute Tox.3 H311, Acute Tox. 3 H331, Skin Corr. 1B H314, Eye Dam. 1 H318, Acute Tox.4 H302, Skin Sens. 1A H317	Aquatic Acute 1 H400, Aquatic Chronic 1 H410

Source: Safety data sheet for Ultracide FFOB.

Table 2.23. Composition and toxicity of NSP-200 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Silver CAS:7440-22-4	1,27–3,17	–	–

Source: Safety data sheet for NSP-200.

Table 2.24. Composition and toxicity of NSP-100 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Silver CAS: 7440-22-4	0,2–0,5	–	–

Source: Safety data sheet for NSP-100.

Table 2.25. Composition and toxicity of Parmetol S15 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
4,5-Dichloro-2-octyl-2H-isothiazol-3-one CAS:64359-81-5	10%	Acute Tox. 2, H330, Acute Tox. 4, H302, Skin Corr. 1, H314, Eye Dam. 1, H318, Skin Sens. 1 A, H317	Aquatic Acute 1, H400, Aquatic Chronic 1, H410

Source: Safety data sheet for Parmetol S15.

Table 2.26. Composition and toxicity of Proxel BD20 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
1,2-Benzisothiazol-3(2H)-one CAS: 2634-33-5	20	Acute Tox. 4, H302, Skin Irrit. 2, H315, Eye Dam. 1, H318, Skin Sens. 1, H317	Aquatic Acute 1, H400

Source: Safety data sheet for Proxel BD20.

Table 2.27. Composition and toxicity of Reputex 20 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Poly(hexamethylenebicyanoguanide-hexamethylenediamine) hydrochloride CAS:27083-27-8	20	Carc. 2, H351, Acute Tox. 2, H330, Acute Tox. 4, H302, STOT RE 1, H372, Eye Dam. 1, H318, Skin Sens. 1B, H317	Aquatic Acute, H400, Aquatic Chronic 1, H410

Source: Safety data sheet for Reputex 20.

Table 2.28. Composition and toxicity of Irgaguard F 3610 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
2-thiazol-4-yl-1H-benzoimidazole (also called thiabendazole) CAS: 148-79-8	5–15	–	Aquatic Acute 1, H400, Aquatic Chronic 1, H410

Source: Safety data sheet for Irgaguard F 3610.

Table 2.29. Composition and toxicity of Irgaguard B 1000 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
5-Chloro-2-(2,4-dichlorophenoxy) phenol (also called triclosan) CAS: 3380-34-5	100	Eye Irrit. 2, H319 Skin Irrit. 2, H315	Aquatic Acute 1, H400, Aquatic Chronic 1, H410

Source: Safety data sheet for Irgaguard B 1000.

Table 2.30. Composition and toxicity of Sodium 2-Phenylphenol sodium salt S30 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Aqueous solution of 2-phenylphenol sodium salt CAS:132-27-4	30	Acute Tox. 4, H302, STOT SE 3, H335, Skin Irrit. 2, H315, Eye Dam. 1, H318,	Aquatic Acute 1, H400

Source: Safety data sheet for Sodium 2-Phenylphenol sodium salt S30.

Table 2.31. Composition and toxicity of P&T230 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Titanium (IV) oxide CAS: 13463-67-7	5%	Carc. 2, H351	–

Source: Safety data sheet for P&T230.

Table 2.32. Composition and toxicity of Slimicide T hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
2H-1,3,5-Thiadiazine-2-thione, tetrahydro-3,5-dimethyl (also called 3,5-Dimethyl-perhydro-1,3,5-thiadiazine-2-thione)	99	–	–

Source: Safety data sheet for Slimicide T.

Table 2.33. Composition and toxicity of Germin KF hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
sodium 4-chloro-3-methylphenol	> 20	–	–
2-hydroxybiphenyl sodium salt CAS:132-27-4	7–25	Acute Tox. 4, H302, STOT SE 3,H335, Skin Irrit. 2, H315, Eye Dam. 1, H318,	Aquatic Acute 1, H400

Source: Safety data sheet for Germin KF.

Table 2.34. Composition and toxicity of Acticide TE hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
N-1H-Benzimidazol-2-yl-carbamic Acid Methyl Ester (Carbendazim) CAS:10605-21-7	2,5–10	Muta. 1B, H340, Repr. 1B, H360FD,	Aquatic Acute 1, H400, Aquatic Chronic 1, H410

Source: Safety data sheet for Acticide TE.

Table 2.35. Composition and toxicity of Acticide SR8282 hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
zinc pyrithione CAS:13463-41-7	2,5–10	Repr. 1B, H360D, Acute Tox. 2, H330, Acute Tox. 3, H301, STOT RE 1, H301, Eye Dam. 1, H318	Aquatic Acute 1, H400, Aquatic Chronic 1, H4100
N-1H-Benzimidazol-2-yl-carbamate Acid Methyl Ester (Carbendazim) CAS:10605-21-7	2,5–10	–	–

Source: Safety data sheet for Acticide SR8282.

Table 2.36. Composition and toxicity of Metasol TK 100LC hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
Thiabendazole CAS:148-79-8	20	–	Aquatic Acute 1, H400, Aquatic Chronic 1, H410

Source: Safety data sheet for Metasol TK 100LC.

Table 2.37. Composition and toxicity of Proxel GXL Antimicrobial hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
1,2-benzoisothiazolin -3-one CAS:2634-33-5	20%	Acute Tox. 4, H302, Skin Irrit. 2, H315, Eye Dam. 1, H318, Skin Sens. 1, H317	Aquatic Acute 1, H400
Dipropylene glycol CAS:25265-71-8	–	–	–

Source: Safety data sheet for Proxel GXL.

Table 2.38. Composition and toxicity of Proxel GXL Preservative hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
1,2-benzoisothiazolin-3-one CAS:2634-33-5	20%	Acute Tox. 4, H302, Skin Irrit. 2, H315, Eye Dam. 1, H318, Skin Sens. 1, H317	Aquatic Acute 1, H400
Dipropylene glycol	–	–	–

Source: Safety data sheet for Proxel GXL.

Table 2.39. Composition and toxicity of Preventol U-Tec G (DE) hazardous for health and the natural environment (in compliance with the CLP Regulation)

Active Substance	Quantity [weight %]	Human Toxicity	Environmental Toxicity
1	2	3	4
2-Phenylphenol CAS:90-43-7	30–50	Skin Irrit. 2 H315; Eye Irrit. 2 H319, STOT SE 3 H335,	Aquatic Acute 1 H400, Aquatic Chromic 1 H410

Table 2.39 (cont.)

1	2	3	4
Chlorocresol CAS: 59-50-7	30–50	Acute Tox. 4 H302, Skin Corr. 1C H314, Eye Dam. 1 H318, Skin Sens. 1B H335	Aquatic Acute 1 H400, Aquatic Chromic 3 H412
2-Octyl-2H-isothiazol-3-one CAS:26530-20-1	5–10	Acute Tox. 4 H302, Acute Tox. 3 H331, Acute Tox. 3 H311, Skin Corr. 1B H314, Eye Dam. 1 H318, Skin Sens. 1 H317	Aquatic Acute 1 H400, Aquatic Chromic 1 H410

Source: Safety data sheet for Preventol U-Tec G (DE).

Explanation of the abbreviations used in accordance with the Regulation:

Table 2.40. Hazard class and category code (human and natural environment)

Hazard class and category code (human)	
Acute Tox.	Acute toxicity
Acute Tox. 2	
Acute Tox. 3	
Acute Tox. 4	
Carc. 2	carcinogenicity
Muta. 1B	Mutagenic effect on germ cells
Skin Corr. 1	Skin corrosion/irritation
Skin Corr. 1B	
Skin Corr. 1C	
Skin Irrit. 2	Skin corrosion/irritation
Skin Sens. 1	Respiratory/skin sensitisation
Skin Sens. 1A	
Skin Sens. 1B	
Repr. 1B	Reproductive toxicity
Eye Dam. 1	Serious eye damage/irritation
Eye Irrit. 2	
STOT RE 1	Toxic effects on target organs
STOT SE 3	

Hazard class and category code (natural environment)	
Aquatic Acute 1	Posing a risk to the aquatic environment
Aquatic Chronic 1	
Aquatic Chronic 2	
Aquatic Chronic 3	

Source: own elaboration according to CLP Regulation.

Table 2.41. Health and environmental hazard statements

Health hazard statements	
H301	Toxic if swallowed.
H302	Harmful if swallowed.
H311	Toxic by skin contact.
H312	Harmful in contact with skin.
H314	Causes severe skin burns and eye damage.
H315	Skin irritation.
H317	May cause an allergic skin reaction.
H318	Causes serious eye damage.
H319	Eye irritation.
H330	There is a risk of death if inhaled.
H331	Toxic if inhaled.
H335	May cause irritation of the respiratory tract.
H341	Suspected of causing genetic defects <state the route of exposure if it is definitively proven that no other route of exposure causes risk>.
H350	May cause cancer <state the route of exposure if it is definitively proven that no other route of exposure causes the hazard>.
H351	May cause cancer <state the route of exposure if it is definitively proven that no other route of exposure causes the hazard>.
H360D	May be harmful to the child in the womb.
H360FD	May cause reproduction damage. May be harmful to the child in the womb.
H372	Causes damage to organs <state all known organs affected > through prolonged or repeated exposure <state the route of exposure if other routes of exposure are proven not to be hazardous>.

Table 2.41 (cont.)

Environmental hazard statement	
H400	Very toxic to aquatic organisms.
H410	Very toxic to aquatic organisms with long-lasting effects.
H411	
H412	

Source: own elaboration according to CLP Regulation.

Chemicals used for preserving fibre, leather, rubber and polymerised materials have diverse health and environmental effects depending on the concentration and type of active substance, as shown in the tables above. Commercial preparations, which contain the above-mentioned chemicals, are intended for the preservation of fibre, leather, rubber and polymerised materials and are officially approved for use.

When compared to essential oils, the chemicals in the formulations have far greater adverse impact on human health and the natural environment.

Only a few constituents of the oils show skin irritation: carvone, linalool, limonene, cymene.

Oregano oil made by Bamer contains 18 substances and 1.99% of them are unidentified. It contains thymoquinone, for which no percentage is given, and only three components have an effect on human health: limonene, linalool, thymol, and only two – on the aquatic environment: limonene and thymol.

Essence Company Cinnamon Bark Oil – 23 constituents and 7.59% of them remain unidentified, proving no concentration of camphene, phellandrene, isoborneol, isosafrole, safrole, carvacrol, and p-eugenol, out of which only 5 may have adverse impact on human health and 4 – on the aquatic environment.

Essence peppermint oil contains 30 ingredients and 5.9% of them remain unidentified, out of which only 3 substances are classified in the CLP Regulation as hazardous to human health (limonene, linalool, carvone) and only one is regarded as hazardous to the natural environment (limonene).

In commercial chemical preparations, the ingredients are chemicals that adversely affect human health and the natural environment and prove high concentration ranging from 1–100%. In addition, some of those substances are classified in the CLP Regulation as hazardous, not only causing skin irritation, e.g. 2-phenylphenol contained in Preventol U-Tec G, proving its concentration of 30–50%. In addition to adverse effects on skin, namely Skin Irritation 2 H315, it also causes Eye Irritation 2 H319, and causes the target organ effect: STOT SE 3 H335, and is additionally toxic to the natural environment: Aquatic Acute 1 H400, Aquatic Chromic 1 H410.

In Proxel GXL Preservative and Proxel GXL Antimicrobial, 1,2-benzoisothiazolin-3-one as the active ingredient is contained at the concentration of 20% and exhibits acute toxicity: Acute Tox. 4, being harmful if swallowed H302, and may cause skin and eye irritation or damage: Skin

Irritation 2, H315, Eye Damage 1, H318, Skin Sensitivity 1, H317. Moreover, the so-called isothiazolinones (1,2-benzisothiazolinone-3-one and 2-methyl-4-isothiazolin-3-one) cause contact allergy and have been withdrawn from "leave-on" cosmetic products (e.g. creams), being permitted in "rinse-off" cosmetic products (shampoos) and in construction and household chemicals.

In Acticide TE the active ingredient is 2-octyl-2H-isothiazol-3-one (2.5–10%) that may have mutagenic effects on germ cells Muta. 1B, H340 and reproductive toxicity Repr. 1B, may impair fertility and may cause harm to the unborn child H360FD. The hazard classification of the chemical components of commercial preparations used for preserving fibre, leather, rubber and polymerised materials is much more hazardous than that of the components of essential oils, and besides, the concentrations of substances that can cause hazards are incomparably higher. Only preparations containing silver: Sanitized T27-22 and Sanitized 28-28M, are not hazardous and have no effects on human health and the natural environment according to the CLP Regulation. However, silver and its compounds, especially in the nano size, can migrate through human cell membranes and consequently deposit in internal organs. Silver Nanoparticles derived from, for example, antiseptic dressings has been shown to migrate into the blood[42] and cause toxic effects on cells and organs[43] in result of entering the body through various routes. Therefore, the safety of its use is limited. Furthermore, by separating from the substrate, it migrates into water bodies where it adversely impacts the development of flora and fauna.

Essential oils are mixtures of compounds that cause far less impact on human health and the natural environment than commercial preparations containing synthetic chemicals. The constituents in essential oils that may adversely impact health and the natural environment are found in small quantities and may mainly cause skin irritation. Chemicals in commercial preparations used for preserving leather, fibre, and polymers are found in high concentration and, in addition to skin irritation, may cause more serious consequences, such as harmful effects on fertility, harmful effects on the unborn child. In addition to their function, that can also be achieved through the use of chemical synthetic preparations (antimicrobial), essential oils impart an aromatic function to the modified material, which is definitely an added value.

One of the objectives of the Cornet Project "Development of microbiologically active, user and environment friendly materials for the light industry" was to develop a method for microencapsulating essential oils and applying the resulting

42 A. Bacciarelli, M. Kołodziejczyk, E. Rybicki, (2008), *Wpływ nanocząstek srebra na funkcjonowanie organizmu człowieka*, Materiały seminaryjne z XXIX Seminarium Polskich Kolorystów.

43 J. Zhang, F. Wang, S.S.K. Yalamarty, N. Filipczak, Y. Jin, X. Li, (2022), *Nano Silver-Induced Toxicity and Associated Mechanisms*, "International Journal of Nanomedicine", vol. 26, no. 17, pp. 1851–1864.

microencapsulations to light industry materials. During the project, it was shown that cinnamon oil has suitable antibacterial and antifungal properties for the protection of footwear materials. It inhibits the growth of micro-organisms and does not disturb the normal microflora of the foot's skin and was therefore selected for further work as a safe substance with no adverse impact on the natural environment or human health.

Cinnamon oil is extracted from cinnamon (Cinnamomum zeylanicum and Cinnamon cassia – a tropical tree belonging to the Lauraceae family) by means of steam distillation. It has a delicate, slightly sweet fragrance and is characterised by its strong antiseptic action. It may be used for preventing foot and nail fungus. In addition, it disinfects and kills skin-unfriendly bacteria. Promotes skin regeneration in cases of inflammation and reduces it.[44]

Footwear manufacturers, in order to meet consumer demands, are constantly looking for functional innovation that may account for a quality product upgraded with additional functions. The encapsulation of active substances including essential oils is the process that will give footwear materials new functions, such as antimicrobial, repellent, fragrance, extended performance, among others. Furthermore, the choice of ingredients used for modifying the materials arising from a group of natural substances that are safe for the environment and the user is an added value that fits in the global environmental and climate protection policy, a part of which is the use of raw materials from renewable sources.

Essential oils being the core of the capsule and mixtures of biopolymers, e.g. polysaccharides and proteins as the envelope, are ideal raw materials derived from renewable sources,[45, 46, 47] which will provide the modified material with additional functions without adversely affecting the natural environment or human health.

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44 G.R. Mallavarapu, S. Ramesh, R.S. Chandrasekhara, B.R.P. Rao, P.N. Kaul, A.K. Bhattacharya, (1995), *Investigation of the essential oil of cinnamon leaf growth at Bangalore and Hyderabad*, "Flavour and Fragrance Journal", vol. 10, pp. 239–242.

45 N. Devi, M. Sarmah, B. Khatun, T. Maji, (2017), *Encapsulation of active ingredients in polysaccharide-protein complex coacervates*, "Advances in colloid and interface science", vol. 239, pp. 136–145.

46 M. Semenova, (2017), *Protein-polysaccharide associative interactions in the design of tailor made colloidal particles*, "Current Opinion in Colloid and Interface Science", vol. 28, pp. 15–21.

47 C. Michon, F. Vigouroux, P. Boulenguer, G. Cuvelier, B. Launay, (2000), *Gelatin/iota carrageenan interactions in non-gelling conditions*, "Food hydrocolloids", vol. 14, no. 3, pp. 203–208.

2.4. Encapsulation as a method of extending the activity of active ingredients applied to light industry materials

2.4.1. Basic Encapsulation Concepts

The encapsulation process involves the entrapment of a substance (active substance) in a carrier material (wall material). The encapsulated material can be referred to as the core, filling, active, internal or loading phase. The encapsulating material is generally referred to as a coating, membrane, envelope, capsule, carrier material, outer phase or matrix.

Encapsulation is defined as a technology in which the active ingredient is contained in a core surrounded by a polymer matrix that produces a capsule.[48]

The purpose of encapsulation is to:

- protect the active compound from environmental factors (light, temperature, moisture, inappropriate pH, etc.) that affect the stability and stability of the active substance,
- release the active compound in a controlled manner at a specific pH and temperature so that the active compound acts at its intended location,
- facilitate the handling of the active compound due to the protection provided by the polymeric matrix,
- reduce or eliminate the unpleasant taste or odour of the active compound or any of the core materials,
- reduce the volatility of the active ingredient.

Many special properties can be imparted to materials through the application of microcapsules, the core of which may be any substance that fulfils specific functions, e.g. antibacterial, antifungal, repellent, therapeutic, moisturising, aromatising, or anti-inflammatory. The quality of microcapsules is influenced by many factors, including preparation techniques, core types and types of wall material.[49] [50] [51] [52]

48 S. Rani, A. Goel, (2021), *Microencapsulation technology in textiles: A review study*, "The Pharma Innovation Journal", vol. 10, no. 5, pp. 660–663.

49 B.B. Podgornik, S. Šandríc, M. Kert, (2021), *Microencapsulation for Functional Textile Coatings with Emphasis on Biodegradability—A Systematic Review*, "Coatings", vol. 11, no. 11, p. 1371.

50 A. Tulshyan, E. Dedhia, (2021), *An overview of microencapsulation technology in the application of aroma and antibacterial finishes*, "International Journal of Home Science", vol. 7, no. 1, pp. 34–39.

51 S. Bansode, S. Banarjee, D. Gaikwad, S. Jadhav, R. Thorat, (2010), *Microencapsulation: A review*, "International Journal of Pharmaceutical Sciences Review and Research", vol. 1, no. 2, p. 43.

52 A. Chanana, M.K. Kataria, M. Sharma, A. Bilandi, (2013), *Microencapsulation: Advantages in applications*, "International Research Journal of Pharmacy", vol. 4, no. 2, pp. 1–5.

Based on the size of the capsules or particles produced, encapsulation is referred to as microencapsulation and nanoencapsulation. Each has specific features that distinguish them from one another.

Microencapsulation is defined as the encapsulation into particles between 1 μm and 1000 μm in size. Microencapsulation is characterised by a prolonged, gradual release of the active ingredient, allowing for the effect to persist over a longer period of time.

Nanocapsules typically have a particle size of 50 nm to 500 nm, and have a larger surface area for the same volume. Due to their small size, nanocapsules can be easily and homogeneously distributed in liquids. Micro- and nanoencapsulation are usually used for encapsulating a single active compound.[53, 54, 55, 56, 57]

2.4.2. Microencapsulation Techniques

The most commonly used microencapsulation techniques include lyophilisation, spray drying and coacervation.

Lyophilisation involves drying at low temperature, usually below 40°C. It is used for active compounds and encapsulating materials that are temperature-sensitive.[58] Lyophilisation reduces the degradation of the core and matrix substances and increases the encapsulation efficiency of the active compound. In this technique, the encapsulating materials and active compounds are homogenised in an aqueous solution until they are fully hydrated, then the solution is lyophilised. Microencapsulates obtained by freeze-drying are characterised by the lack of size uniformity and a smooth surface, which, according to some authors, may hinder the release of active substances.[59]

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53 E. Assadpour, S.M. Jafari, (2019), *Advances in spray-drying encapsulation of food bioactive ingredients: from microcapsules to nanocapsules*, "Annual Review of Food Science and Technology", vol. 10, pp. 103–131.

54 B. Prakash, A. Kujur, A. Yadav et al., (2018), *Nanoencapsulation: an efficient technology to boost the antimicrobial potential of plant essential oils in food system*, "Food Control", vol. 89, pp. 1–11.

55 Y.P. Timilsena, T.O. Akanbi, N. Khalid et al., (2019), *Complex coacervation: principles, mechanisms and applications in microencapsulation*, "International Journal of Biological Macromolecules", vol. 121, pp. 1276–1286.

56 R. Pisano, A. Arsiccio, L.C. Capozzi et al., (2019), *Achieving continuous manufacturing in lyophilization: technologies and approaches*, "European Journal of Pharmaceutics and Biopharmaceutics", vol. 142, pp. 265–279.

57 S.A. Mahdavi, S.M. Jafari, E. Assadpoor et al., (2016), *Microencapsulation optimization of natural anthocyanins with maltodextrin, gum Arabic and gelatin*, "International Journal of Biological Macromolecules", vol. 85, pp. 379–385.

58 M. Przybysławska, K. Winnicka, (2012), *Technologie otrzymywania mikrokapsułek*, „Farmacja Polska", vol. 68, no. 4, pp. 283–289.

59 Rani, S., Goel A., (2021), *Microencapsulation technology…*

Spray drying involves drying at high temperature, generally above 100°C, to convert a liquid solution into microencapsulated powder of controlled size and morphology. The disadvantage of using spray drying is that it can damage the active compound and the encapsulating materials, mainly due to the high temperature in the drying chamber. Therefore, when choosing a spray drying technique for microencapsulation, it is necessary to evaluate and select the ideal temperature for the process. Spray drying is a continuous and economical process that produces dry particles of good quality and is carried out in spray dryers that are now widely available.[60]

Coacervation is the most commonly used microencapsulation technique. This process involves the separation of phases in a colloid or polymer solution and the formation of two or more liquid phases. The 'rich' colloid phase is the coacervate. Phase separation occurs under the influence of a change in temperature, pH or salt addition. Due to the way the process is carried out, a distinction is made between simple and complex coacervation.[61]

Simple coacervation involves a single envelope material, using gelatine as an example. The process involves combining an aqueous gelatine solution with an alcoholic oil solution under appropriate mixing parameters and temperature. The microcapsules are precipitated with acetone or through addition of e.g. sodium sulphate, which facilitates the formation of a polymeric envelope around the core.[62] Simple coacervation is achieved by changing the parameters that cause molecular dehydration of macromolecules, e.g. temperature change, pH change, through addition of ions or insoluble substances. The core should be compatible with the carrier and insoluble in the coacervation environment.

Complex coacervation is a method using two types of wall materials with opposite ionic charges. By mixing the two wall materials, their solubility is reduced due to the mutual attraction of positive and negative charges, which solidify and precipitate, and the core material is encapsulated. This method is typically used for encapsulating liquid substances susceptible to oxidative degradation. The main compounds used for complex coacervation are polysaccharides and proteins,[63] both of which are polymers with opposite charges that form the envelope.

The complex coacervation process consists of 5 steps: polymer dissolution, emulsion, coacervation, curing and rinsing/filtering/drying.

Among the parameters that can change during the coacervation process are: pH, temperature, ionic strength of each encapsulating material, compatibility of the

60 S.G. Bayryamov, (2020), *Microencapsulation of natural oils by a coacervation technique using gelatin as shell material*, "Journal of Chemical Technology and Metallurgy", vol. 55, no. 6, pp. 1985–1989.

61 Y.P. Timilsena, T.O. Akanbi, N. Khalid et al., (2019), *Complex coacervation…*

62 C.E. Sing, (2017), *Development of the modern theory of polymeric complex coacervation*, "Advances in Colloid and Interface Science", vol. 239, pp. 2–16.

63 N. Devi, M. Sarmah, B. Khatun, T. Maji, (2017), *Encapsulation of…*

encapsulating material, concentration of each encapsulating material, amount of salts possibly added, homogenisation rate of the encapsulating materials and active compound. All these variables have an impact on the performance of the process, so it is necessary to investigate the optimal conditions for each encapsulating material.[64] [65]

The authors of the study emphasise that, once the encapsulation methodology is developed, compound coacervation is highly reproducible, scalable, economical, does not require highly specialised equipment and allows for high encapsulation efficiencies of the active compound (> 99%), thus reducing wastage.

The choice of microencapsulation method depends on specific applications and parameters, such as the required particle size, physicochemical properties of the core and coating materials, release mechanisms, process cost, etc.[66]

2.4.3. Encapsulating/Coating Materials

Coating materials are substances that are used for ensuring the appropriate structure of microcapsules. The characteristics of an ideal encapsulating material for a microcapsule include: biodegradability, non-reactivity with the core material (chemical inertness), ability to tightly retain the core inside the capsule, ability to form maximum protection of the core against adverse factors (moisture, light, temperature, oxygen, etc.), plasticity. The most commonly used encapsulating materials are mainly natural and synthetic polymers, such as starch, dextrins, sucrose, cellulose, chitosan, gum arabic, alginate, carrageenan. They can also include fatty substances such as paraffin, waxes, monoglycerides and diglycerides, hydrogenated oils and fats, as well as inorganic materials such as calcium sulphate and silicates, and proteins such as gluten, casein, gelatine and albumin. The capsule shell is made up of one or more of the substances listed above.

Gelatine is a protein material obtained by partial hydrolysis of collagen. Depending on the type of hydrolysis carried out, a different type of gelatine is produced. Type A gelatine is obtained by acid hydrolysis, mainly from pig skin, and type B gelatine is obtained by alkaline hydrolysis, mainly from animal bones and skin.[67] Typically, gelatine is used for microencapsulating bioactive compounds by means of coacervation in combination with polysaccharides[68] e.g. alginate, carrageenan.

Carrageenans constitute a family of linear, sulphated polysaccharides (galactans) extracted from marine organisms – the red algae, Gigartinales.

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64 L. Lin, J.M. Regenstein, S. Lv et al., (2017), *An overview of gelatin derived from aquatic animals: properties and modification*, "Trends in Food Science & Technology", vol. 68, pp. 102–112.

65 N. Devi, M. Sarmah, B. Khatun, T. Maji, (2017), *Encapsulation of…*

66 S.G. Bayryamov, (2020), *Microencapsulation of…*

67 L. Hilliou, (2021), *Structure-Elastic Properties Relationships in Gelling Carrageenans*, "Polymers", vol. 13, no. 23, p. 4120.

68 C. Michon, F. Vigouroux, P. Boulenguer, G. Cuvelier, B. Launay, (2000), *Gelatin/iota carrageenan…*

There are three types of carrageenan most commonly used: kappa (κ), iota (ι) and lambda (λ), having two and three sulphate ester groups. Among them, κ-carrageenin is the most commonly produced and used due to its high gelling ability caused by the C4 conformation of 3,6-anhydro-D-galactopyranosyl, which forms a helix-like structure. The formation of the helix structure is facilitated by the huge number of -OH groups that form many hydrogen bonds. The commercial importance of carrageenans results from their thermo-reversible gelling ability.[69] The electrostatic interaction between gelatine and ι-carrageenan in aqueous solutions, at pH below the isoelectric point of the protein, leads to the formation of polyelectrolyte complexes through complex coacervation.[70, 71]

Chitosan is a linear polysaccharide obtained by deacetylation of chitin. Chitin is a naturally occurring polymer found in the shells of shrimps and other crustaceans. The structure of chitosan consists of a deacetylated part (β-(1,4)-D-glucosamine) and an acetylated part (N-acetyl-D-glucosamine).

Chitosan owes its wide range of applications to its safety, non-toxicity, biocompatibility, biodegradability and other unique properties, such as its film-forming ability and antimicrobial activity. Those properties provide for a broad spectrum of chitosan applications: antimicrobial/antifouling coatings, controlled-release coatings and microcapsules, hydrogels for drug delivery, and tissue engineering.[72]

Alginate is a polysaccharide extracted from marine algae, mainly brown algae (Phaeophyceae).[73] Alginates are naturally occurring polysaccharide copolymers consisting of ß-D-mannuronic (M-blocks) and α-L-guluronic acid (G-blocks) residues linked together by glycosidic bonds. The interaction of alginates with divalent cations, especially Ca^{2+}, leads to the formation of gels. The distinctive molecular structure resulting from those interactions is defined by the 'eggs-box' model ('egg in an egg-box' or 'egg stamping'), where homopolymeric G-blocks form three-dimensional ordered regions in which Ca2+ ions are embedded like eggs in a cardboard box.[74] Immediate gelation of alginate, when combined with

69 M.A.R.D. Fauzi et al., (2021), *Preparation, Properties and Potential of Carrageenan-Based Hard Capsules for Replacing Gelatine: A Review*, "Polymers", vol. 13, no. 16, p. 2666.

70 P.S. Bakshi, D. Selvakumar, K. Kadirvelu, (2020), *Chitosan as an environment friendly biomaterial – a review on recent modifications and applications*, "International Journal of Biological Macromolecules", vol. 150, pp. 1072–1083.

71 H.H. Tonnesen, J. Karlsen, (2002), *Alginate in drug delivery system*, "Drug Development and Industrial Pharmacy", vol. 28, no. 6, pp. 621–630.

72 N. Emmerichs, J. Wingender, H.-C. Flemming, C. Mayer, (2004), *Interaction between alginates and manganese cations: identification of preferred cation binding sites*, "International Journal of Biological Macromolecules", vol. 34, pp. 73–79.

73 J. Tu, S. Bolla et al., (2005), *Alginate microparticles prepared by spray-coagulation method: preparation, drug loading and release characterization*, "International Journal of Pharmaceutics", vol. 303, no. 1–2, pp. 171–181.

74 Q. Cheng, L. Yan, (2005), *Nonwoven substrate finishing with essence microcapsules,* "AATCC Review", vol. 8, pp. 46–48.

calcium ions, results in the formation of particles with diverse diameters and porosity.[75] Alginate microcapsules containing essential oil have been applied to non-woven fabrics used as substrates in the production of synthetic leather.[76]

Cyclodextrins (CDs) are cyclic oligosaccharides consisting of glucopyranose units linked by α-(1,4)-acetal bonds. Commonly used natural cyclodextrins are α-, β- and γ-cyclodextrins consisting of 6, 7 and 8 glucopyranose units, respectively. Cyclodextrin molecules have a unique structure with a hydrophobic cavity and a hydrophilic surface that can form an inclusion complex with guest compounds. This property allows for cyclodextrins to be used in microencapsulation processes. Studies have shown that this method is one of the most effective options to ensure the protection of active compounds from oxidation, thermal degradation or evaporation.[77]

2.4.4. Release Methods

Release from microcapsules may be planned and triggered by external stimuli:

- rupture of the microcapsule wall under mechanical stress, using external pressure;
- diffusion of the substance constituting the microcapsule core after degradation of the wall, caused by chemicals or enzymes, by external factors, e.g. temperature, pH level, light;
- extraction of the microcapsule core material by placement in a suitable solvent;
- rupture of the microcapsule wall by swelling of the core substance.

While the rate of release of the substance contained in the microcapsule depends on:

- the type of polymer from which the wall is formed;
- the thickness of the wall;
- the diameter of the microcapsule.

If the microcapsules are bonded to the fibrous structure with a binding agent, the release of the contents of the microcapsules depends not only on the parameters of the microcapsule but also on the properties of the agent.[78, 79, 80]

75 J.F. Ayala-Zavala, H. Soto-Valdez, A. González-León et al., (2008), *Microencapsulation of cinnamon leaf (Cinnamomum zeylanicum) and garlic (Allium sativum) oils in b-cyclodextrin*, "Journal of Inclusion Phenomena and Macrocyclic Chemistry", vol. 60, pp. 359–368.

76 S. Jothi Sri et al., (2012), *Microencapsulation: A Review*, "International Journal of Pharma and Biosciences", vol. 3, no. 1, pp. 509–531.

77 A. Valdes, M. Ramos, (2018), *Recent Trends in Microencapsulation for Smart and Active Innovative Textile Products*, "Current Organic Chemistry", vol. 22, no. 12, pp. 1237–1248.

78 B.B. Podgornik, S. Šandríc, M. Kert, (2021), *Microencapsulation for…*

79 B. Boh, E. Knez, (2006), *Microencapsulation of essential oils and phase change materials for applications in textiles products*, "Indian Journal of Fibre and Textile Research", vol. 31, no. 1, pp. 72–82.

80 N. Singh, J. Sheikha, (2020), *Microencapsulation and its application in production of functional textiles*, "Indian Journal of Fibre & Textile Research", vol. 45, pp. 495–509.

2.4.5. Application of Microcapsules to Light Industry Materials

Published studies reveal several technologies for the incorporation of microcapsules into materials. The most common way is to disperse microcapsules in a binding agent and then apply this dispersion to a fabric (non-woven or knitted fabric) by means of various techniques: surfacing, coating, laminating, printing, nozzle spraying.[81, 82, 83, 84, 85, 86]

The disadvantage of using a bonding agent is that the performance of the products may be impaired. To ensure a permanent bond to the fibre structure, the amount of bonding agent used must be sufficiently large. However, a large amount of binding agent increases the stiffness of the fabric, deteriorates its grip, reduces air permeability and water vapour permeability, and reduces thermal resistance. The binding agent may also interfere with the controlled release of the active substance.

Microcapsule walls coated with a binding agent may offer too much resistance to wear and tear. The layer of binding agent may also interfere with the release of the active substance from the microcapsule when the wall is torn.

A method of bonding microcapsules to the fibre surface analogous to the fibre/reactive dye bond is sometimes used. In order to achieve such a bond, the polymer from which the encapsulant is formed must have reactive groups capable of forming covalent bonds with functional groups of the fibre polymer (e.g. with a hydroxyl group in the case of cellulosic fibre). This way of linking microcapsules to the fibre structure ensures more effective control of the release of the active substance from the textile product. The microcapsules obtained by polycondensation at the interface are immobilised by chemical bonding after modification of the envelope surface. It is possible to chemically bind microcapsules to the fibre of natural and synthetic polymers. This method of incorporating microcapsules into fibre does not require the use of binding agents. The bonding of microcapsules to the textile remains permanent even after 20 washes.

Another method of incorporating microcapsules into a fibre structure involves integrating microcapsules into the matrix of the polymer from which the fibre is formed. Fibre containing microcapsules is currently manufactured, the components

81 A. Tulshyan, E. Dedhia, (2021), *An overview of…*

82 Rani, S., Goel A., (2021), *Microencapsulation technology…*

83 A. Nadi, A. Boukhriss, A. Bentis, E. Jabrane, S. Gmouh, (2018), *Evolution in the Surface Modification of Textiles: A Review*, "Textile Progress", vol. 50, pp. 67–108.

84 B. Boh Podgornik, M. Starešiníc, (2016), *Microencapsulation Technology and Applications in Added-Value Functional Textiles*, "Physical Sciences Reviews", vol. 1, no. 1, pp. 20150003.

85 M. Starešiníc, B. Šumiga, B. Boh, (2011), *Microencapsulation for Textile Applications and Use of SEM Image Analysis for Visualisation of Microcapsules*, "Tekstilec", vol. 54, pp. 80–103.

86 G. Nelson, (2002), *Application of Microencapsulation in Textiles*, "International Journal of Pharmaceutics", vol. 242, pp. 55–62.

of which are the so-called phase change materials (PCMs), i.e. materials capable of changing their state of aggregation within a certain temperature range called the phase change temperature. They are used for manufacturing the so-called 'smart textiles' that have a thermoregulatory effect due to the absorption or emission of heat depending on the temperature change.

In the process of manufacturing functional textiles, microencapsulation aims to improve properties or impart new functionalities, resulting in broader usability and higher added value of products.

The main functionalities achieved by microencapsulation in textile coatings *inter alia* include thermochromic and photochromic effects, flame retardancy, improved thermal regulation, UV absorption, insecticidal and insect repellent effects, prolonged fragrance release, antimicrobial properties.

The Functionalisation of textiles with microcapsules containing natural essential oils (EOs) is an ecological solution. Those exhibit a broad spectrum of antimicrobial and biological activity and, depending on their chemical composition, can exhibit repellent, antibacterial, antifungal, UV-protective and other properties.

Manufacture of environmentally friendly biodegradable textiles containing biodegradable microcapsules is one of the biggest challenges for textile functionalisation research.

The physical and chemical properties of microencapsulation methods based on natural polymers (chitosan, gum arabic and gelatine or biodegradable synthetic polymers such as PLA) have been used for the purpose of the research, the outcome of which has been published so far.

In the textile industry, microcapsules can be applied to fibre, yarn and fabric-based techniques such as impregnation, spray, pad-dry-cure and screen printing.

One of the main obstacles to the widespread use of biodegradable microcapsules in functional textiles is their unsatisfactory durability and resistance to washing, wiping and light, which are crucial for textile care and sustainable functionality.

Further research should focus on the possibility of introducing new biodegradable materials as microcapsule envelopes and coating compositions with improved property technology or the use of functional groups on the microcapsule envelope to allow covalent bonds to be formed with the functional groups of biodegradable textiles, so that higher adhesion between microcapsule and fibre can be achieved.

For textile applications, essential oils can be encapsulated through simple coacervation with e.g. gum arabic,[87] ethyl cellulose[88] or through complex

87 R. Sharma, A. Goel, (2018), *Development of insect repellent finish by a simple coacervation microencapsulation technique*, "International Journal of Clothing Science and Technology", vol. 30, no. 2, pp. 152–158.

88 G.C. Türkoğlu, A.M. Sariişik, G. Erkan, H. Kayalar, O. Kontart, S. Öztuna, (2017), *Determination of antioxidant capacity of capsule loaded textiles,* "Indian Journal of Fibre & Textile Research", vol. 42, pp. 189–195.

coacervation with e.g. chitosan/gum arabic,[89, 90] gelatine/gum arabic,[91] gelatine/carboxy cellulose.[92]

Few companies offer microcapsules dedicated to textiles in order to ensure the presence of active substances with a specific effect. Textiles modified with microcapsules of a suitable composition allow for a prolonged, slow or controlled release of active substances, the possibility of transferring those active substances to the skin, and the possibility of immobilising the capsules on the fibres.

In the leather industry, many additives and functional agents are known which, when applied to the skin, effectively perform their functions. Such additives, depending on their nature, can be applied using a number of different processes depending on the type of functional preparation. As in the case of textiles, the effective long-lasting effect of functional additives dedicated to leather can be achieved by encapsulating them.[93]

In the footwear industry, the incorporation of encapsulated antimicrobial substances into leather materials or components will allow for the creation of active footwear, which will contribute to improvement of user comfort, satisfaction of customer needs and expectations by eliminating odours generated during footwear use, incorporating controlled odour release chemical substance or preventing degradation and improving durability.

Buket et al.[94] showed that orange oil microparticles obtained by spray drying and applied to leather shoe insoles exhibited natural antibacterial properties.

2.4.6. Development of the Microencapsulation Method for Cinnamon Oil

Essential oils are volatile compounds with a core coating that slows down their release, prolonging their effect.

Preliminary studies were carried out to select the most favourable composition of the cinnamon oil microcapsule matrix in terms of form and encapsulation

89 A. Sharkawy, I.P. Fernandes, M.F. Barreiro, A.E. Rodrigues, T. Shoeib, (2017), *Aroma-Loaded Microcapsules with Antibacterial Activity for Eco-Friendly Textile Application: Synthesis, Characterization, Release, and Green Grafting*, "Industrial & Engineering Chemistry Research", vol. 56, no. 19, pp. 5516–5526.

90 M.M. Sánchez-Navarro, M.Á. Pérez-Limiñana, F. Arán-Ais, C. Orgilés-Barceló, (2015), *Scent properties…*

91 F.M. Bezerra, O.G. Carmona, C.G. Carmona, M.J. Lis, F.F. de Moraes, (2016), *Controlled release of microencapsulated citronella essential oil on cotton and polyester matrices*, "Cellulose", vol. 23, no. 2, pp. 1459–1470.

92 M.Á. Pérez-Limiñana, F.J. Payá-Nohales, F. Arán-Ais, C. Orgilés-Barceló, (2013), *Effect of the shell-forming polymer ratio on the encapsulation of tea tree oil by complex coacervation as a natural biocide*, "Journal of Microencapsulation", vol.31, no. 2, pp. 176–83.

93 R. Painter, US-6685746-B1, *Impregnation of leather with micro-encapsulated material*.

94 B. Yılmaz, H.A. Karavana, (2020), *Application of Chitosan-Encapsulated Orange Oil onto Footwear Insock Leathers*, "Johnson Matthey Technology Review", vol. 64, no. 4, p. 443.

efficiency. The microcapsules were prepared through a complex coacervation method derived from published but modified methods.

The following polymer blends were selected for testing:

- a mixture of gelatine A and K-carrageenan;
- a mixture of gelatine A and K-carrageenan and calcium chloride;
- a mixture of gelatine and gum arabic;
- a mixture of chitosan and gum arabic;
- β-cyclodextrin.

The analysis of the microencapsulation methods has proven a variety of encapsulation efficiencies and microencapsulation shapes depending on the matrix used. The images obtained from the microscope highlight the different structure of the microcapsules obtained and suggest that they may have diversified mechanical resistance. The microscopic image of the capsules containing dextrin as a matrix (Figure 2.1.) illustrates that the powder particles have irregular shapes and diversified size, which may result in lower mechanical strength.

The image of the microcapsules with the gelatine/carrageenan/$CaCl_2$ matrix reveals spherical structures largely assembled into agglomerates (Figure 2.2.). The most favourable capsules have been obtained with the gelatine/carrageenan matrix (Figure 2.3.). They have the smallest size, spherical, regular and smooth shapes, and the highest yield of 72% has been obtained with this process. This method had been selected for optimisation that was followed by the reproducibility and efficiency test on an enlarged scale.

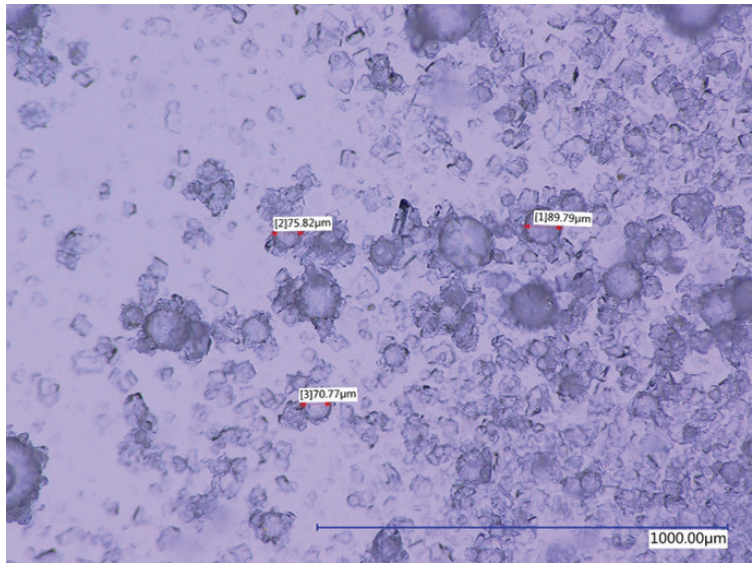

Figure 2.1. Microcapsules characteristic of the β-cyclodextrin content as the encapsulating material (Keyence digital microscope)
Source: own elaboration.

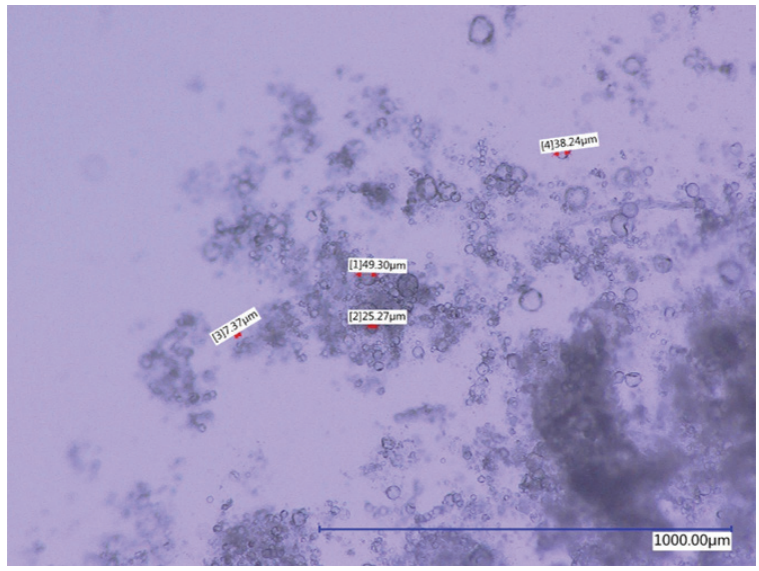

Figure 2.2. Microcapsules characteristic of the gelatine/carrageenan/$CaCl_2$ content as encapsulating material (Keyence digital microscope)
Source: own elaboration.

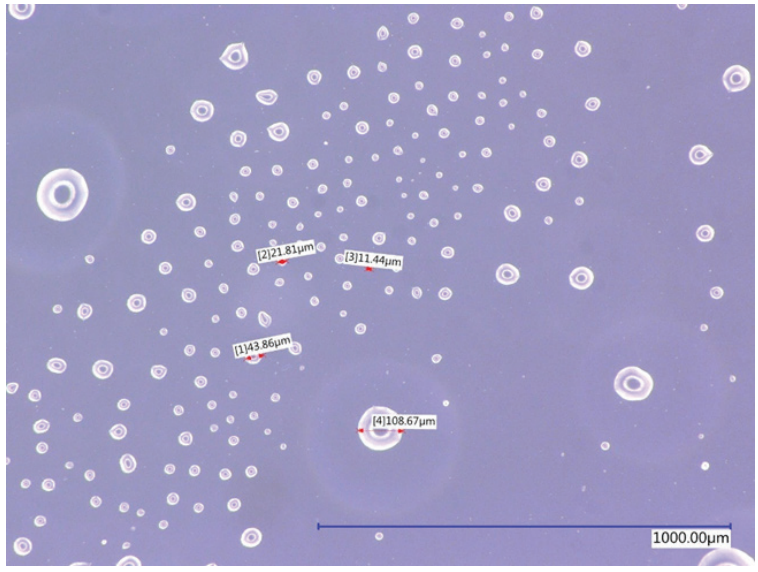

Figure 2.3. Microcapsules characteristic of the gelatine/carrageenan content as the encapsulating material (Keyence digital microscope)
Source: own elaboration.

As part of the optimisation study, the encapsulation of cinnamon oil, using gelatine/carrageenan as the matrix, has been carried out under diverse conditions set by varying the polymer and oil content with the physico-chemical parameters (volume, temperature, pH, mixing, homogenisation and separation conditions) in the preliminary study.

General Synthetic Procedure

5, 10, 15 ml of cinnamon oil was dispersed at 50°C in a solution of 50 ml in volume containing 2.5 g of gelatine. The mixture was stirred by means of a mechanical stirrer at the stirring rate of 400 rpm at 50°C for 30 min to produce a stable oil-in-water emulsion.

250 ml of 0.2 or 0.5% carrageenan solution at 45–50°C and pH = 7 adjusted with 1M NaOH solution was added into the produced emulsion.

Maintaining a constant temperature of 50±2°C, the emulsion was stirred at the stirring rate of 400 rpm for 15 min. The pH of the emulsion was then brought to 4.0 by adding a 1 M HCl solution to stabilise the polymers. At this pH value, gelatine was positively charged and k-carrageenan negatively charged. To allow for coacervation, the emulsion was stirred at the stirring rate of 400 rpm for 1.5 h. At the end of coacervation, the heating was turned off and 600 ml of cold deionised water was added, and the system was then cooled down to 5–10°C in an ice bath.

Under those conditions, gelatine and carrageenan surrounded the oil droplets and microcapsules were formed. Curing of the microcapsules was carried out through slow stirring for 2 h at the stirring rate of 300 rpm and storage at 4°C for 24 h.

The resulting microcapsules were filtered and washed by means of 20 ml of water.

The effect of oil loading variation, polymer concentration on microcapsule behaviour is summarised in Table 2.42.

Table 2.42. Average Values for Microencapsulation Yield and Effectiveness

Amount of Oil (g)	Amount of Gelatine (g)	K-karagen n (g)	Micro-encapsulation Yield (%)	Micro-encapsulation Effectiveness (%)	Method of Separation and Observations
5	2,5	0,5	72	51,2	Slow filtration
10	2,5	0,5	91	68,6	Very fast filtration
15	2,5	0,5	_	_	Emulsion, no phase separation
5	2,5	1,25	60	31,5	Slow filtration
10	2,5	1,25	82	46,7	Slow filtration
15	2,5	1,25	_	_	Emulsion, no phase separation

Source: own elaboration.

Within the framework of the trials conducted, the highest coacervate yields (%) were obtained with the gelatine/carrageenan encapsulating polymer weight ratio of 5:1 and the use of 10 g of oil.

Given those weight ratios and the target conditions, the interaction between the two polymers was top efficient, resulting in the maximum amount of insoluble coacervate that was produced.

2.4.7. Application of Microcapsules to Carrier Materials (Leather, Cotton)

Light industry materials (cotton fabric, wet blue leather) were used for the purpose of applying manufactured microcapsules containing cinnamon oil providing for microbiological protection.

The padding process involved Keeper cotton fabric of 260 g/m^2 in surface weight, that had been pre-washed at the boiling point in a bath containing the anionic surfactant Rokanol O18 (1g/l), and wet-blue leather of 830 g/m^2 in surface weight.

The process of applying the capsules to the fabric was carried out through batch processing by means of a Foulard laboratory surfacing machine with adjustable roller pressure.

Pre-washed cotton fabric of 10 x 25 cm in size and leather of 10 x 25 cm in size were impregnated in the in the padder at 25°C using a water bath containing gelatine-carrageenan microcapsules.

In order to evaluate the effective bioactive effect depending on the amount of microcapsules applied, surfacing baths were prepared to use three concentrations of microcapsules: 10, 20, 30 g /l.

The samples in the surfacing baths were maintained for 30 min.

They were then destained between the surfacer rollers at a pressure of the rollers allowing for a post-padding weight gain of 190–200% in relation to dry weight. After surfacing, the samples were air-dried to avoid possible damage to the microcapsules.

2.4.8. Microbiological Activity of Materials Modified with Microcapsules Containing Cinnamon Oil

The samples obtained were subjected to microbiological tests for the presence of bacteria and fungi (E.Cola, S.aureus, A.niger, C.albicans, Ch.globosum) according to the following procedures:

Procedure 1. Testing the antibacterial properties of leather and fabric surfaced with essential oil encapsulated in microcapsules against two bacterial strains.

Objective of the study: To determine the antibacterial activity of the tested leather and fabric against two bacterial strains: Escherichia coli, Staphylococcus aureus.

Test method: PN-EN ISO 20645:2006 "Flat textile products. Determination of antimicrobial activity. Diffusion method on agar plate."[95]

Principle of the method: Working samples are placed on two-layer agar plates. The lower layer contains only agar, the upper layer – agar inoculated with a bacterial suspension of a certain density. Both sides of the product are tested. After the incubation period, the zone of bacterial growth in the contact zone between the agar and the test specimen and the zone of growth inhibition around the test specimen, if found, are assessed.

Test microorganisms: Escherichia coli ATCC 8739, Staphylococcus aureus ATCC 9144.

Dimensions and number of working samples: Circular specimens of (25±5) mm in diameter were cut. Two specimens were used for each test strain for fabric-testing one side of the product due to homogeneity of the material and two specimens for each test strain for leather-testing both sides of the product.

Preparation of the bacterial suspension: Bacteria were activated by inoculation onto TSA agar medium (Tryptic Soy Agar). Agar plates were incubated 18–24h at 37±1°C. After the incubation period, bacterial suspension from the culture cultivated on TSA agar was prepared in 0.85% saline. The density of the suspension, determined densitometrically, was 0.77 McF for E. coli and 0.98 McF for S. aureus, which is within the range of 1–5x108 cfu/ml, respectively.

Performance of the assay: TSA (Tryptic Soya Agar) medium was prepared first. The medium was sterilised in an autoclave at 121°C for 30 min. It was then poured into previously prepared petri dishes. At the same time, 150 ml of TSA medium in a bottle was prepared for each test strain and inoculated with 1 ml of a fixed density bacterial suspension. The bacterial medium was poured onto the surface of the agar plates with the agar medium already solidified and the tested working samples were placed on the solidified two-layer agar. The test was carried out on both sides of the product in the case of leather, placing the specimens once with the face and once with the flesh on the agar surface. In the case of fabric, the test was carried out on one side due to the homogeneity of the material.

Incubation: Incubation was carried out for 24 h at 37°C ±1°C.

Growth assessment: Bacterial growth was assessed according to the applicable standard (Table 2.43.). Bacterial growth in the contact zone between the agar and the working sample was assessed and the zone of growth inhibition around the working sample was measured.

95 PN-EN ISO 20645:2006, *Płaskie wyroby włókiennicze. Wyznaczanie aktywności antybakteryjnej. Metoda dyfuzji na płytce z agarem*.

Table 2.43. Assessment of Bacterial Growth

Inhibition Zone	Growth	Description	Assessment
>1	lack	Inhibition zone above 1 mm, lack of growth	Good effect
1–0	lack	Inhibition zone up to 1 mm, lack of growth	
0	lack	No inhibition zone, lack of growth	
0	low	No inhibition zone, only some colonies limited in number, growth stopped almost completely	Limited efficiency
0	medium	No inhibition zone, half the increase as compared to the control group	No effect
0	strong	No inhibition zone, no reduction in growth as compared to the control group, or only a slight reduction in growth	

Source: own elaboration.

Procedure 2. Testing the antifungal properties of leather and fabric surfaced with essential oil encapsulated in microcapsules against three fungal strains.

Objective of the study: To determine the antifungal activity of the tested leather and fabric against three fungal strains: A. Niger, C. Albicans, Ch. Globosum.

Test method: PN-EN 14119:2005 Textile testing. Assessment of microfungal activity. Method B1 and method B2.[96]

Principle of the method: Working samples are treated with a standard mixture of test fungal spores on a complete agar medium (the agar medium contains a carbon source). The tested fungi can grow on the agar medium and on the article if the article has not been treated with an antifungal agent. The fungi test outcome is assessed by determining their growth rate (determination of the antifungal effect).

Test microorganisms: Aspergillus niger ATCC 6275, Candida albicans ATCC 10231, Chaetomium globosum ATCC 6205.

96 PN-EN 14119:2005, *Badania tekstyliów. Ocena działania mikrogrzybów. Metoda B1 oraz metoda B2.*

Dimensions and the number of working samples: METHOD B1: Specimens of 2.5 cm x 8 cm in size were cut and then trimmed to reach the width equivalent to 2 cm. Two specimens from each type of fabric and leather were tested. METHOD B2: Specimens of a circular shape and 30 mm in diameter were cut. Two specimens from each type of test fabric and leather were used for testing.

Preparation of the spore suspension: Fungi were activated by streaking from agar slants onto fresh Potato Dextrose Agar (PDA) plates and cultured for 6 days (29±1°C). The fungi were then streaked onto agar slants with PDA medium and incubated for 14 days at 29±1°C. The cultures prepared in this way served the basis for the spore suspension prepared by means of a solution of mineral salts ($NaNO_3$ – 2.0 g; KH_2PO_4 – 0.7 g; K_2HPO_4 – 0.3 g; KCl – 0.5 g; $MgSO_4$ x $7H_2O$ – 0.5 g; $FeSO_4$ x H_2O – 0.01 g; distilled water – 1000 ml) with a wetting agent (Tween 80). For that purpose, 5 ml of the salt solution with the wetting agent was placed in test tubes and the culture surface was gently scraped with a sterile microbiological loops. The tube was shaken to obtain an aqueous spore suspension. The suspension was then shaken with sterile glass beads and was swirled sequentially on sterile gauze pads to separate the mycelial fragments. The suspension was poured into to sterile 15 ml phalcones and centrifuged (6,000 rpm, 10 min). The supernatant was decanted and the pellet resuspended in a fresh mineral salt solution. The spores were centrifuged and washed 3 times then resuspended in 40 ml of mineral salts so that the spore concentration estimated using the Thoma Counting Chamber reached 10^6 in 1 ml.

Test Procedure:

METHOD B1: First, a complete mineral medium was prepared. For this purpose, the following salts solutions were dissolved in 1000 ml of distilled water: $NaNO_3$ – 2.0 g; KH_2PO_4 – 0.7 g; K_2HPO_4 – 0.3 g; KCl – 0.5 g; $MgSO_4$ x $7H_2O$ – 0.5 g; $FeSO_4$ x H_2O – 0.01 g. The agar added in the amount of 20g/l was then dissolved in a hot bath. Finally, glucose was added at 20 g/l. It was all sterilised in an autoclave at 121°C for 30 min. The medium was then poured into the previously prepared petri dishes. The test working samples were placed on the solidified complete agar medium. Then 0.5 ml of the spore suspension (spore suspensions of the three strains, mixed in a 1:1 ratio) was pipetted evenly onto the surface of each working sample.

METHOD B2: In respect of each separate test strain, 1 ml of spore suspension for was added to 100 ml of still liquid complete agar medium. This was mixed to distribute evenly in the agar medium in order to be poured onto the surface of petri dishes. This was allowed to solidify, after which the working samples were placed on the surface of the solidified agar.

Incubation: Incubation was carried out for 14 days at 29°C±1°C.

Growth assessment: Fungal growth was assessed according to the standard. The degree of fungal growth on the test sample as well as the zone of growth inhibition around the sample were assessed (Table 2.44.).

Table 2.44. Assessment of fungal growth on working samples

The degree of growth	Assessment
0	No visible growth assessed by microscope (50x)
1	Growth clearly visible under the microscope
2	Visible growth, covering up to 25% of the tested area
3	Visible growth, covering up to 50% of the tested area
4	Visible growth, covering more than 50% of the tested area
5	Strong growth, covering the entire tested area

Source: own elaboration.according to PN-EN 14119:2005

Table 2.45. Assessment of fungal growth on the agar around the samples

The degree of growth	Assessment
0	No visible growth assessed by microscope (50x)
1	Growth clearly visible under the microscope
2	Growth visible, intensity up to 25% of control grow
3	Visible growth, intensity up to 50% of control growth
4	Significant growth, intensity greater than 50% of control growth.
5	Strong growth, intensity the same as control growth.

Source: own elaboration according to PN-EN 14119:2005

The bioactive properties of textile (T-1, T-2, T-3) and leather (S-1, S-2, S-3) in respect of the concentration of microcapsules in the surfacing bath are shown in Table 2.46.

A very good and good microbiological and antifungal effect was achieved with as little as 10% of microcapsules in the drip. This value was assumed to be optimal for modification on an industrial scale.

Table 2.46. Microbiological activity of materials modified with microcapsules containing cinnamon oil in respect of the concentration of microcapsules in the bath

Sample	Microcapsules concentration in the bath (g/l)	Increase in weight of materials (g)	Amount of oil in capsules (g)	Bioactivity				
				E. Coli	*S. Aureus*	*A. Niger,*	*C. Albicans*	*Ch. Globosum*
1	2	3	4	5	6	7	8	9
T-1	10	8,3	6,15	Growth under sample: none Inhibition zone: 5.5 mm; Very good antibacterial effect	Growth under sample: none Inhibition zone: 7.5 mm; Very good antibacterial effect	No growth on fabric. On agar, growth covering up to 25% of the tested area. Good antifungal effect. Almost complete inhibition of growth of the test strain.	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete growth inhibition of the test strain.	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete growth inhibition of the test strain.
T-2	20	11,87	8,87	Growth under sample: none Inhibition zone: 7.0 mm; Very good antibacterial effect	Growth under sample: none Inhibition zone: 10.0 mm; Very good antibacterial effect	No growth on fabric. On agar, growth covering up to 50% of the tested area. Good antifungal effect.	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete inhibition of growth of the test strain.	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete growth inhibition of the test strain.

1	2	3	4	5	6	7	8	9
T-3	30	13,1	9,68	Growth under sample: none Inhibition zone: 9.5 mm; Very good antibacterial effect	Growth under sample: none Inhibition zone: 12.0 mm; Very good antibacterial effect	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete growth inhibition of the test strain.	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete growth inhibition of the test strain.	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete growth inhibition of the test strain.
S-1	10	5,6	4,18	Growth under sample: none Inhibition zone: Flesh 7.5 mm Face 9.0 mm Very good antibacterial effect	Growth under sample: none Inhibition zone: Flesh 6 mm Face/Grain 10 mm Very good antibacterial effect	No growth on fabric. On agar, growth covering up to 50% of the tested area. Good antifungal effect.	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete growth inhibition of the test strain.	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete growth inhibition of the test strain.
S-2	20	7,42	5,52	Growth under sample: none Inhibition zone: Flesh 10 mm Face 8.5 mm Very good antibacterial effect	Growth under sample: none Inhibition zone: flesh 8.5 mm Face 10.5 mm Very good antibacterial effect	No growth on fabric. On agar, growth covering up to 25% of the tested area. Good antifungal effect. Almost complete inhibition of growth of the test strain.	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete growth inhibition of the test strain.	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete growth inhibition of the test strain.

Table 2.46 (cont.)

1	2	3	4	5	6	7	8	9
S-3	30	9,5	7,00	Growth under sample: none Inhibition zone: Flesh 14.5 mm Face 11.5 mm Very good antibacterial effect	Growth under sample: none Inhibition zone: Flesh 13.5 mm Face 14.0 mm Very good antibacterial effect	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete growth inhibition of the test strain.	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete growth inhibition of the test strain.	No growth on fabric and agar as assessed under the microscope (over 50x). Very good antifungal effect. Complete growth inhibition of the test strain.

Source: own elaboration.

2.4.9. Durability of Carrier Materials Modified by Means of Microcapsules

Tests were also carried out on the durability of microcapsule-modified carrier materials. Samples of modified knitwear and leather were weighed and placed in a Pol Eko KKS 115 Top plus climate chamber-temperature 35°C and relative humidity 50%. Exposure time of the samples was 24 hours. The content of active substances that remained on the carrier was then examined by means of the solvent extraction and the chromatographic analysis (GC-MS). The values were related to the spray-modified samples – the content of the applied oil identical to that of the oil in the microcapsules – calculated on the basis of the microencapsulation efficiency, the concentration of the microcapsules in the surfacing bath, and the weight gain of the materials after the application process. The study shows that cinnamaldehyde remained in both the spray-modified sample and the microcapsule-modified sample after the accelerated ageing processes. This was 25.84% in the leather sample, 24.05% in the fabric sample (spray method) and 43.81% in the leather sample and 76.7% in the knitted fabric sample (microcapsule modification with cinnamon oil) in relation to the amounts applied. While the results for the spray-modified samples are similar for leather and knitwear, for the microcapsule-modified samples significantly more of the active substance remained on the knitwear (the looser structure of the knitwear resulted in immobilisation of the active substance microcapsules within the fibre network). In addition, the microbiological activity of skin and knitwear modified with cinnamon oil microcapsules subjected to accelerated ageing was confirmed. In the case of the leather sample, the zone of inhibition of 4.5 mm in size was observed for Staphylococcus aureus and for Escherichia coli it was 2.5 mm in size, while in the case of the knitted fabric, the zone of 7 mm in size was observed for both Staphylococcus aureus and Escherichia coli. The samples tested also showed a very good effect against C. Albicans, Ch. Globosum and A. Niger. No growth of any of those microorganisms was observed on their surface or around the working samples. The conducted analyses demonstrated the durability of the bioactive finish of the carrier materials with cinnamon oil encapsulated in a gelatine-carrageenan microcapsule.

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2.5. Self-cleaning Properties of Light Industry Materials Exemplified by Cotton Fabric and Velour Leather – Inspired by Nature[97]

The self-cleaning effect is related to the following concepts developed by scientists: TiO_2-based superhydrophilic self-cleaning, lotus effect self-cleaning, gecko setae-derived self-cleaning, and underwater organisms-inspired antifouling self-cleaning. The self-cleaning mechanism depends on the superhydrophilicity or superhydrophobicity of the surface. In the case of the superhydrophilic surface, water droplets can spread and form a thin layer on the surface that washes away contaminants as it flows off. The self-cleaning mechanism caused by superhydrophobicity, as exemplified by the so-called lotus effect, is associated with the presence of numerous microtubes on the modified surface.[98] The presence of microtubes results in a smaller contact area between the surface and the water droplets, allowing the water droplets to roll over the surface, collecting the contaminants from the surface.[99, 100, 101, 102] The self-cleaning properties of the surface are of great interest due to the wide range of applications in various industries (textile, construction, sanitary appliances, car parts – car body, mirrors, photovoltaic panels, cameras, mobile phones, cosmonautics, etc.).[103] In the textile industry, self-cleaning fabric is mainly based on surface modification with TiO_2 or SiO_2 nanoparticles. One of the methods of applying nanoparticles (nano-TiO_2 or nano-SiO_2) to fabric is the sol-gel method. Nanoparticles are produced by acidic or alkaline hydrolysis in the presence of the so-called precursors. Precursors are most often organic salts of the appropriate metals (e.g. titanium isopropoxide, tetraethyl orthosilicate). The produced nanoparticles have a high surface area to volume ratio and high surface

97 I. Masłowska-Lipowicz, A. Słubik, (2023), *Novel method of obtaining textile fabrics with self-cleaning and antimicrobial properties*, "The Journal of The Textile Institute", Vol. 114:10, 1509–1517, DOI: 10.1080/00405000.2022.2131954

98 Ibidem.

99 K. Liu, L. Jiang, (2012), *Bio-Inspired Self-Cleaning Surfaces,* "Annual Review of Materials Research", vol. 42, pp. 231–263.

100 Y. Shao, J. Zhao, Y. Fan, Z. Wan, L. Lu, Z. Zhang, W. Ming, L. Ren, (2020), *Shape memory superhydrophobic surface with switchable transition between "Lotus Effect" to "Rose Petal Effect"*, "Chemical Engineering Journal", vol. 382, 122989.

101 M.S. Hasan, M. Nosonovsky, (2020), *Lotus Effect and Friction: Does Nonsticky Mean Slippery?*, "Biomimetics", vol. 5, p. 28.

102 Z. Chan-Juan, T. Dan, H. Ji-Huan, (2018), *What factors affect lotus effect?*, "Thermal Science", vol. 22, pp. 1737–1743.

103 C.H. Han, B.G. Min, (2020), *Superhydrophobic and Antibacterial Properties of Cotton Fabrics Coated with Copper Nanoparticles through Sonochemical Process*, "Fibers Polymers", vol. 21, pp. 785–791.

energy, thanks to which they show a high affinity for fabric.[104] Additionally, the use of photocatalytic nano-TiO_2 gives textile the function of photocatalytic cleaning. In this type of fabric, contamination is broken down by UV radiation.[105, 106, 107, 108]

Self-cleaning cotton fabric with dual functions of superhydrophobicity and photocatalytic activity using micro-hierarchical TiO_2 particles was developed by Pakdel. Fluorine-free coating formulations composed of flower-like particles, either TiO_2 or nitrogen-doped TiO_2, and polydimethyl siloxane (PDMS) polymer were applied to cotton fabric using a facile dip-coating method. The produced coatings on the cotton fabric were characterised by excellent superhydrophobicity with the water contact angle of 156.7° ± 1.9°. In addition, the coated fabric showed a highly efficient photocatalytic effect, breaking down absorbed stains after 30 minutes of irradiation.[109] Chauhan et al. investigated the self-cleaning efficiency of cotton fabric surface by modifying with non-fluorinated hexadecyltrimethoxysilane solution (HDTMS). This modified cotton fabric showed repellency to water and liquids with a static contact angle greater than 150° and tilt angle less than 10°,[110] while the method of obtaining a superhydrophobic coating on cotton fabric by simply immersing in TiO_2 nanoparticles and perfluorodecyltriethoxysilane solution is described in the article by Tudu and his co-workers. The obtained coating, apart from superhydrophobic and self-cleaning properties, was characterised by excellent mechanical durability, chemical and thermal stability[111] whereas the facile, mild and low-cost approach of the fabrication of self-cleaning cotton textile was proposed by Liu et al. The fabric surface was coated with pure

104 M. Krifa, C. Prichard, (2020), *Nanotechnology in textile and apparel research – an overview of technologies and processes*, "The Journal of The Textile Institute", vol. 111, pp. 1–16.

105 Z. Altangerel, B. Purev-Ochir, A. Ganzorig, T. Tsagaantsooj, G. Lkhamsuren, A. Choisuren, G. Chimed, (2020), *Superhydrophobic modification and characterization of cashmere fiber surfaces by wet coating techniques of silica nanoparticles*, "Surfaces and Interfaces", vol. 19, 100533.

106 J. Wan, L.H. Xu, H. Pan et al., (2021), *Green water-based fabrication of SiO_2-TiO_2 aerogels with superhydrophobic and photocatalytic properties and their application on cotton fabric*, "Journal of Porous Materials", vol. 28, pp. 1501–1510.

107 M. Diaa, A.G. Hassabo, (2022), *Self-Cleaning Properties of Cellulosic Fabrics (A Review)*, "Biointerface Research in Applied Chemistry", vol. 12, pp. 1847–1855.

108 Z. Wu, K. Fang, W. Chen, Y. Zhao, Y. Xu, C. Zhang, (2021), *Durable superhydrophobic and photocatalytic cotton modified by PDMS with TiO_2 supported bamboo charcoal nanocomposites*, "Industrial Crops and Product", vol. 171, 113896.

109 E. Pakdel, H. Zhao, J. Wang et al., (2021), *Superhydrophobic and photocatalytic self-cleaning cotton fabric using flower-like N-doped TiO_2/PDMS coating*, "Cellulose", vol. 28, pp. 8807–8820.

110 P. Chauhan, A. Kumar, B. Bhushan, (2019), *Self-cleaning, stain-resistant and anti-bacterial superhydrophobic cotton fabric prepared by simple immersion technique*, "Journal of Colloid and Interface Science", vol. 535, pp. 66–74.

111 B.K. Tudu, A. Sinhamahapatra, A. Kumar, (2020), *Surface Modification of Cotton Fabric Using TiO_2 Nanoparticles for Self-Cleaning, Oil-Water Separation, Antistain, Anti-Water Absorption and Antibacterial Properties*, "ACS Omega", vol. 5, pp. 7850–7860.

TiO_2 nanoparticles through a sol-gel method catalysed by glacial acetic acid and then modified by (heptadecafluoro-1,1,2,2-tetrahydrodecyl) triethoxysilane. Such a modification led to produce a surface with self-cleaning properties in relation to solid contaminants, everyday liquids, oil, and even organic pollutants, assigning a synergistic function of superhydrophobicity and photocatalysis of TiO_2 nanoparticles.[112] [113] There are also known methods for obtaining self-cleaning coatings by coating photocatalytic zinc oxide nanoparticles (nano-ZnO)[114], [115] or titanium dioxide nanoparticle (nano-TiO_2)[116] [117] [118] on cotton surfaces using the traditional dip-pad-dry-cure coating process.

2.5.1. The Method of Obtaining Textile Fabric with Self-cleaning and Antimicrobial Properties[119]

Materials

The cotton/acrylic fabric proving the grammage of 130 g/m^2 was used in this study. The polydimethylsiloxane (PDMS) prepolymer with terminal hydroxyl groups, a product from Sigma Aldrich, was used. Titanium(IV) isopropoxide from Sigma Aldrich was used for the purpose of the synthesis of TiO_2. Ethyl tetraethyl orthosilicate was used for the purpose of the synthesis of SiO_2. Aprettan N92111 from Clarchem Poland Sp. z.o.o. was used as the crosslinking agent. In order to impart antibacterial properties of textile fabric, Sanitised T 99-19 from Clarchem Poland Sp. z.o.o was used.

112 R.S. Goonetilleke, (1999), *Footwear cushioning…*

113 M. Yang, W. Liu, C. Jiang et al., (2019), *Robust fabrication of superhydrophobic and photocatalytic self-cleaning cotton textile based on TiO_2 and fluoroalkylsilane*, "Journal of Materials Science", vol. 54, pp. 2079–2092.

114 C. Zhu, J. Shi, S. Xu et al., (2017), *Design and characterization of self-cleaning cotton fabrics exploiting zinc oxide nanoparticle-triggered photocatalytic degradation*, "Cellulose", vol. 24, pp. 2657–2667.

115 V.H.T. Thi, B.K. Lee, (2017), *Development of multifunctional self-cleaning and UV blocking cotton fabric with modification of photoactive ZnO coating via microwave method*, "Journal of Photochemistry and Photobiology A: Chemistry", vol. 338, pp. 13–22.

116 I. Ahmad, C.-W. Kan, Z. Yao, (2019), *Photoactive cotton fabric for UV protection and self-cleaning*, "RSC Advances", vol. 9, pp. 18106–18114.

117 A. Nazari, (2019), *Superior Self-cleaning and Antimicrobial Properties on Cotton Fabrics Using Nano Titanium Dioxide along with Green Walnut Shell Dye*, "Fibers Polymers", vol. 20, pp. 2503–2509.

118 I. Ahmad, C.W. Kan, (2017), *Visible-Light-Driven, Dye-Sensitized TiO_2 Photo-Catalyst for Self-Cleaning Cotton Fabrics*, "Coatings", vol. 7, no 11, p. 192.

119 I. Masłowska-Lipowicz, A. Słubik, (2023), *Novel method…*

Preparation of TiO_2 colloid by sol/gel method

TiO_2 particles were obtained by means of the sol/gel method by mixing water and ethanol in a 1:1 ratio, followed by dropwise addition of 24 ml of titanium(IV) isopropoxide. The resulting mixture was then stirred for half an hour at room temperature. At this time, 0.1 M hydrochloric acid (HCl) was added dropwise to the mixture until the pH was in the range of 3–4. The acidified mixture was stirred for 24 hours.

Preparation of SiO_2 colloid by sol/gel method

SiO_2 particles suspended in the solution were obtained by mixing water and ethanol in a 1:1 ratio, and then dropwise addition of 120 ml of ethyl tetraethyl orthosilicate. The resulting mixture was stirred for half an hour at room temperature. At this time, 0.1 M HCl was added dropwise to the mixture until the pH was in the range of 3–4. The acidified solution was stirred for 24h.

Preparation and application of PDMS/TiO_2 coatings on the fabric

The PDMS solution was prepared by mixing 200 mL of acetone with 4.2 g of poly(methylhydrosiloxane) and followed by adding 0.1% Appretan N92111 used as the crosslinker. The resulting mixture was stirred at room temperature for half an hour. The mixture prepared in this way was mixed with TiO_2 colloid in a ratio of 2:1 and applied to the fabric surface with the immersion method. Then the cotton fabric was dried at 100°C.

Preparation and application of coatings with additional antibacterial properties

5% Sanitized T 99-19 antibacterial agent containing the active ingredient quaternary ammonium salt – dimethyltetradecyl [3-(trimethoxysilyl) propyl] ammonium chloride was incorporated into PDMS/TiO_2 and PDMS/SiO_2 mixtures.

2.5.2. Characterisation Methods

Spectroscopy Characterisation

The infrared spectra of the unmodified and modified fabric were developed by means of the Thermo Scientific Nicolet 6700 FT-IR spectrometer equipped with Smart Orbit ATR (Waltkam, MA, USA) diamond attachment, using the attenuated total reflectance (ATR) method. The spectra were made for the wavenumber range of 500–3900 cm^{-1}.

In order to determine the mechanism of joining the fabric with the applied finish, for fabric before and after modification with PDMS/SiO_2 and PDMS/TiO_2 infrared spectra were made (Figure 2.4.).

In the case of the spectrum for the unmodified (cotton-acrylic fabric) sample, a wide and intense peak was observed at the wavenumber from 3000 to 3600 cm^{-1}, corresponding to the stretching vibrations of the-OH groups found in cellulose and lignin. The peak at the wavenumber of 2895 cm^{-1} was related to the > C-H group found in cotton (cellulose, hemicellulose), while the peak at the wavenumber of 2936 cm^{-1} and 2165 cm^{-1} indicated the content of -CH, $-CH_2$, $-CH_3$ groups (CH stretching vibration) and nitrile group > C≡N, respectively, found in acrylic fibre. The peak at the wavenumber of 1732 cm^{-1} corresponded to the stretching vibration of the carboxyl group > C=O found in hemicellulose and acrylic fibre. Additionally, the following peaks at the wavenumber of 1428 cm^{-1} (>CH_2 group in cellulose), 1364 cm^{-1} (> CH group in the aromatic ring in cellulose polysaccharides), 1312 cm^{-1} (> CO group in the aromatic ring in cellulose polysaccharides) and 1032 cm^{-1} (C-O and -OH group in cellulose polysaccharides) are characteristic for cotton.[120, 121] After applying PDMS/SiO_2 or PDMS/TiO_2 finish, a decrease in the intensity of the peak was observed at the wavenumber of 2965 cm^{-1}, 2165 cm^{-1} characteristic for acrylic fibre and at the number of 1732 cm^{-1} and 1032 cm^{-1} characteristic for cotton. In addition, after the application of PDMS/SiO_2 or PDMS/TiO_2 finish, the appearance of new peaks was observed at the wavenumber from 1026 cm^{-1} and 1000 cm^{-1}, probably attributed to asymmetric stretching vibrations Si-O and Si-O-Si, respectively.[122, 123, 124] The band characterising the Ti-O-Ti group was probably obscured by the peak at the wavenumber of 1310 cm^{-1} characteristic for the CH group.[125]

120 E.H. Portellaa, D. Romanzinib, C.C. Angrizanib, S.C. Amicob, A.J. Zatteraa, (2016), *Influence of Stacking Sequence on the Mechanical and Dynamic Mechanical Properties of Cotton/Glass Fiber Reinforced Polyester Composites*, "Material Research", vol. 19, no 3, pp. 542–547.

121 M. Abdouss, A. Mousavi, A. Shoushtari, A. Haji, B. Moshref, (2012), *Fabrication of chelating diethylenetriaminated PAN micro- and nano-fibres for heavy metal removal*, "Chemical Industry &Chemical Engineering Quarterly", vol. 18, pp. 27–34.

122 E. Pakdel, H. Zhao, J. Wang et al., (2021), *Superhydrophobic and photocatalytic…*

123 A.G. Koozekonan, M.R.M. Esmaeilpour, S. Kalantary, A. Karimi, K. Azam, V.A. Moshiran, F. Golbabaei, (2020), *Fabrication and characterization of PAN/CNT, PAN/TiO_2, and PAN/CNT/TiO_2 nanofibers for UV protection properties*, "The Journal of The Textile Institute", vol. 112, pp. 946–954.

124 M. Hu, Z. Wu, L. Sun, S. Guo, H. Li, J. Liao, B. Wang, (2019), *Improving pervaporation performance of PDMS membranes by interpenetrating polymer network for recovery of bio-butanol*, "Separation and Purification Technology", vol. 228, no. 1, 115690.

125 S. Foorginezhad, M.M. Zerafat, (2018), *Fabrication of stable fluorine-free superhydrophobic fabrics for anti-adhesion and self-cleaning properties*, "Applied Surface Science", vol. 464, pp. 458–471.

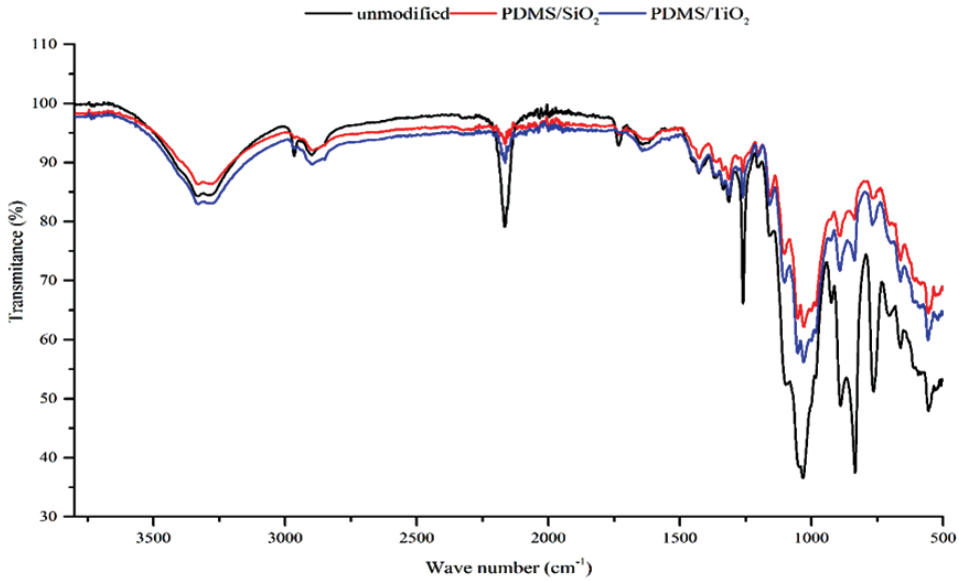

Figure 2.4. FTIR of the unmodified and modified textile fabric by PDMS/SiO_2 or PDMS/TiO_2
Source: I. Masłowska-Lipowicz, A. Słubik, (2023), *Novel method of obtaining textile fabrics with self-cleaning and antimicrobial properties*, "The Journal of The Textile Institute", Vol. 114:10, 1509–1517, DOI: 10.1080/00405000.2022.2131954

Contact Angle Measurements

The hydrophobicity of coated fabric was measured using a water contact angle meter (Phoenix-Alpha apparatus from SEO (SEO, Suwon, Korea)). A droplet of 10–3 cm^3 volume was applied to the surface of the sample with a syringe, and its photo was taken and analysed with Phoenix Alpha Contact Angle Analyzer software (SEO, Suwon, Korea). The contact angle measurements for deionised water at room temperature were performed for samples before and after application of coating. Ten contact angle measurements were conducted for each sample.

The wettability of the fabric, which is affected by the surface structure, was tested using the contact angle. The values of contact angles for the textile fabric sample before and after modification with PDMS/SiO_2 or PDMS/TiO_2 are presented in Table 2.47. and Figure 2.5. Fabric is an excellent adsorption material due to the capillary effect and high porous structure, thanks to which the liquid can be drawn into the matrix and trapped amongst the fibre.[126] Therefore, in the case of the unmodified sample, rapid absorption of the drop of water applied to the fabric was observed. However, in order to make the fabric hydrophobic, its surface was chemically modified with PDMS/SiO_2 and PDMS/TiO_2. The use of the

126 M. Adebajo, R. Frost, J. Kloprogge, O. Carmody, (2003), *Porous Materials for oil spill cleanup: A revive of synthesis and absorbing properties*, "Journal of Porous Materials", vol. 10, pp. 159–170.

proposed modifications of the surface of the textile fabric had a positive effect on the value of the contact angle and led to the formation of hydrophobic coatings, as evidenced by the value of the contact angle obtained. The contact angle for the surface modified by PDMS/SiO_2 was 147.3°, while for the surface modified by PDMS/TiO_2 was 143.5°.

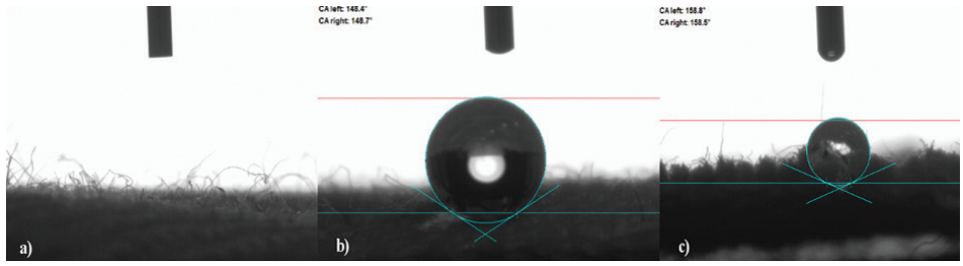

Figure 2.5. Contact angle of: a) unmodified and modified textile fabric by b) PDMS/SiO_2; c) PDMS/TiO_2
Source: I. Masłowska-Lipowicz, A. Słubik, (2023), *Novel method of obtaining textile fabrics with self-cleaning and antimicrobial properties*, "The Journal of The Textile Institute", Vol. 114:10, 1509–1517, DOI: 10.1080/00405000.2022.2131954

The durability of the obtained surface is also an important criterion for the practical application of superhydrophobic/hydrophobic surface coatings on textile fabrics. The durability of the superhydrophobic coating may result from the adhesion of SiO_2 or TiO_2 nanoparticles on the fabric surface. The durability of the surface was assessed by testing the chemical stability of the applied coatings by dipping the fabric in various solvents and water solutions with different pH values and then measuring their contact angle. The results obtained are presented in Table 2.47. The obtained PDMS/SiO_2 and PDMS/TiO_2 coatings show a very high chemical stability, as evidenced by the obtained contact angle results. The contact angle, regardless of the type of modification, increased on fabric immersed in both organic solvents (acetone, ethanol, THF) and aqueous solutions with pH 4 and pH 9. Increasing the contact angle may indicate the presence of strong chemical bonds between the fabric used and the coating layers formed.

Table 2.47. Contact angle measurement of unmodified and modified textile fabric

Sample	Contact Angle Measurement [°]
1	2
Unmodified textile fabric	a drop of water to soaked
PDMS/SiO_2	147.3
PDMS/SiO_2 (acetone)	157.3
PDMS/SiO_2 (ethanol)	155.5

1	2
PDMS/SiO_2 (THF)	154.5
PDMS/SiO_2 (pH4)	157.0
PDMS/SiO_2 (pH9)	157.3
PDMS/TiO_2	143.5
PDMS/TiO_2 (acetone)	161.3
PDMS/TiO_2 (ethanol)	156.1
PDMS/TiO_2 (THF)	153.5
PDMS/TiO_2 (pH4)	157.5
PDMS/TiO_2 (pH9)	149.2

Source: I. Masłowska-Lipowicz, A. Słubik, (2023), *Novel method of obtaining textile fabrics with self-cleaning and antimicrobial properties*, "The Journal of The Textile Institute", Vol. 114:10, 1509–1517, DOI: 10.1080/00405000.2022.2131954

Materials with a high contact angle are also self-cleaning. In the case of textile fabrics, the self-cleaning properties were assessed by applying various liquid contaminants to the fabric, and then the degree of soiling was visually assessed. Water, dye, raspberry juice, wine, and cinnamon oil were used as contaminants, and in the case of velour leather – mud. As shown in Figure 2.6. the liquid droplets on the unmodified fabric were absorbed, while on those modified by PDMS/SiO_2 or PDMS/TiO_2 coatings, the liquid droplets had a spherical shape, which proves the excellent repulsive properties of the resulting surface in relation to various types of the contamination. These liquid contamination also ran down the coated surface immediately and did not leave any dirt, unlike the unmodified fabric. In the case of applying cinnamon oil, the drops of this liquid were absorbed on both the unmodified and the modified fabric, which proves that the proposed modifications do not show oleophobic properties.

The same method was used for modifying leather – dyed velour. As shown in Figure 2.8., the mud was applied to the unmodified and modified skin. Mud composition: soil mixture taken from the residential area mixed with water in a 5:1 weight ratio. After removing the impurity, a stain remained on the unmodified leather, and there was no impurity on the modified leather.

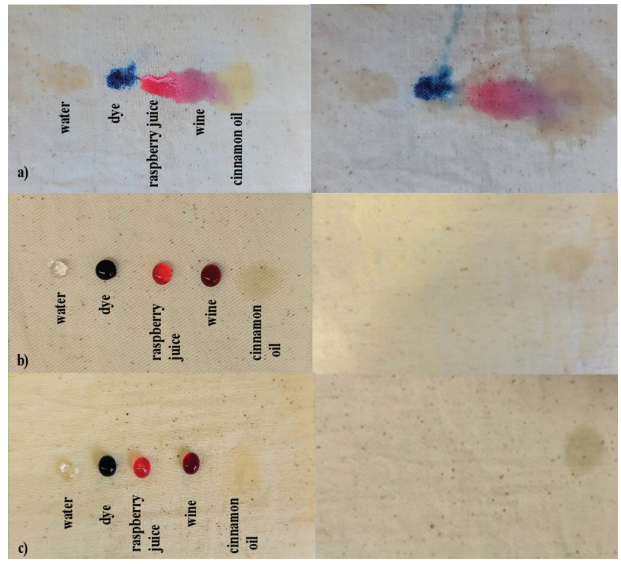

Figure 2.6. Self-cleaning properties of a) unmodified and modified textile fabric; b) PDMS/SiO_2; c) PDMS/TiO_2
Source: I. Masłowska-Lipowicz, A. Słubik, (2023), *Novel method of obtaining textile fabrics with self-cleaning and antimicrobial properties*, "The Journal of The Textile Institute", Vol. 114:10, 1509–1517, DOI: 10.1080/00405000.2022.2131954

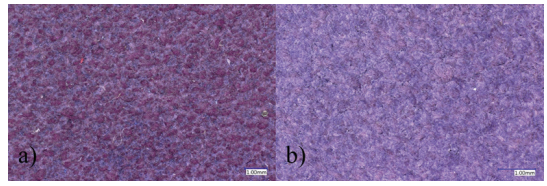

Figure 2.7. Microscopic image of velour-violet leather (a) face, (b) flesh
Source: own elaboration.

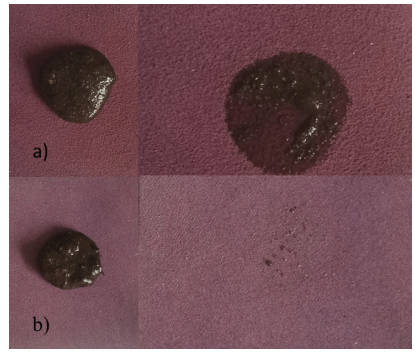

Figure 2.8. Self-cleaning properties of a) unmodified, b) modified velour leather PDMS/SiO_2
Source: own elaboration.

Antibacterial and antifungal properties of the coating

Two bacterial strains*: Escherichia coli* ATCC 8739 and *Staphylococcus aureus* ATCC 9144 were used as bacteria to test the antimicrobial properties of superhydrophobic/hydrophobic coatings on the fabric surfaces. Antibacterial tests were carried out in accordance with the PN-EN ISO 20645 standard.[127]

Two fungal strains, *Aspergillus niger* ATCC 6275, and *Candida albicans* ATCC 10231 were used as model fungi to test the antifungal properties of superhydrophobic/hydrophobic coatings on the fabric surfaces. The antifungal tests were performed in accordance with the PN-EN 14119:2005 standard.[128]

The results of testing the antibacterial activity of fabric samples against *E. coli* and *S. aureus* are presented in Table 2.48., Figure 2.9. and Figure 2.10.

Table 2.48. The results of the antibacterial activity against *E. coli* and *S. aureus* of the tested samples modified by PDMS/SiO_2 or PDMS/TiO_2

Bacterial strain	Type of sample	Growth	Inhibition zone	Description	Assessment
E. coli	PDMS/SiO_2	lack	0	No inhibition zone, lack of growth	Good effect
	PDMS/TiO_2	lack	0	No inhibition zone, lack of growth	Good effect
S. aureus	PDMS/SiO_2	lack	9.0	Inhibition zone above 1 mm, lack of growth	Good effect
	PDMS/TiO_2	lack	9.0	Inhibition zone above 1 mm, lack of growth	Good effect

Source: I. Masłowska-Lipowicz, A. Słubik, (2023), *Novel method of obtaining textile fabrics with self-cleaning and antimicrobial properties*, "The Journal of The Textile Institute", Vol. 114:10, 1509–1517, DOI: 10.1080/00405000.2022.2131954

In the case of the PDMS/SiO_2- and PDMS/TiO_2-modified fabric, in the *E. coli* test, no zone of growth inhibition around the working samples was observed. Bacterial growth directly under the fabric was not observed, either (Figure 2.4.). This means that the fabric modified with the antibacterial agent showed a good effect against *E. coli*. However, in the case of the PDMS/SiO_2- and PDMS/TiO_2-modified fabric samples, the 9.0 mm zone of growth inhibition around the samples was observed in the *S. aureus* test. There was also no growth of bacteria directly under the fabric samples (Figure 2.5.), which evidenced that the fabrics used with Sanitised T 99-19 showed a good effect against *S. aureus*. Better antibacterial effect of the PDMS/SiO_2 and PDMS/TiO_2-modified fabric was observed in the case of

127 PN-EN ISO 20645:2006, *Płaskie wyroby…*, p. 32.
128 PN-EN 14119:2005, *Badania tekstyliów…*, p. 33.

gram-positive bacteria (*S. aureus*), which is probably related to the structure of bacteria, in particular with the structure of their cell wall.

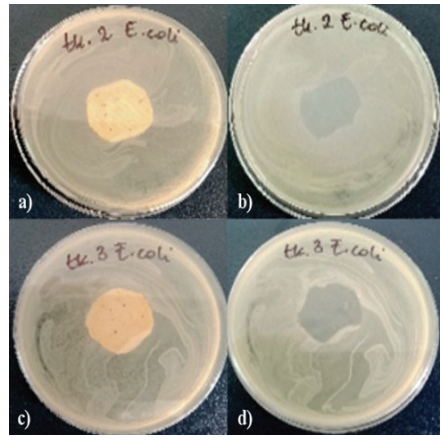

Figure 2.9. Growth of *E. coli*: a) around the PDMS/SiO_2-modified fabric; b) under the PDMS/SiO_2-modified fabric; c) around the PDMS/TiO_2-modified fabric; d) under the PDMS/TiO_2-modified fabric
Source: I. Masłowska-Lipowicz, A. Słubik, (2023), *Novel method of obtaining textile fabrics with self-cleaning and antimicrobial properties*, "The Journal of The Textile Institute", Vol. 114:10, 1509–1517, DOI: 10.1080/00405000.2022.2131954

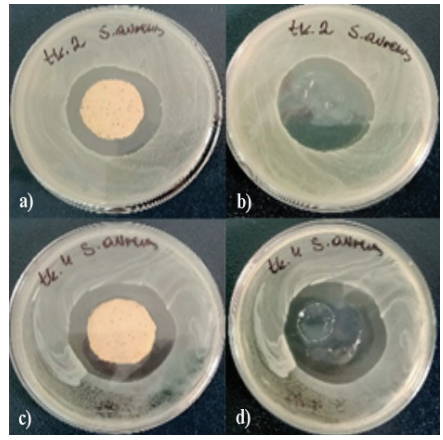

Figure 2.10. Growth of *S. aureus*: a) around the PDMS/SiO_2-modified fabric; b) under the PDMS/SiO_2-modified fabric; c) around the PDMS/TiO_2-modified fabric; d) under the PDMS/TiO_2-modified fabric
Source: I. Masłowska-Lipowicz, A. Słubik, (2023), *Novel method of obtaining textile fabrics with self-cleaning and antimicrobial properties*, "The Journal of The Textile Institute", Vol. 114:10, 1509–1517, DOI: 10.1080/00405000.2022.2131954

The results of tests of antifungal activity of the fabric samples against *Aspergillus niger* and *Candida albicans* are presented in Table 2.49.

Table 2.49. The result of the antifungal activity against *Aspergillus niger* and *Candida albicans* of the tested samples modified by PDMS/SiO_2 or PDMS/TiO_2

Fungal strain	Type of sample	Growth	Inhibition zone	Description
Aspergillus niger	PDMS/SiO_2	2	Visible growth, covering up to 25% of the tested area	Limited efficiency
	PDMS/TiO_2	2	Visible growth, covering up to 25% of the tested area	Limited efficiency
Candida albicans	PDMS/SiO_2	0	No visible growth on the fabric assessed by microscope, growth over the entire surface of the agar	Good effect
	PDMS/TiO_2	0	No visible growth on fabric assessed by microscope, minimal zone of inhibition on agar	Good effect

Source: I. Masłowska-Lipowicz, A. Słubik, (2022), *Novel method of obtaining textile fabrics with self-cleaning and antimicrobial properties*, "The Journal of the Textile Institute", https://www.tandfonline.com/doi/abs/10.1080/00405000.2022.2131954 (accessed: 09.03.2023).

Antifungal agents applied to the tested fabric had a different effect on the growth of *Aspergillus niger* and *Candida albicans*. For the fabric modified by the PDMS/SiO_2 and PDMS/TiO_2, better action against fungi was observed due to *Candida albicans* than with *Aspergillus niger*. *Candida albicans* growth was not observed on the surface of the modified fabric. For that fabric, a minimal zone of inhibition of growth around the test sample was also observed. A slightly weaker fungistatic effect of the modified fabrics was observed in the case of *Aspergillus Niger*. The growth of *Aspergillus Niger* appeared on about 25% of the tested fabric area.

The use of the proposed finish to modify the surface of the fabric made it self-cleaning. Before modification, the droplets of water and liquid impurities had been absorbed into the fabric. However, the modification resulted in obtaining hydrophobic surfaces characterised by the contact angle of about 145°. Additionally, the modified surfaces showed high durability in organic solvents and in strongly acidic and strongly alkaline solutions. The Sanitized TH 99-19 finish inhibited the growth of selected bacteria and fungi.

2.6. Auxetic Structures Used in Footwear and Clothing Materials[129]

Auxetic materials and structures have a Negative Poisson's Ratio (NPR). The Poisson's Ratio characterises the response to uniaxial stress. It is defined as the negative ratio of the transverse strain to the corresponding axial strain. The Poisson's Ratio is a dimensionless quantity>. It does not determine the elasticity of a material but the way in which it deforms. It is determined according to the following equation formula:

$$\nu = -\frac{\varepsilon_x}{\varepsilon_y} \tag{1}$$

ν – Poisson's Ratio;
ε_x – deformation along the x-axis,
ε_y – deformation along the y-axis.

Auxetics exhibit counterintuitive response. In uniaxial compression (tension), those materials and structures contract (expand) laterally.

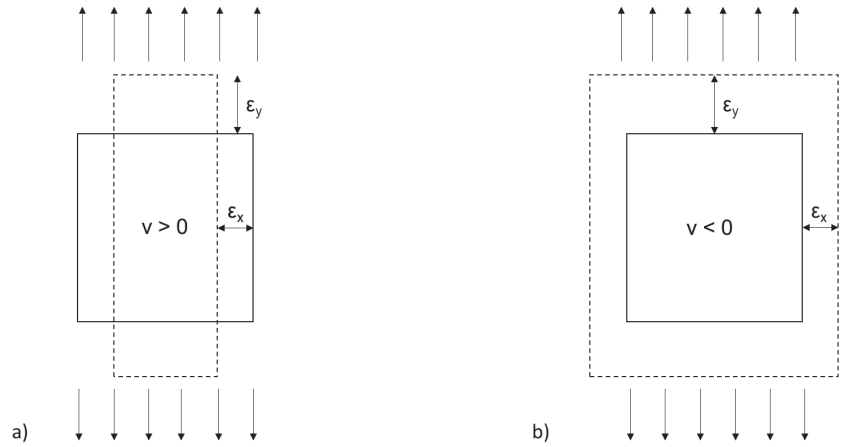

Figure 2.11. The diagram of undeformed (solid line) and deformed (dashed line):
a) conventional; b) auxetic material; ν – Poisson's Ratio; ε_x – deformation along the x-axis; ε_y – deformation along the y-axis
Source: own elaboration.

129 D. Prall, R.S. Lakes, (1997), *Properties of a chiral honeycomb with a Poisson's ratio of –1*, "International Journal of Mechanical Sciences", vol. 39, pp. 305–314.

Only few auxetic materials have been found in the natural environment. The first experimental study suggesting the existence of auxetic materials in the natural environment was reported in 1882 for iron pyrite monocrystals, the Poisson's Ratio of which was estimated to be –0.14. Other examples of natural auxetic materials include α-crystobalite, cow teat skin, pyrolytic graphite, polymorphic silicones, zeolites, silicates and crystalline cadmium.[130] [131]

The properties of materials characterised by the Negative Poisson's Ratio are for the first time mentioned in Voigt's work[132] dating back to the early 20th century. Subsequently, Lempriere[133] presented theoretical considerations for three-dimensional isotropic materials characterised by the Negative Poisson's Ratio. By and large, on the basis of the classical theory of elasticity and the thermodynamic stability of materials, the Poisson's Ratio for isotropic materials is assumed to take values within the interval (–1, 1) for the two-dimensional theory of elasticity and values within the interval (–1, 0.5) for three-dimensional materials.[134] For anisotropic materials, there are no such restrictions. In the 1980s, Gibson[135] published a paper on cellular materials inter alia containing theoretical and experimental results in respect of the materials characterised by the Negative Poisson's Ratio, and Lakes[136] presented a method for producing a synthetic foam sample showing auxetic properties.

In recent years the literature has many a time described structures, the deformation magnitude and the related Poisson's Ratio of which depend on external conditions, e.g. temperature, magnetic field, applied force or displacement.

130 R.S. Lakes, R. Witt, (2000), *Making and characterizing negative Poisson's ratio materials*, "International Journal of Metallurgical Engineering Education", vol. 30, no. 1, pp. 50–58.

131 VH. Carneiro, J. Meireles, H. Puga, (2013), *Auxetic materials – a review*, "Mater Sci – Poland", vol. 31, pp. 561–71.

132 W. Voigt, (1928), *Lehrbuch der Kristallphysik*, B. G. Teubner-Verlag, Leipzig, Berlin.

133 B.M. Lempriere, (1968), *Poisson's ratio in orthotropic materials*, "AIAA J.", vol. 6, no. 11, p. 2226.

134 K.W. Wojciechowski, (1987), *Constant thermodynamic tension Monte Carlo studies of elastic properties of a two-dimensional system of hard cyclic hexamers*, "Molecular Physics", vol. 61, p. 1247.

135 L.J. Gibson, (1981), *The elastic and plastic behaviour of cellular materials*, Churchill College, University of Cambridge, UK.

136 R.S. Lakes, (1987), *Foam structures with a negative Poisson's ratio*, "Science", vol. 235, p. 1038.

In a number of papers,[137, 138, 139, 140, 141, 142, 143] it has been shown that, by means of the above factors, the value of the Poisson's Ration can be controlled so that the structure exhibits auxetic response under certain known and controlled conditions and not under other conditions.

Short-listed models for auxetic structures

A number of research centres are investigating new deformation mechanisms leading to auxetic response with high controllability and low production costs. Representative mechanisms include re-entrant structures,[144, 145, 146, 147, 148, 149] rotating

137 I.V. Shadrivov, M. Lapine, Y.S. Kivshar (eds), (2015), *Nonlinear, Tunable and Active Metamaterials, Nonlinear, Tunable and Active Metamaterials*, Springer International Publishing, Switzerland.

138 R.S. Lakes, (2007), *Cellular solids with tunable positive or negative thermal expansion of unbounded magnitude*, "Applied Physics Letters", vol. 90, 221905.

139 R.S. Lakes, (2017), *Negative Poisson's Ratio Materials: Auxetic Solids*, "Annual Review of Materials Research", vol. 47, pp. 63–81.

140 J.N. Grima, R. Caruana-Gauci, M.R. Dudek, K.W. Wojciechowski, R. Gatt, (2013), *Smart metamaterials with tunable auxetic and other properties*, "Smart Materials and Structures", vol. 22, 084016.

141 D. Li, L. Dong, R.S. Lakes, (2016), *A unit cell structure with tunable Poisson's ratio from positive to negative*, "Materials Letters", vol. 164, pp. 456–459.

142 D. Li, J. Maa, L. Dong, R.S. Lakes, (2016), *A bi-material structure with Poisson's ratio tunable from positive to negative via temperature control*, "Materials Letters", vol. 181, pp. 285–288.

143 C.S. Ha, M.E. Plesha, R.S. Lakes, (2016), *Chiral three-dimensional lattices with tunable Poisson's ratio*, "Smart Materials and Structures", vol. 25, 054005.

144 I.G. Masters, K.E. Evans, (1996), *Models for the elastic deformation of honeycombs*, "Composite Structures", vol. 35, pp. 403–422.

145 L. Yang, O. Harrysson, H. West, D. Cormier, (2015), *Mechanical properties of 3D re-entrant honeycomb auxetic structures realized via additive manufacturing*, "International Journal of Solids and Structures", vol. 69, pp. 475–490.

146 U.D. Larsen, O. Signund, S. Bouwsta, (1997), *Design and fabrication of compliant micromechanisms and structures with negative Poisson's ratio*, "Journal of Microelectromechanical Systems", vol. 6, pp. 99–106.

147 P.S. Theocaris, G.E. Stavroulakis, P.D. Panagiotopoulos, (1997), *Negative Poisson's ratios in composites with star-shaped inclusions: a numerical homogenization approach*, "Archive of Applied Mechanics", vol. 67, pp. 274–286.

148 Z.P. Wang, L.H. Poh, J. Dirrenberger, Y. Zhu, S. Forest, (2017), *Isogeometric shape optimization of smoothed petal auxetic structures via computational periodic homogenization*, "Computer Methods in Applied Mechanics and Engineering", vol. 323, pp. 250–271.

149 X.T. Wang, B. Wang, X.W. Li, L. Ma, (2017), *Mechanical properties of 3D re-entrant auxetic cellular structures*, "International Journal of Mechanical Sciences", vol. 131, pp. 396–407.

rigid or semi-rigid units,[150, 151, 152, 153, 154, 155] chiral structures,[156, 157] filamentous / nodular structures,[158, 159] spiral auxetic yarn.[160]

'Re-entrant' honeycomb structures represent one of the earliest developed models of structures proving the Negative Poisson's Ratio. The adjective 're-entrant' means that the shape has an angle in its structure greater than 180° pointing inwards (Fig. 2.12.).

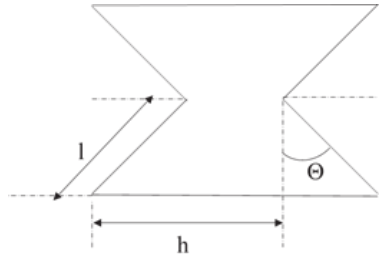

Figure 2.12. The basic hexagonal cell of the re-entrant honeycomb structure
Source: own elaboration according to W. Miller, P.B. Hook, C.W. Smith, X. Wang, K.E. Evans, (2009), *The manufacture and characterisation of a novel, low modulus, negative Poisson's ratio composite*, "Composites Science and Technology", vol. 69, pp. 651–655.

150 J.N. Grima, K.E. Evans, (2000), *Auxetic behavior from rotating squares*, "Journal of Materials Science Letters", vol. 19, pp. 1563–1565.

151 J.N. Grima, P.S. Farrugia, R. Gatt, D. Attard, (2008), *On the auxetic properties of rotating rhombi and parallelograms: a preliminary investigation*, "Physica Status Solidi B.", vol. 245, pp. 521–529.

152 J.N. Grima, R. Gatt, A. Alderson, K.E. Evans, (2005), *On the auxetic properties of rotating rectangles with different connectivity*, "Journal of the Physical Society of Japan", vol. 74, pp. 2866–2867.

153 J.N. Grima, E. Chetcuti, E. Manicaro, D. Attard, M. Camilleri, R. Gatt, K.E. Evans, (2011), *On the auxetic properties of generic rotating rigid triangles*, Proceedings of the Royal Society of London A, vol. 468, pp. 810–830.

154 S. Shan, S.H. Kang, Z. Zhao, L. Fang, K. Bertoldi, (2015), *Design of planar isotropic negative Poisson's ratio structures*, "Extreme Mechanics Letters", vol. 4, pp. 96–102.

155 J. Kim, D. Shin, D.S. Yoo, K. Ki, (2017), *Regularly configured structures with polygonal prisms for three-dimensional auxetic behavior*, Proceedings of the Royal Society of London A, vol. 473, 20160926.

156 D. Prall, R.S. Lakes, (1997), *Properties of a chiral…*

157 J.N. Grima, R. Gatt, P.S. Farrugia, (2008), *On the properties of auxetic meta-tetrachiral structures*, "Physica Status Solidi B.", vol. 245, pp. 511–520.

158 K.E. Evans, B.D. Caddock, (1989), *Microporous materials with negative Poisson's ratios II, Mechanisms and interpretation*, "Journal of Physics D: Applied Physics", vol. 2, pp. 1877–1883.

159 C. He, P. Liu, A.C. Griffin, (1998), *Toward negative Poisson ratio polymers through molecular design*, "Macromolecules", vol. 31, pp. 3145–3147.

160 W. Miller, P.B. Hook, C.W. Smith, X. Wang, K.E. Evans, (2009), *The manufacture and characterisation of a novel, low modulus, negative Poisson's ratio composite*, "Composites Science and Technology", vol. 69, pp. 651–655.

A graphical elaboration of two-dimensional re-entrant auxetic structures: the honeycomb triangular structure and the star-shaped structure can be found in the Handbook of Mechanics of Materials.[161] Three-dimensional re-entrant structures are well-illustrated by the authors of the publication "Mechanical Properties of 3D Re-entrant Auxetic Cellular Structures".[162]

Structures consisting of the so-called rigid or semi-rigid rotating units.

Structures consisting of the so-called rigid or semi-rigid rotating units account for still another model of structures that may have auxetic properties. Rotating mechanism structures consist of rigid units connected by hinges. The rigid units are arranged according to a consistent principle, and their initial positions are slightly inclined in a clockwise or anti-clockwise direction, which is opposite to the direction of tilt of the neighbouring units.

Chiral structures

The so-called chiral structures represent another model of an auxetic structure that is for the first time presented by Prall and Lakes in the context of the Negative Poisson's Ratio.[163, 164] The word chiral denotes the non-overlap of an object with its mirror image. A single auxetic structure consists of central nodes that are circles, rectangles or other geometric figures, and connectors (ligaments). A chiral structure is formed by connecting multiple single cells. The auxetic effect is achieved by wrapping and unwrapping the linkers around the nodes in response to a given force.

Fibre/nodule structures

The effect of the Negative Poisson's Ratio is achieved by an internal structure consisting of coarsening/thicknesses connected by fibre. Under load, the knobs rotate around the fibres, giving rise to an auxetic property.

161 H. Cho, D. Seo, D.N. Kim, (2019), *Mechanics of Auxetic Materials*, [in:] CH. Hsueh et al. (eds), *Handbook of Mechanics of Materials,* Springer, Singapore.

162 X.T. Wang, B. Wang, X.W. Li, L. Ma, (2017), *Mechanical properties…*

163 D. Prall, R.S. Lakes, (1997), *Properties of a chiral…*

164 C. He, P. Liu, A.C. Griffin, (1998), *Toward negative…*

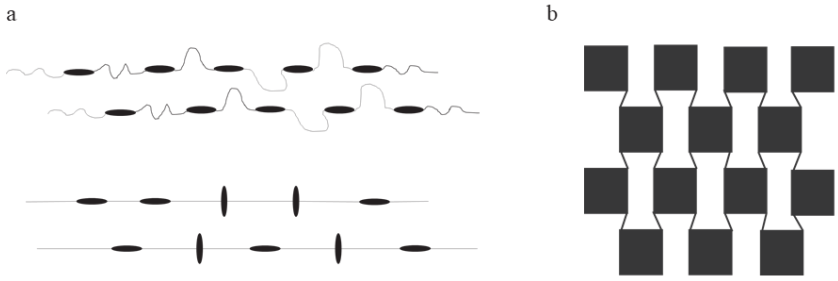

Figure 2.13. Typical shape of fibril-nodule structures: (a) single fibril-type structural model for a liquid crystalline polymer (bundle type), (b) multifibril structures with rectangular nodules/thickenings (lattice type)
Source: I. Masłowska-Lipowicz, Ł. Wyrębska, B. Szałek, P. Olszewski, R. Gajewski, (2020), *Materiały auksetyczne – struktury, potencjalne zastosowanie*, „Technologia i Jakość Wyrobów", vol. 65, pp. 116–128.

Helical Auxetic Yarn

Spiral auxetic yarn is a unique auxetic material that consists of two types of thread.[165, 166] The core thread is a thick but flexible thread that has a straight shape in its unstressed state. The core thread is wrapped with a thin and 'stiff' thread that is the second component of the auxetic yarn. The effective diameter of the yarn is the sum of the diameter of the core thread and twice the diameter of the spiral thread wrapped around it. When a tensile load is applied to the spiral yarn, a radical change occurs due to the difference in stiffness values between the two threads – the spiral-wound stiffer (wrapping) thread straightens in the direction of the tensile load. As a result, the core thread is now spirally wound around the stiffer thread. In such a state, the effective diameter of the deformed shape is defined as the diameter of the wrapping thread plus twice the diameter of the core thread (it is larger than the diameter of a single yarn fibre in the initial state, increasing under tensile load). As a result, the entire fabric composed of helical auxetic yarn proves the NPR and stretches in the direction perpendicular to the applied load.

Potential applications

Auxetic materials and the models describing their properties are subject to intensive research, not only in terms of basic research, but also in terms of potential applications. The auxetic response of materials derives from the deformation mechanism of specific geometries and internal structures in result of uniaxial loads. As compared to conventional materials with the Positive Poisson's Ratio, auxetic materials are expected to have several interesting features in terms of their

165 W. Miller, P.B. Hook, C.W. Smith, X. Wang, K.E. Evans, (2009), *The manufacture and…*
166 Z. Ge, H. Hu, S. Liu, (2016), *A novel plied yarn structure with negative Poisson's ratio*, "The Journal of the Textile Institute", vol. 107, no. 5, pp. 578–588.

geometrical and mechanical properties, including synclastic bending curvature,[167, 168] variable permeability,[169] high shear stiffness,[170, 171] enhanced dent resistance,[172, 173, 174] high fracture toughness[175, 176, 177, 178] and sound damping, and absorption.[179, 180, 181, 182] Those remarkable properties offer a wide range of applications for auxetic materials, inter alia, in biomedical materials,[183] cushioning materials,[184] energy harvesting

167 R.S. Lakes, (1987), *Foam structures with a negative Poisson's ratio*, "Science", vol. 235, pp. 1038–1041.

168 K.E. Evans, A. Alderson, (2000), *Auxetic materials: functional materials and structures from lateral thinking,* "Advanced Materials", vol. 12, pp. 617–28.

169 Z. Wang, H. Hu, (2014), *Auxetic materials and their potential applications in textiles*, "Textile Research Journal", vol. 84, pp. 1600–1611.

170 K.E. Evans, A. Alderson, (2000), *Auxetic materials…*

171 R.S. Underhill, (2014), *Defense applications of Auxetic materials*, "Advanced Materials", vol. 1, pp. 7–13.

172 K.E. Evans, A. Alderson, (2000), *Auxetic materials…*

173 K.L. Alderson, A.P. Pickles, P.J. Neale, K.E. Evans, (1994), *Auxetic polyethylene: the effect of a negative Poisson's ratio on hardness*, "Acta Metallurgica et Materialia", vol. 42, pp. 2261–2266.

174 Q. Liu, (2006), *Literature review: materials with negative Poisson's ratios and potential applications to aerospace and defence*, Defence Science and Technology Organisation, Victoria.

175 R.S. Lakes, (1987), *Foam structures…*, pp. 1038–1041.

176 J.B. Choi, R.S. Lakes, (1996), *Fracture toughness of re-entrant foam materials with a negative Poisson's ratio: experiment and analysis*, "International Journal of Fracture", vol. 80, pp. 73–83.

177 J.P. Donoghue, K.L. Alderson, K.E. Evans, (2009), *The fracture toughness of composite laminates with a negative Poisson's ratio*, "Physica Status Solidi B.", vol. 246, pp. 2011–2017.

178 S.K. Maiti, M.F. Ashby, L.J. Gibson, (1984), *Fracture toughness of brittle cellular solids*, "Scripta Metallurgica", vol. 18, pp. 213–217.

179 I. Chekkal, M. Bianchi, C. Remillat, F.X. Becot, L. Jaouen, F. Scarpa, (2010), *Vibro-acoustic properties of auxetic open cell foam: model and experimental results*, "Acta Acustica United Acustica", vol. 96, pp. 266–274.

180 B. Howell, P. Prendergast, L. Hansen, (1994), *Examination of acoustic behavior of negative Poisson's ratio materials*, "Applied Acoustics", vol. 43, pp. 141–148.

181 K.L. Alderson, R.S. Webber, U.F. Mohammed, E. Murphy, K.E. Evans, (1997), *An experimental study of ultrasonic attenuation in microporous polyethylene*, "Applied Acoustics", vol. 50, pp. 23–33.

182 F. Scarpa, L.G. Ciffo, J.R. Yates, (2003), *Dynamic properties of high structural integrity auxetic open cell foam*, "Smart Materials and Structures", vol. 13, p. 49.

183 S.K. Bhullar, N.L. Lala, S. Ramkrishna, (2015), *Smart biomaterials – a review*, "Reviews on Advanced Materials Science", vol. 40, pp. 303–314.

184 N. Novak, M. Vesenjak, Z. Ren, (2016), *Auxetic cellular materials – a review*. "Strojniški Vestnik – Journal of Mechanical Engineering", vol. 62, pp. 485–493.

devices,[185] sports equipment,[186] filters,[187] robotics,[188] textiles[189, 190] or materials used in the aerospace industry[191] and construction.[192] Medical applications include auxetic bandage that effectively compresses a wound as well as the so-called stents that cause the cross-section through which blood flows to be increased, creating a kind of artificial blood vessel that resists dangerous constriction of the vessel cross-section.[193]

Auxetic textiles

Auxetic textile materials (fibre, yarn, fabric, textile-reinforced composites) have been of interest to many researchers in recent years. Although most of the literature refers to auxetic textile that has better properties than conventional materials, very few types of auxetic materials have been manufactured on a scale larger than the laboratory scale. The major limitations of manufacturing auxetic textiles include: low structural stability, low elastic return, greater thickness and difficulty in manufacturing due to their complex geometric structures. Undoubtedly, auxetic textile shows a great potential to be classified as smart textile to be used, for example, in the manufacture of clothing, but this is a matter of research that is still ongoing.

In a US patent,[194] a multilayer sole was developed, in which one layer has auxetic properties, during an activity (running, jumping, etc.), causing increased lateral or longitudinal stress, better grip (by increasing surface area) as well as cushioning.

185 G. Imbalzano, P. Tran, T.D. Ngo, P.V. Lee, (2017), *Three-dimensional modelling of auxetic sandwich panels for localised impact resistance*, "Journal of Sandwich Structures & Materials", vol. 19, no. 3, pp. 291–316.

186 K.L. Alderson, A.P. Pickles, P.J. Neale, K.E. Evans, (1994), *Auxetic polyethylene…*

187 A. Alderson, J. Rasburn, S. Ameer-Beg, P.G. Mullarkey, W. Perrie, K.E. Evans, (2000), *An auxetic filter: a tuneable filter displaying enhanced size selectivity or defouling properties*, "Industrial & Engineering Chemistry Research", vol. 39, no. 3, pp. 654–665.

188 A.G. Mark, S. Palagi, T. Qiu, P. Fischer, (2016), *Auxetic metamaterial simplifies soft robot design*, "2016 IEEE International Conference on Robotics and Automation (ICRA)", pp. 4951–4956.

189 K.E. Evans, A. Alderson, (2000), *Auxetic materials…*

190 M. Konaković, K. Crane, B. Deng, S. Bouaziz, D. Piker, M. Pauly, (2016), *Beyond developable: computational design and fabrication with auxetic materials*, "ACM Transactions on Graphics (TOG)", vol. 35, pp. 79–89.

191 R.S. Underhill, (2014), *Defense applications…*

192 D. Park, J. Lee, A. Romo, (2015), *Poisson's Ratio Material Distributions*, [in:] Y. Ikeda, C.M. Herr, D. Holzer, S. Kaijima, M.J. Kim, A. Schnabel (eds), *In Emerging Experience in Past, Present and Future of Digital Architecture, Proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia CAADRIA 2015*, Hong Kong, pp. 725–744.

193 S.K. Bhullar, N.L. Lala, S. Ramkrishna, (2015), *Smart biomaterials…*

194 T.M. Cross, K.W. Hoffer, D.P. Jones, P.B. Kirschner, E. Langvin, J.C. Meschter, US-9402439-B2, *Auxetic structures and footwear with soles having auxetic structures*.

The effectiveness of the auxetic footbed in reducing forefoot pressure during the use of high-heeled shoes has been confirmed. The use of auxetic foam decreases forefoot sole pressure whereas a commercial product, a material traditionally used for sole padding, increases pressure in the area of the second-fourth metatarsophalangeal joint.[195]

The right way of deforming under tension makes auxetics a protective material that may be used in items that protect people from injury or the effects of any impact. Protective helmets, footwear, bulletproof vests or knee and shin guards are made from them.

Clothing or shoes made from auxetics adjust very easily to the shape of the human body improving ergonomics and comfort and, in the case of children's textile, can eliminate the problem of short use of garments due to the rapid growth of children (growing clothes).[196, 197]

The wide use of auxetic materials results from their properties, e.g. synclastic bending curvature, variable permeability, high shear stiffness, increased dent resistance, high fracture toughness and sound attenuation and absorption. Potential areas of application for auxetics include biomedical materials, cushioning, energy harvesting devices, sports equipment, filters, robotics, textiles or materials used in the aerospace and construction industries.

Auxetic materials have enormous potential but their production for widespread use is still limited. The issue requires further research into both the properties and applicability of auxetic materials.

195 L.A. Stojmanovski Mercieca, C. Formosa, J.N. Grima, N. Chockalingam, R. Gatt, A. Gatt, (2017), *On the Use of Auxetics in Footwear: Investigating the Effect of Padding and Padding Material on Forefoot Pressure in High Heels*, "Physica Status Solidi B", vol. 254, no. 12, 1700528.

196 H. Cho, D. Seo, D.N. Kim, (2019), *Mechanics of Auxetic…*

197 R.S. Underhill, (2014), *Defense applications…*

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Chapter 3

Utilisation of Production Residue from the Footwear and Clothing Industry

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3.1. Characteristics of the Footwear and Clothing Industry in terms of Waste Management

The leather industry covers a wide range of sectors ranging from the leather markets that provide the tanning industry with raw materials from meat abattoirs to the leather goods manufacturers. Some of those sectors are highly industrialised, others are based mainly on arts and crafts, and still others focus on trade and ancillary services.[1] Leather manufacture is one of the world's oldest handicrafts. Thanks to appropriate processing, we achieve an extremely durable raw material that is used for manufacturing common goods. The leather tanning process consists of a series of mechanical processes and chemical reactions. As a result, unstable raw leather is

1 All-European Industry Federation, (2012), Social and Environmental Report of the European Leather Industry, COTANCE.

transformed into a finished product with enhanced resistance to external factors, while maintaining the natural features resulting from the specific structure of the leather tissue. Leather tanning is the basic process, that, together with a series of mechanical leather processing operations, leads to obtaining a finished product with specific properties such as appearance, durability, flexibility, resistance to water and temperature, air and sweat permeability. After tanning, tanning hides may be used for manufacturing footwear, clothing, leather goods, furniture upholstery, cars, boats, and planes.[2]

The analysis of the leather industry production output in Poland in terms of animal typology indicates that the major raw material processed by this industry mainly includes large bovine hides (71% of the total) followed by sheepskin (14%), goat skin (8%) and veal (6%). Other processed animal skin (particularly reptile, pig, deer) accounts for a small part of the leather industry (less than 1%). This raw material segmentation is closely related to the meat industry [1]. According to estimates, 50% of the leather manufactured in the European Union is used in the footwear industry. The garment industry processes 20% of Europe's tanners' output, while the leather for upholstery accounts for 17% of the production output. Therefore, the Polish tanning industry is characteristic of a strong dependence on the economic situation in the footwear industry,[3] which is evidenced by the related figures presented in Table 3.1.1.

Table 3.1.1. Leather manufacturing processes in Europe

Use of Leather	Share [%]
Footwear industry	50
Clothing industry	20
Upholstery	17
Other industries	13

Source: Reference Document for the Best Available Technology: Leather tanning, Joint Research Center Institute for Prospective Technological Studies, Sustainable Production and Consumption Unit European IPPC Bureau 2013. [Available at: https://docplayer.pl/8261017-Garbowanie-skor-dokument-referencyjny-dotyczacy-najlepszych-dostepnych-technik-bat-dla.html (accessed: 07.08.2023)] (in Polish).

2 W. Domański, J. Surgiewicz, (2001), *Chemical hazards in the tanning industry*, "WORK SAFETY science and practice", vol. 4, pp. 6–9.

3 Reference Document for the Best Available Technology: Leather tanning, Joint Research Center Institute for Prospective Technological Studies, Sustainable Production and Consumption Unit European IPPC Bureau 2013. [Available at: https://docplayer.pl/8261017-Garbowanie-skor-dokument-referencyjny-dotyczacy-najlepszych-dostepnych-technik-bat-dla.html (accessed: 07.08.2023)] (in Polish).

According to the data published by the Central Statistical Office, in 2018 the sales revenue in the leather industry in Poland amounted to PLN 2.57 billion. 5,350 of companies operated in Poland in 2019 in the leather industry, which was 3.78% lower than the number of companies operating in that industry in 2018. According to the latest "Statistics of the Footwear Industry" developed by the Polish Chamber of Leather Industry, in Poland in 2019 there were 3,265 footwear manufacturers; 1,717 manufacturers of luggage bags, handbags and similar leather goods as well as saddlery; and 368 companies dealing with leather tanning, and fur tanning. The leather industry production output in the years 2017–2019 is presented in Table 3.2. The production output figures include the total volume of finished products manufactured from own or entrusted raw materials in a calendar year, intended for sale, as well as for further processing within the enterprise (i.e. used for manufacturing purposes). The footwear production output in Poland in 2019 decreased by 15% as compared to 2018. The production output of tanned bovine hides or tanned equine skin without hair on substantially decreased (38%). In 2019 the production output of hand-made leather bags increased by 8.77%.[4]

Table 3.1.2. Leather industry production output for 2017–2019

Sector	Unit	2017	2018	2019	Change % 2019/2018
Footwear production output, including:	million pairs	46.61	43.43	36.88	–15.08
Waterproof footwear		3.74	4.05	3.96	–2.22
Outdoor shoes		13.97	13.89	11.36	–18.21
Slippers or other indoor footwear		2.54	2.70	1.91	–29.26
Leather footwear		14.85	11.46	9.84	–14.14
Textile footwear		8.79	8.07	7.21	–10.66
Production output – bovine hide/ horse skin, without hair on	t	22 589	20 310	12 578	–38.07
Including soft cowhide with full grain for footwear		13 496	11 999	4 429	–63.09
Production output – luggage bags, handbags and the like made of any raw material	million	4.04	4.66	3.92	–15.88
Including leather handbags		0.35	0.52	0.57	8.77

Source: Polish chamber of shoe and leather industry. Statistics of the footwear industry for 2019, source: annual collection of the Department of the Analytical Center of the Tax Administration Chamber in Warsaw approved by the Central Statistical Office, Poland, 2019, pp. 1–13.

4 Polish chamber of shoe and leather industry. Statistics of the footwear industry for 2019, source: annual collection of the Department of the Analytical Center of the Tax Administration Chamber in Warsaw approved by the Central Statistical Office, Poland, 2019, pp. 1–13.

Recently, the Polish footwear market has been growing at a high rate, as shown by the sales revenue of over EUR 4.5 billion in 2019. Poland ranks among the top fifteen exporters and importers of footwear in Central Europe. In 2015–2019 exports of the footwear industry from Poland increased by 131.3% from EUR 943 million to EUR 2.2 billion, and imports by 100.9% from EUR 1.4 billion to EUR 2.7 billion. Polish shoes are mainly exported to the EU Member States. For many years the largest importer has been Germany, accounting for 39% of the Polish exports (the figures from 2019), followed by the Czech Republic, Romania and Italy. The footwear is mainly imported from China that dominates the global market as a manufacturer of cheap footwear. In 2019 as many as 133.17 million pairs of shoes were imported from this country to Poland, which accounts for an increase of 8.79% as compared to 2018.[5] A huge amount of solid waste, a significant amount of which consists of organic matter, i.e. hair, wool, scraps, fleshing waste, planing, fats and tallow, is inherent in the processing and tanning of hides. Table 3.1.3. shows the types and amounts of solid waste output arising from processing 1 tonne of raw bovine hide.[6]

Table 3.1.3. Type, amounts of solid waste when processing 1 tonne of raw bovine hide

Type of solid waste	Treatment	Amount [kg]
Salt	Untanned	300
Hair		100
Untanned scraps		40
Lime slime		60
Fleshing waste		120
Tanned leather shavings	Tanned	95
Tanned peels		65
Dust		65
Tanned leather scraps		35
Sediments		125

Source: C.P. Framis, (2018), *Assessment of tannery solid waste management, A case of Sheba Leather Industry in Wukro (Ethiopia) – report*, Wydawnictwo ETESEIB, pp. 2–92.

5 Reference Document for the Best Available Technology: Leather tanning, JOINT RESEARCH CENTER Institute for Prospective Technological Studies, Sustainable Production and Consumption Unit European IPPC Bureau 2013. [Available at: https://docplayer.pl/8261017-Garbowanie-skor-dokument-referencyjny-dotyczacy-najlepszych-dostepnych-technik-bat-dla.html (accessed: 07.08.2023)] (in Polish).

6 C.P. Framis, (2018), *Assessment of tannery solid waste management, A case of Sheba Leather Industry in Wukro (Ethiopia) – report*, Wydawnictwo ETESEIB, pp. 2–92.

According to the Central Statistical Office, the volume of solid waste generated in this section in 2019 equaled 55.1 thousand tonnes, out of which as much as 53.6 thousand tonnes was handed to be reused. However, it should be remembered that animal skin itself is a by-product of the meat industry. Within this context, leather manufacturing itself is an example of effective management of production residue, which is in line with the principles of the circular economy. According to the figures published by the Central Statistical Office and the reference document (BREF) for tanning,[7] in 2019 the domestic leather industry generated approx. tonnes of solid waste. For every 4 tonnes of raw leather subjected to tanning processes, 1 tonne of solid waste is estimated to be produced. Furthermore, residue typically makes up 2 to 20% of the weight of tanned leather – that's more than 2 kg of solid waste for every square meter of a finished leather product. The amounts of solid waste output in the leather industry in 2018 are listed in Table 3.1.4.

Table 3.1.4. Solid waste output in the leather industry in 2018

	Annual Solid Waste Volume		**Solid Waste Stored so far in 2018**
	In general	**Provided to be reused**	
Manufacture of textile products [thousand of tonnes]	6.6	6.6	–
Manufacture of leather and leather goods [thousand of tonnes]	55.1	53.6	31.4

Source: Reference Document for the Best Available Technology: Leather tanning, Joint Research Center Institute for Prospective Technological Studies, Sustainable Production and Consumption Unit European IPPC Bureau 2013. [Available at: https://docplayer.pl/8261017-Garbowanie-skor-dokument-referencyjny-dotyczacy-najlepszych-dostepnych-technik-bat-dla.html (accessed: 07.08.2023)] (in Polish).

The physical and chemical characteristics of solid tannery waste depend on the composition of the hides and the agents applied the hides. Raw hides contain over 50% of carbon, 25% of oxygen, 17.8% of nitrogen and 7% of hydrogen, as well as small amounts of mineral salts and sulphur. In the case of goat skin, the average fat content is 5–10%, in sheepskin it is 5–30%, in pig skins it can even reach 40%. Leather with a significant fat content will actually consist of proportionally less

7 Reference Document for the Best Available Technology: Leather tanning, Joint Research Center Institute for Prospective Technological Studies, Sustainable Production and Consumption Unit European IPPC Bureau 2013. [Available at: https://docplayer.pl/8261017-Garbowanie-skor-dokument-referencyjny-dotyczacy-najlepszych-dostepnych-technik-bat-dla.html (accessed: 07.08.2023)] (in Polish).

water. In turn, bovine hides contain about 60–65% of water, 30–33% of protein, 0.5% of minerals, 2% of fats and other ingredients.[8] The composition of leather waste depends on the stage from which it is obtained. For example, waste obtained after the fleshing process will be characterised by a higher amount of fat, while after the chrome plating process it will contain chromium (III). Sewage sludge, in turn, contains less organic matter (65%) than waste obtained from the tanning process (87.5%). By-products in the leather industry are primarily an important source of good quality collagen and collagen hydrolysates, which may have many applications in various industries. Collagen hydrolysates contain, depending on the method of obtaining them, from 8% to 35% of solid matter, from 0.5% to 35.5% of ash, from 14% to 16% of nitrogen, 83% to 87% of organic matter, 0–2% of nitrogen amide.[9]

Utilisation of untanned waste does not pose major problems, as it is processed into gelatine, adhesives, cosmetic preparations, artificial intestines, foil, feed or fertiliser ingredients.[10] [11] Technical gelatine may be used in cosmetics, photography or adhesives. A much bigger problem is tanned waste that may be used as secondary raw material. Therefore, effective methods of disposal management in respect of those types of solid waste have been sought for many years, e.g. for the purpose of producing biodiesel, biogas, biopolymers, adsorbents and for use in agriculture.[12] Research on the possibility of producing biodiesel and biogas from those types of solid waste seems necessary due to the ecological benefit of such a solution. Tannery waste is also an alternative to synthetic additives in the production of such materials as polymers, foil, and elastomers. Leather waste may also be used in the fertiliser industry and the production of fodder, that are crucial for the development of agriculture in Poland. The growing number of scientific reports on new methods of tanning waste management will contribute to the systematic reduction of environmental pollution. Thanks to the effective

8 S. Famielec, (2014), Doctoral dissertation *Tanning waste burning process In the tunnel furnace as their method Disposal*, Politechnika Krakowska, , Kraków.

9 D. Gendaszewska, M. Lasoń-Rydel, K. Ławińska, E. Grzesiak, P. Pipiak, (2021), *Characteristics of collagen preparations from leather wastes by the high pressure liquid chromatography method*, "Fibres & Textiles in Eastern Europe", vol. 29, pp. 75–79.

10 M. Parisi, A. Nanni, M. Colonna, (2021), *Recycling of Chrome-Tanned Leather and Its Utilization as Polymeric Materials and in Polymer-Based Composites: A Review*, "Polymers (Basel)", vol. 13, pp. 2–23.

11 K. Ławińska, M. Lasoń-Rydel, D. Gendaszewska, E. Grzesiak, K. Sieczyńska, C. Gaidau, D.G. Epure, A. Obraniak, (2019), *Coating of seeds with collagen hydrolysates from leather waste*, "Fibres & Textiles in Eastern Europe", vol. 27, pp. 59–64.

12 C.V.T. Rigueto, M.T. Nazari, C.F. De Souza, J.S. Cadore, V.B. Brião, J.S. Piccin, (2020), *Alternative techniques for caffeine removal from wastewater: an overview of opportunities and challenges*, "Journal of Water Process Engineering", vol. 35, pp. 1–12.

management of waste, benefits such as reducing CO_2 emissions to the atmosphere or obtaining new composite materials are also achieved.[13]

In the leather industry, as in many other technological industries, there is a process of automation and robotisation of the most burdensome work for human health. This process also makes it possible to increase the efficiency of the use of materials and raw materials thanks to optimisation based on more objective criteria including the reduction of the human factor as the evaluation criterion. According to Marek Górecki, President of the Management Board of the Polish Chamber of Leather: *The most important thing for the footwear and leather industry is the protection of the internal market by limiting the import of low-quality footwear and leather products from third countries, which carry the risk of substances banned in the EU and may pose a threat to consumer health. We also strive for the introduction of mandatory marking of the country of origin of all goods introduced to the intra-Community market, the so-called MADE IN. We also want to change the consumer's awareness towards perceiving leather products as fully ecological and natural products. The mission of the leather and footwear industry is the rational use of goods of natural origin, in accordance with the principles of sustainable management and widely understood recycling.*[14]

3.1.1. Implementation of the Principles of Sustainable Development

The principle of sustainable development is at the heart of all current and applicable environmental law systems. In accordance with this conceptual framework, individual legal systems seek a compromise between the needs of environmental protection and the need to influence the environment. Therefore, the principle of sustainable development focuses on finding solutions that will allow to reconcile the values protected by law and will take into account the needs of future generations.[15]

The conceptual framework of sustainable development has been the subject of interest in legal, economic and social sciences for many years. In the international arena, this conceptual framework began to take shape from 1968, during the proceedings of the UNESCO International Conference of Scientific Experts, as a result of which the "Man and the Biosphere" Programme was created. In 1972, the "Stockholm Declaration" was issued, which contained the principles of rational

13 D. Gendaszewska, D., Wieczorek, (2022), *Solid tanning waste as secondary raw materials*, "Environmental protection – new solutions and perspectives for the future", TYGIEL Scientific Publishing House, Lublin, pp. 18–36.

14 https://www.pracujwlogistyce.pl/raporty/21-raporty/7372-polskie-firmy-produkuja-46-5-mln-par-butow-rocznie-a-wartosc-tego-rynku-wynosi-3-3-mld-euro (accessed: 07.08.2023).

15 B. Rakoczy, (2015), *The procedural dimension of the principle of sustainable development*, Białostockie Studia Prawnicze, vol. 18, pp. 35–44,

resource management and planning, which is a tool for combining the needs of development with the needs of environmental protection. In 1983, on behalf of the UN, the World Commission for Environment and Development was established, which four years later presented a definition of sustainable development that is still valid in Poland. According to the Report of the World Commission on Environment and Development of the United Nations entitled "Our Common Future" (the so-called Brundtland Report) sustainable development was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The next step in the development of the conceptual framework of sustainable development was the organisation of the First Earth Summit in 1992, at which two documents were drawn up, i.e. the Declaration on Environment and Development (Earth Charter) and the Global Action Program (Agenda 21). The Earth Charter states that people are the focus of sustainable development and have the right to a healthy and creative life in harmony with nature. Agenda 21, on the other hand, is a set of recommendations and guidelines for activities in the field of protection and shaping of the human living environment in order to ensure sustainable development. In turn, in 2000, at the Millennium Summit, the United Nations Millennium Declaration was signed, according to which natural resources should be protected in a prudent manner and in accordance with the assumptions of sustainable development, and production and consumption patterns should be changed in the name of a better future for the next generations. Another declaration "The future we want" from 2012 was adopted at the World Summit in Rio de Janeiro. It defines sustainable development as "development that meets the needs of the present generations without compromising the ability to meet the needs of the next generations".[16] In 2015, during the Sustainable Development Summit, the 2030 Agenda was adopted, which includes 17 global goals and 169 related tasks. This document is historically significant as it establishes an action plan for people, planet and prosperity. The Sustainable Development Goals are interdependent and indivisible and ensure a balance between the three aspects of sustainable development – economic, social and environmental. The 2030 Agenda, which is to be fully implemented by 2030, strongly emphasises human rights and dignity, the rule of law, justice and non-discrimination. Economic growth based on sustainable consumption and production patterns is essential, and the use of natural resources – from air to soil, from rivers, lakes and aquifers to seas and oceans – is sustainable.[17]

The conceptual framework of sustainable development can also be found in publications by foreign authors and has been proposed by institutions dealing directly

16 *The Future We Want*, RIO+20, United Nations Conference on Sustainable Development, Rio de Janeiro, Brazil, June 20–22, 2011.

17 https://izrs.eu/aktualnosci/prawnik-przyszlosci---lider-zrownowazonego-rozwoju (accessed: 07.08.2023).

or indirectly with monitoring the degree of achieving sustainable development. Table 3.1.5. presents exemplary definitions of this term. The analysis of those definitions indicates that the conceptual framework of sustainable development is defined in various ways and, depending on the approach, it may refer to various aspects of the social life. The common element is paying special attention to the environment of a given society and the role and place of man in taking care of natural resources and the quality of life. As mentioned earlier, the conceptual framework of sustainable development can be analysed in economic and environmental terms.[18]

Table 3.1.5. The conceptual framework of sustainable development in international terms

Definition source	What should be balanced	What should be developed
Wellbeing Index	A state in which an ecosystem maintains its diversity and quality, and therefore its ability to support humans and other living things, and the potential to adapt to change and provide a wide range of choices and opportunities in the future.	A state in which all members of the society are able to identify and meet their needs and have a wide range of options to realise their potential.
Environmental Sustainability Index	Maintaining key environmental systems at a „healthy" level and improving them instead of worsening, with low anthropogenic stress that does not threaten those systems.	Immune to environmental disturbances. Humans and social systems are not sensitive to health or food, and become less sensitive to environmental disturbances; it is a sign that society is on the way to greater ‚sustainability'; Social institutions and patterns, skills, attitudes and networks effectively support action on environmental challenges and cooperation between countries in managing common environmental problems.
Global Reporting Initiative	Reduced consumption of raw materials and reduced emissions and environmental pollution from the production or use of the product.	Profitability, employment, workforce diversity, workforce dignity, employee health/safety in professional and private life.

Source: A. Rudnicka, M. Kostrzewska, (2020), *Sewn with class. The clothing industry in the face of social and environmental challenges*, University of Lodz Publishing House, Lodz [Available at: https://wydawnictwo.uni.lodz.pl/wp-content/uploads/2020/07/Rudnicka_UszyteZklasa_ONLINE-.pdf (accessed: 07.08.2023)]; R.W. Kates et al., (2005), *What is sustainable development? Goals, indicators, values, and practice*, "Environment: Science and Policy for Sustainable Development", vol. 47, no. 3, pp. 8–21.

18 A. Rudnicka, M. Kostrzewska, (2020), Sewn with class. The clothing industry in the face of social and environmental challenges, University of Lodz Publishing House, Lodz [Available at: https://wydawnictwo.uni.lodz.pl/wp-content/uploads/2020/07/Rudnicka_UszyteZklasa_ONLINE-.pdf (accessed: 07.08.2023)].

Globalisation and technological progress have a significant impact on the operations of most industries, including the footwear industry. In order to maintain a strong position in the market, enterprises in the textile, clothing and leather industry need to set out the effective strategies and constantly solve problems that directly affect them. The well-known consumerism, in which social, individual and ecological costs do not count, begins to take on enormous proportions. This may have an impact on the natural environment through its excessive pollution. Observing current trends, contemporary consumers are increasingly aware of the negative effects on the environment that the products purchased and used by them may have. For this reason, modern product design increasingly focuses on natural materials or refers to ecology.[19] Unfortunately, the leather industry itself is associated with harmful processes that have an adverse impact on the environment and the health of workers. The most damaging processes include: tanning, processing of animal skin into finished leather products and the leather goods manufacturing stage. The use of chemicals and improper disposal of waste, including the discharge of untreated wastewater, is also a huge health and safety concern for the industry. Unfortunately, there are many threats, from chemicals used in the leather manufacturing, toxins contained in adhesives and plastics, through cheap labour, to environmental costs of production – contamination of water, soil and air resources by waste, sewage.[20] It is therefore necessary to increase efforts in the leather industry in the field of systematic business risk self-assessment and ensure respect for labour and human rights throughout the global supply chain, in particular in the aspects of ensuring a living wage, health and safety and transparency. Such activities for sustainable development and environmental protection are carried out by the nationwide Buy Responsible Foundation established in 2002. It places great emphasis on the cooperation with other NGOs, both at the national and international level. This organisation is also active in the field of responsible consumption and production as well as respecting human rights and environmental protection principles in business.[21] The Foundation focuses on five key areas:

- Improving working conditions in all parts of the production supply chain (from tanneries to factories), including decent wages, permanent employment contracts, protection of vulnerable groups of workers, acceptable working hours;

19 P.K. Olszewski, J. Kwiecień, (2017), *Slow fashion in the footwear industry – consumer and entrepreneur perception in the light of sustainable development policy*, "Product Technology and Quality", vol. 62, pp. 39–52.

20 P. Portich, Footwear Industry, ILO [MOP], 29 March 2011, http://iloencyclopaedia.org/part-xiv-42166/leather-fur-and-footwear/143-88-leather-fur-and-footwear/footwear-industry (accessed: 07.08.2023).

21 https://ekonsument.pl/s56_co_robimy.html (accessed: 07.08.2023).

- Occupational health and safety (OSH) for workers in all parts of the manufacturing supply chain, including safety measures and audits for hazardous substances and materials used in the production process;
- The right to freedom of association, including ensuring good labour relations, effective resolution of labour disputes and active support for labour and trade union rights;
- Counteracting environmental problems in the production of leather and footwear, including striving to eliminate toxic and hazardous substances, increasing the use of environmentally friendly materials and processes, sustainable waste management, transport;
- Transparency and traceability of the supply chain, including the publication of audit results, supplier lists, information on grievance mechanisms, disclosure of wages.[22]

The Foundation emphasises that a permanent solution to the problems common in the production of footwear and leather tanning can only be solved by key stakeholders in this industry, i.e. brands, suppliers, trade unions, employers' federations, NGOs, and government representatives. Currently, the term responsible fashion, i.e. one that is created in a way that respects the natural ecosystem and man, in the social and ecological aspect, is gaining importance.[23] It is important to realise that sustainability is not a matter of choice. It is a key element in ensuring a secure future for each company and creating value for all consumers and stakeholders. Due to the increased awareness of the conceptual framework of sustainable development, a number of activities are implemented to implement it. Such actions include selective collection of solid waste, application of the best available techniques (BAT) and product life cycle planning.

The conceptual framework of sustainable development results in the implementation of the principles of selective solid waste collection. Thanks to it, you can reduce the space for solid waste and landfills. One of the most important aspects is that the solid waste becomes a raw material, so there is a saving of real raw materials. Thanks to that, the raw materials will suffice for a longer period of time. The next step will be to plan the consumption of energy and raw materials through an in-depth analysis of the production process. In this way, it will be possible to implement modifications, thanks to which it will be possible to minimise the amount of raw materials and energy used, as well as solid waste output. The Polish law has already set forth the obligation to use the best available techniques (BAT). The idea of implementing this standard is to introduce the most material- and

22 D. Muller, A. Paluszekiw, (2017), *Towards better solutions. Good practices in the footwear industry* – Report prepared as part of the international campaign Buy Responsibly Shoes. Publisher: Buy Responsibly Foundation, Krakow/Warsaw 2017, https://www.ekonsument.pl/materialy/publ_660_strone_lepszych_praktyk_strony.pdf (accessed: 07.08.2023).

23 https://ekonsument.pl/s56_co_robimy.html (accessed: 07.08.2023).

energy-intensive and economical techniques. In 2013–2016, the Life+ ShoeBAT Project was implemented in Poland, Spain and Italy. That Project analysed the BAT knowledge of companies in the leather and footwear industries. The aim of the Project was to increase the knowledge and use of the most environmentally friendly technologies in the tanning and footwear industries. In the initial phase of the Project, more than 80 best available techniques (BAT) were identified and companies' knowledge in this area was assessed. The results of the survey showed that 65% of the surveyed footwear companies had never heard of the BAT. Interestingly, the BAT awareness was higher (61%) for tanneries, which is probably the result of the development of the BAT reference document for tanning technologies.[24] The footwear industry does not have any of the BAT reference documents, therefore, as part of the ShoeBAT Project, a list of technologies meeting the criteria for this industry was developed.[25] In order to expand the knowledge in the area under consideration, an internet platform was created to contain information on the best available techniques (BAT) for the leather and footwear industries. The platform is available in four languages, i.e. Polish, English, Italian and Spanish.[26] It includes an intuitive graphical interface, showing the various stages of the footwear and leather goods manufacturing process. A data sheet has been developed for each technique, containing, among others, technical descriptions of equipment necessary to implement production processes, obtained environmental benefits, economic factors related to their introduction, applicable laws and regulations. The result of the Project is the implementation of the following best available technologies (BAT) in 17 European companies producing footwear and leather products: replacement of halogen organic compounds used for degreasing leather, computer-aided design of footwear and cutting elements, use of water-based adhesives (100% solid adhesives or hot-melts), replacement of pigments and dyes containing metal complexes and replacement of nitrogenous compounds used in the post-tanning phase, prevention of hexavalent chromium formation in the post-tanning phase, use of biocides approved by the European Union and efficient use of rainwater. The effect of those activities is to reduce the impact of enterprises on the natural environment and human health. Enterprises, that have implemented the BAT, have reduced the number of hazards at work (thanks to the reduction of solvent emissions), reduced the number of stages in the gluing process, which saves time and energy consumption in the footwear production process, and saves time

24 Reference Document for the Best Available Technology: Leather tanning, JOINT RESEARCH CENTER Institute for Prospective Technological Studies, Sustainable Production and Consumption Unit European IPPC Bureau 2013. [Available at: https://docplayer.pl/8261017-Garbowanie-skor-dokument-referencyjny-dotyczacy-najlepszych-dostepnych-technik-bat-dla.html (accessed: 07.08.2023)].

25 http://www.life-shoebat.eu/pl/ (accessed: 07.02.2023).

26 https://www.parp.gov.pl/storage/publications/pdf/sektor-moda_raport_24-06-2020.pdf (accessed: 07.08.2023).

and materials in the punching process. In addition, it has caused the reduction in the amount of nitrogen in the tannery effluent, the reduction in the toxicity of the effluent due to the presence of biocides, and the reduction in hexavalent chromium and metal content in the finished leather. In effect it has also mitigated problems related to allergic reactions caused by contact with leather products. Moreover, the absence of chlorides in the degreasing phase of the tanning process has been noted. Finally, a 20% reduction in water consumption in the tanning process, a 20% reduction in pollutants in the tanning wastewater, an 80% reduction in the sulphide content in the wastewater, a 60% reduction in the chromium salt content in the wastewater and a reduction in the amount of water used in the leather production process have been accomplished. The analysis of the life cycle of products from the moment of their production through operation and use to withdrawal from use is also important in the perspective of implementing the principles of sustainable development. The point is that each item is designed in such a way that it is as durable as possible and can be used for as long as possible. Care is taken to ensure that no waste is generated during its operation, so that there is no emission of pollutants. Such an object, after its use, is to be easily disassembled into parts consisting of one type of raw material, and those raw materials are to be reused.[27]

Summing up, it should be emphasised that although the principle of sustainable development is not a procedural principle, it plays an important role in the application of law, especially as far as the environmental protection law is concerned. Hence, we can talk about its procedural dimension. Sustainable development-oriented fashion requires joint actions and consistency from the entire business sector. Only in this way is it possible to achieve an optimal state. Managing environmental and social aspects in the footwear and clothing industry in a conscious and comprehensive manner requires rethinking such basic business constructs as the main purpose of operation, the method of creating value or building relationships in the supply chain.

3.1.2. Utilisation of Production Residue

3.1.2.1. Plant Biostimulators

Modern agriculture is associated with intensive production, which is aimed at improving the quantity and quality of the crop, as well as increasing the profitability of farms. Therefore, proper nutrition of cultivated plants has become of great importance for agriculture. In the agriculture of the 20th century, mineral fertilisers were the main source of nutrients for crops. At present, efforts are being made to precisely adjust appropriate fertilisation to soil conditions as well as

27 https://histmag.org/Ekologia-spoleczenstwo-gospodarka-koncepcja-zrownowazonego-rozwoju.-952 (accessed: 07.08.2023).

to the requirements of specific varieties of crops. Their role is to provide plants with easily assimilable nutrients in the form of single elements or simple organic compounds.[28] Increasing the value of food products should go hand in hand with maximising production per unit area while minimising the environmental impact. Achieving this goal will be possible thanks to the use of economically viable, ecologically sustainable and socially acceptable means in agricultural crops. Those features are characteristic of plant biostimulants that are becoming more and more popular among breeders, as evidenced by the constant increase in their economic importance.[29] Pursuant to the Act of 10 July 2007 on fertilisers and fertilisation,[30] a growth stimulant is an organic or mineral compound, or a mixture thereof, which has a positive effect on plant development or other plant life processes, with the exception of a growth regulator being a plant protection product within the meaning of the provisions on plant protection. The latter is understood as agents that affect the life processes of plants, for example through substances that regulate the plant, other than nutrients.[31] The association of producers of biostimulants, the European Biostimulants Industry Council (EBIC), has proposed a definition of a biostimulant as a fertilising product that, regardless of the content of nutrients, contains an active substance(s) or microorganisms. When applied to a plant, this material stimulates natural processes that lead to an improvement in one or more of the following characteristics of the plant: nutrient utilisation efficiency, tolerance to abiotic stress, or crop quality characteristics. During the First World Scientific Congress devoted to the use of biostimulants in agriculture, which took place in November 2012 in Strasbourg, their classification was presented, taking into account the following groups: humic substances, complex organic materials, components of mineral origin, inorganic salts (containing phosphite), seaweed extracts sea salts, chitin and chitosan derivatives, antitranspirants (substances used as foliar that limits transpiration) and free amino acids and other nitrogenous compounds. The latter are particularly noteworthy because they can be obtained from the waste biomass of the tanning industry. It is one of the methods of solid waste management in line with the principles of circular economy. Plant stimulants also include microbial inoculants. The operational efficiency of the most common groups of stimulants in the Polish market, including biostimulants obtained from tannery waste, is discussed below.[32]

28 P. Pipiak, M. Skwarek, (2020), *The use of amino acid fertilizers in agriculture*, "Technology and Quality of Products", vol. 65, pp. 144–157.

29 P. Hara, (2019), *The importance of biostimulators in potato cultivation*, "Polish potato", vol. 2, pp. 18–24.

30 Dz.U. Nr 147, poz. 1033, 2007: Act of 10 July 2007 on fertilizers and fertilization.

31 Dz.Urz. WE, 24.11.2009: Regulation (EC) No. 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414 EEC.

32 A. Rutkowska, (2016), *Biostimulators in modern plant cultivation*, "ISSUE", vol. 48, pp. 65–80.

Microbial inoculants, or in other words, microbial stimulators, contain microorganisms that, when applied to grain, plant surface or soil, support plant growth through various mechanisms, including: increasing the uptake of nutrients, root mass growth or accumulation of plant biomass. Microbial preparations contain free-living bacteria and fungi, including mycorrhizal fungi, which are isolated from soil, plants, water and composted manure. Microbial stimulators include, among others: plant-growth promoting rhizobacteria (PGPR) (Figure 3.1.1.). Currently, several dozen PGPR strains are known. Bacteria that promote plant growth and development belong to different phylogenetic groups. The most abundant group includes bacteria of the genus Pseudomonas, as well as Bacillus, Enterobacter and Erwinia.[33] PGPR bacteria colonise the soil thanks to their ability to adapt to various environmental conditions, the ability to grow quickly and metabolise many compounds. PGPR stimulate plant growth in a direct and indirect way. The first one consists in the production of growth-stimulating phytohormones, reducing the level of ethylene and facilitating the uptake of mineral compounds. On the other hand, indirect stimulation is based on protection against phytopathogens.[34] The improvement of the nutritional status of plants under the influence of the use of microbial inoculants also occurs by increasing the pool of soil nitrogen, derived from the binding of atmospheric nitrogen by the so-called diazotrophic bacteria.[35] Biopreparations containing beneficial soil microorganisms isolated from climatic and soil conditions other than Poland are already available in the European market, but their use in combating diseases and pests in Polish conditions is often associated with low effectiveness. The number of offered natural fertilisers enriched with useful microorganisms, suitable for organic cultivation of horticultural and agricultural plants, is still small. On the other hand, the interest of the market in microbiological bioproducts is dynamically growing, which creates the need to implement new microbiological bioproducts into agricultural practice.

Humic acids constitute another important group among biostimulators. Those are preparations containing humic substances (HS) including humic and fulvic acids. HS improve the structure and fertility of the soil and influence the uptake of nutrients by plants. Those substances, affecting the physical, chemical and microbiological properties of the soil, facilitate the absorption of nutrients by plants and thus affect their growth and development of the root system. Changes in plant physiology result mainly from increased enzymatic activity and water

33 Ibidem, pp. 65–80.

34 G. Dąbrowska, E. Zdziechowska, (2015), *The role of rhizobacteria in the stimulation of the growth and development processes and protection of plants against environmental factors*, "Progress in Plant Protection", vol. 55, no. 4, pp. 498–506.

35 A. Rutkowska, (2016), *Biostimulators in modern…*

retention in the leaves.[36] Anjum et al.[37] showed that the treatment of maize with fulvic acid caused an increase in the intensity of photosynthesis, transpiration rate and intercellular CO2 concentration, which was associated with the stimulation of plant growth. In turn, Ezzat et al. (2009) showed that the use of 4% of the solution of humic substances in the form of foliar application significantly improved the physiological parameters of potato plants, expressed in height, number of stems, leaf area and dry weight of plants. The authors attributed those changes to increased water retention, nutrient uptake, and improved photosynthesis. An important problem in agricultural crops is the progressive shortage of water in the soil. The key to solve this problem is the optimal management of organic matter and the more widespread use of biotechnological solutions based on natural biohumus and humic acids obtained from domestic raw materials such as peat, compost or lignite. Actions to increase the content of humus in Polish soil constitute the strategy that will allow to increase the water capacity of agricultural land in the long term.[38]

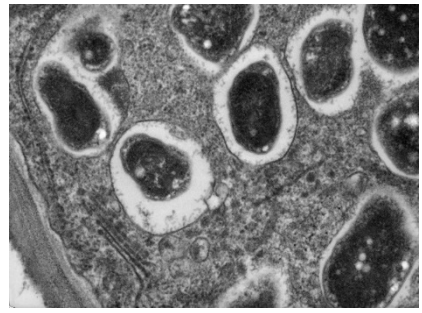

Figure 3.1.1. The rhizobacteria colonises the soybean roots
Source: https://en.wikipedia.org/wiki/Rhizobacteria (accessed: 07.08.2023).

Seaweed extracts are also products that are increasingly used in agriculture around the world. Particular interest in those products is associated primarily with the pro-ecological trend in plant cultivation and greater care for the natural environment and food safety. Literature reports emphasise the beneficial effect of algae on increasing the yield of plants, their condition, increasing resistance to pests or pathogens. Many researchers also emphasise the importance of marine algae in counteracting the effects of stress factors for crop plants, such as: excessive salinity, high temperature, cold, etc., and attribute an antioxidant effect in the

36 P. Hara, (2019), *The importance of …*
37 S.A. Anjum, L. Wang, M. Farooq, L. Xue, S. Ali, (2011), Fulvic acid application improves the maize performance under well- watered and drought conditions, "Journal of Agronomy and Crop Science", vol. 197, pp. 409–417.
38 D. Gawroński, (2021), *Reducing the effects of drought in crops by using humic acids and biohumus*, "Agricultural advisory issues", vol. 2, no. 104, pp. 48–59.

plant to them.[39] Sea algae-based biostimulants are mainly obtained by extracting red or green seaweed. However, a lot of attention is also paid to the production of natural preparations from brown algae (Phaeophyceae), from such species as: Ascophyllum nodosum, Ecklonia maxima, Durvillaea potatorum, Durvillaea antarctica, Fucus serratus, Himanthalia elongata, Laminaria digitata. Sea algae vary in chemical composition and, to some extent, also in their properties.[40] The greatest biostimulating properties are attributed to brown algae (Figure 3.1.2.). The physiological activity of algae extracts is due to the alginic acids, numerous polysaccharides and amino acids contained in them, but in particular the plant hormones found in all plants: auxins and cytokinins.

Figure 3.1.2. Brown seaweeds
Source: http://www.wildsingapore.com/wildfacts/plants/seaweed/phaeophyta/phaeophyta.html (accessed: 07.08.2023).

Prajapati et al. (2016), evaluating the possibility of using Kappaphycus alvarezii and Gracilaria edulis extracts in potato cultivation, found that their foliar application resulted in taller plants and more stems as compared to the control group, where only water was used. According to the authors, this effect was possible due to the content of growth regulators in biostimulators: auxins, cytokines and gibberellins.[41] In turn, Matysiak et al. (2012) conducted a field study to evaluate the effect of Ecklonia maxima (kelp) algae extract used as Kelpak SL on winter wheat plants. In the course of the research, the beneficial effect of sea algae extract on the weight of 1000 grains, yield, grain density, protein, starch and gluten content in the period of drought or semi-drought was confirmed. An increase in plant yield was noted on all objects where algae were applied.[42] It can therefore be concluded

39 K. Matysiak, S. Kaczmarek, R. Kierzek, (2012), *Effect of Ecklonia maxima (Kelpak SL) marine algae extract on winter oilseed rape plants*, "OILSEED CROPS", vol. 33, pp. 43–49.

40 P. Hara, (2019), *The importance of …*

41 P. Hara, (2019), *The importance of …*

42 K. Matysiak, S. Kaczmarek, D. Leszczyska, (2012), *Influence Of Liquid Seaweed Extract of Ecklonia Maxima On Winter Wheat Cv Tonacja*, "Journal of Research and Applications in Agricultural Engineering", vol. 57, no. 4, pp. 44–47.

that marine algae, especially from the brown algae class, are a valuable source of bioactive substances that stimulate plant life processes, have a beneficial effect on the soil and soil microorganisms. Their stimulating effect has been scientifically proven many times but some of the mechanisms of action remain unexplained, which poses a number of challenges to scientists.

Biopreparations based on free amino acids constitute still another group of biostimulants called protein hydrolysates. Those preparations are defined as "mixtures of polypeptides, oligopeptides and amino acids that are produced from protein sources by partial hydrolysis".[43] Fertiliser products based on protein can be divided into protein hydrolysates consisting of a mixture of peptides and amino acids or preparations containing single amino acids.[44] It is extremely important that protein hydrolysates can be produced from animal waste, e.g. animal and fish skin or plant biomass, e.g. from legume seeds.[45] Obtaining those hydrolysates is possible thanks to chemical, thermal or enzymatic hydrolysis.[46] The use of animal waste for the production of biostimulants is consistent with the circular economy and is the opportunity to reduce environmental pollution associated with the storage of this type of solid waste. It is estimated that the market of biostimulants in 2018 reached USD 2.241 billion. In Europe, the economic value of those preparations is estimated to amount to EUR 200–400 million.[47] On a global scale, most amino acid fertilisers for agriculture are produced in Italy, Spain, the United States, China and India. Amino acid fertilisers are available in the form of liquid extracts, soluble powder or granules and can be applied to the soil or foliar. Commercially available preparations vary in composition and content of amino acids.[48]

Amino acids are well-known biostimulants that directly and indirectly affect the growth and yield of plants. This is due to the fact that they are known precursors of proteins that perform building, metabolic and transport functions in plants. Those compounds, thanks to their structure, act as buffers that help maintain a favourable pH in the plant cell. They can also mitigate the effects of environmental stress on plants. In addition, amino acids have a positive effect on the photosynthesis process and mitochondrial respiration of plants. The advantage of their use as biostimulants is their mobility and easy transport in plants.[49] Examples of selected amino acid functions in plants are shown in Table 3.1.6.

43 P. Hara, (2019), *The importance of …*

44 P. Pipiak, M. Skwarek, (2020), *The use of amino acid…*

45 G. Colla, L. Hoagland, M. Ruzzi, M. Cardarelli, P. Bonini, R. Canaguier, Y. Rouphael, (2017), *Biostimulant action of protein hydrolysates: unraveling their effects on plant physiology and microbiome*, "Frontiers in Plant Science", vol. 8, p. 2202.

46 P. Pipiak, M. Skwarek, (2020), *The use of amino acid…*

47 P. Hara, (2019), *The importance of …*

48 P. Pipiak, M. Skwarek, (2020), *The use of amino acid…*

49 Ibidem.

Table 3.1.6. Selected functions of amino acids in plants, where Gly – Glycylglycine, Ala – Alanine, Pro – Proline, Hyp – Hydroxyproline, Phe – Phenylalanine, Ser – Serine, Thr – Threonine, Arg – Arginine, Asp – Aspartic acid, Glu – Glutamic acid

Code	Role in plant
Gly	Chelating agent; chlorophyll precursor that boosts the efficiency of photosynthesis.
Ala	Participates in resistance to low temperature; stimulates the synthesis of chlorophyll; participates in hormone metabolism; stimulates the mechanism of resistance to viruses.
Pro	Stress response marker; improves pollen fertility and fruit setting; regulates water management in the plant.
Hyp	Stress response marker; improves pollen fertility and fruit setting; regulates water management in the plant.
Phe	Triggers germination; precursor of lignin and lignified tissues.
Ser	Auxin precursor; participates in the regulation of water balance; necessary for the synthesis of chlorophyll.
Thr	Stimulates seed germination.
Arg	Participates in resistance to low temperature; polyamine precursor; necessary to trigger cell division.
Asp	Stimulates seed germination.
Glu	Chelating agent; growth stimulator; stimulates germination; is a reserve pool of organic nitrogen necessary for the synthesis of other amino acids and proteins.

Source: P. Pipiak, M. Skwarek, (2020), *The use of amino acid fertilizers in agriculture*, "Technology and Quality of Products", vol. 65, p. 144–157.

In the related literature one can find many studies describing the beneficial effect of amino acid agents on plant growth, especially in conditions of environmental stress. The study by Sadak et al. (2015) describes the assessment of the effect of exogenous amino acid treatment on faba bean growing under salt stress conditions. They aimed at assessing the reduction of salinity damage to faba bean by using a mixture of amino acids in order to improve morphological and biochemical parameters, and thus to increase the plant yield. The application of amino acids in the form of foliar spray significantly improved all the reduced parameters caused by sea water stress.[50] Studies conducted by Cuin et al. (2007) confirm that the use of amino acids under conditions of salt stress enables plants to maintain an optimal ratio of potassium to sodium and ultimately reduces their sensitivity to salinity.[51] In addition to salinity, water shortages also affect the deterioration of

50 M.S.H. Sadak, M.T. Abdelhamid, U. Schmidhalter, (2015), *Effect of foliar application of aminoacids on plant yield and some physiological parameters in bean plants irrigated with seawater*, "Acta Biologica Colombiana", vol. 20, pp. 141–152.

51 T.A. Cuin, S. Shabala, (2007), *Amino acids regulate salinity-induced potassium efflux in barley root epidermis*, "Planta", vol. 225, pp. 753–761.

crops. Drought is a global problem that severely limits global crop production, and recent global climate change has made this situation even worse. For this reason, Hammad and Ali (2014) conducted experiments to assess the effect of foliar spraying with amino acid biostimulants on reducing the risk of drought stress on common wheat. The obtained results showed that the use of amino acids significantly increased all the assessed parameters. It was found that the interaction between the tested water stress and biostimulants was significant for the majority of physiological characteristics as well as yield and its components.[52] The effectiveness of amino acid preparations was also demonstrated in the cultivation of alfalfa in conditions of excess water in the soil. Foliar application of amino acid preparations resulted in an increase in plant height, an increase in the amount of dry matter and an increase in protein content after the application of the tested amino acid biostimulators.[53] Temperature stress is also an important factor limiting the growth of most crop plants. The research conducted by Matysiak et al. (2020) confirmed that the exogenous application of certain amino acids had a positive effect on the growth and development of plants under stress conditions. In plants that had been obtained from seeds pretreated with L-arginine and L-glycine, the amino acids increased both root length and the number of lateral roots.[54] The growth and yield of plants are also affected by biotic stress factors, i.e. mainly microorganisms and pests. The possibility of using amino acids in plant protection against pathogens was studied, among others, at the Institute of Horticulture in Skierniewice. The amino acid preparations showed effectiveness in inhibiting the development of the fungus Sclerotinia sclerotiorum causing black bean rot. The conducted tests confirmed the effect of biostimulators on the pathogen during cultivation and storage of the tested plants. Field studies have shown high effectiveness of amino acid preparations in limiting fungal infections of beans and induction of resistance in plants.[55]

The effect of amino acid fertilisers on plant growth and crop quality is positive. Currently, in the related literature much attention is paid to the possibility of using amino acids and peptides for plant nutrition.[56] The effectiveness of the use of

52 A.R. Hammad Salwa, A.M. Ali Osama, (2014), *Physiological and biochemical studies on drought tolerance of wheat plants by application of amino acids and yeast extract*, "Annals of Agricultural Sciences", vol. 59, no. 1, pp. 133–145.

53 M. Pooryousef, K. Alizadeh, (2014), *Effect of foliar application of free amino acids on alfalfa performance under rainfed conditions*, "Research on Crops", vol. 15, pp. 254–258.

54 K. Matysiak, R. Kierzek, I. Siatkowski, J. Kowalska, R. Krawczyk, W. Miziniak, (2020), *Effect of Exogenous Application of Amino Acids L-Arginine and Glycine on Maize under Temperature Stress*, "Agronomy", vol. 10, no. 6 p. 769.

55 A.T. Wojdyła, J. Sobolewski, (2016), *The possibility of using agents containing amino acids in the protection of beans against black rot*, "Scientific Journals Institute of Horticulture", vol. 24, pp. 131–140.

56 G. Colla, L. Hoagland, M. Ruzzi, M. Cardarelli, P. Bonini, R. Canaguier, Y. Rouphael, (2017), *Biostimulant action…*

amino acid preparations in stimulating the growth of shoot and root biomass was tested during tomato cultivation in a greenhouse. Studies have shown that soil or foliar application of amino acid biostimulators increases crop yield by increasing the number of fruits and their average weight as well as the total amount of dry matter.[57] The observed increased nitrogen content in the leaves of tomatoes treated with biostimulators results from increased nitrogen assimilation, which may be based on an increase in enzyme activity or may be related to the development of the root system.[58] Another interesting solution is the use of collagen hydrolysates obtained from tannery waste in the process of coating leguminous seeds. The developed seed coats are designed to increase resistance to drought and pests during seed germination and emergence of seedlings. The encapsulation process was carried out in a disc granulator separately for three different species of legumes, including: pea, bean and soybean. For that purpose, collagen hydrolysate isolated from tannery waste was used as a binding liquid as well as a fungicide and a mineral additive. Figure 3.1.3. shows pea grains after the encapsulation process.

Figure 3.1.3. Pea grains after the encapsulation process
Source: own elaboration.

After the capsule had been formed, the seeds were sown in universal soil along with the control group, i.e. the seeds without the capsule. After a certain time following the sowing procedure, the average length of the seedlings was measured. The coating containing the collagen preparation provided the plant with favorable conditions in the early growth phase by creating a barrier protecting the sprouts against attack by pathogens. Good wettability of the granulated material, non-toxicity and adequate strength of the granule after drying are the features that justify the possibility of using collagen preparations in the seed coating process.[59, 60] This study

57 K. Ławińska, D. Gendaszewska, E. Grzesiak, J. Jagiełło, A. Obraniak, (2017), *Use of tanning waste in seed production*, "Chemical industry", vol. 96, pp. 2344–2347.

58 G. Colla, L. Hoagland, M. Ruzzi, M. Cardarelli, P. Bonini, R. Canaguier, Y. Rouphael, (2017), *Biostimulant action…*

59 K. Ławińska, M. Lasoń-Rydel, D. Gendaszewska, E. Grzesiak, K. Sieczyńska, C. Gaidau, D.G. Epure, A. Obraniak, (2019), *Coating of Seeds…*

60 K. Ławińska, D. Gendaszewska, E. Grzesiak, M. Lasoń-Rydel, A. Obraniak, (2017), *Coating legume seeds with collagen hydrolysates from tannery waste*, "Chemical Industry", vol. 96, no. 9, pp. 1877–1880.

confirmed that crop productivity was related to the availability of nutrients in the soil during the development of a given plant species.[61]

Biostimulators are natural preparations that are safe for human and animal health, and do not burden the natural environment. Their use in plant cultivation can bring many undeniable benefits.[62] Particularly noteworthy is the use of tannery waste for the production of amino acid biostimulators. Those activities make up the trend related to the concept of "clean production", waste management and minimisation of environmental burden, including the use of environmentally friendly technologies.[63]

3.1.2.2. IPS21 Strain

Leather industry waste is a serious problem for tanneries and the leather industry. It is estimated that for every tonne of raw material, as much as 50 kg of solid waste is produced. Approximately 6.5 million tonnes of raw hides are processed annually in the world.[64] That process generates approximately 325,000 tonnes of solid waste per annum. That waste, due to its harmfulness, should be properly treated. This is a problem as tanneries do not have the technology to dispose of or fully utilise this type of waste. Appropriate management and/or transformation of that waste is required in accordance with the idea of sustainable development and economic growth. In some countries, leather waste is used as a raw material for producing adhesives, gelatine, collagen, fodder or fertilisers.[65, 66] New waste treatment methods in tanneries are focused on biodegradation,[67] waste reuse[68, 69] or removal and recovery of heavy metals.[70] Tanned waste is a protein-based waste

61 D. Gendaszewska, D. Wieczorek, (2022), *Solid tanning…*

62 P. Hara, (2019), *The importance of biostimulators…*

63 K. Ławińska, D. Gendaszewska, E. Grzesiak, J. Jagiełło, A. Obraniak, (2017), Use of tanning…

64 FAO (2013), *World Statistical Compendium for Raw Hides and Skins, Leather and Leather Footwear 1993–2012*.

65 D. Masilamani, B. Madhan, G. Shanmugam, S. Palanivel, B. Narayan, (2016), *Extraction of collagen from raw trimming wastes of tannery: a waste to wealth approach*, "Journal of Cleaner Production", vol. 113, pp. 338–344.

66 M. Łaczkowska, D. Gendaszewska, E. Grzesiak, M. Lasoń-Rydel, (2016), *Review of collagen extraction methods from leather waste*, "Technology and Quality of Products", vol. 61, pp. 74–79.

67 M.S. Sanjay, D. Sudarsanam, G.A. Raj, K. Baskar, (2020), *Isolation and identification of chromium reducing bacteria from tannery effluent*, "Journal of King Saud University – Science", vol. 32, no. 1, pp. 265–271.

68 M. Skwarek, M. Wala, J. Kołodziejek, K. Sieczyńska, M. Lasoń-Rydel, K. Ławińska, A. Obraniak, (2021), *Seed coating with biowaste materials and biocides—environment-friendly biostimulation or threat?*, "Agronomy", vol. 11, p. 1034.

69 K. Ławińska, S. Szufa, R. Modrzewski, A. Obraniak, T. Wężyk, A. Rostocki, T.P. Olejnik, (2020), *Obtaining granules from waste tannery shavings and mineral additives by wet pulp granulation*, "Molecules", vol 25, no. 22, 5419, pp. 1–13.

70 L. Pietrelli, S.Ferrom, A.P. Reverberi, M. Vocciante, (2020), *Removal and recovery of heavy metals from tannery sludge subjected to plasma pyro-gasification process*, "Journal of Cleaner Production", vol. 273, p. 123166.

consisting of splits, offcuts and chips (so-called shavings) from chrome-tanned leather. Tannery chrome shavings (CTS) are small, thin pieces of leather produced during the shaving operation. They are not bio-stabilised but they contain a large amount (up to 90%) of valuable collagen.[71]

It has been proven that microorganisms can degrade collagen-based matter. The mechanism of biodegradation consists in the enzymatic decomposition of protein using alkaline proteases produced by microorganisms. Those enzymes catalyse the decomposition of protein waste, e.g. keratin and collagen, derived from technological processes in tanneries. Enzymatic hydrolysis, however, requires the use of acid and alkali pretreatment methods for the solid waste management purpose. Muhammad et al. (2006)[72] and Pillai et al. (2012)[73] describe the method of hydrolysing tannery shavings and using *Bacillus subtilis* bacteria as a chromium-resistant strain. *B. subtilis* is an alkaline protease producer that can hydrolyse chromium shavings. Those bacteria have the ability to use the thermally treated collagen contained in the shavings as the only source of protein. In the described studies, the strain tolerated chromium in the amount of up to 35 ppm and 350 ppm of Cr(VI) and Cr(III) salts and showed bioaccumulation and biosorption of chromium. In turn, another paper describes the enzymatic hydrolysis of chromium shavings by means of Alcaligenes faecalis bacteria that also show proteolytic abilities and resistance to chromium. The strain was found to have degraded about 90% of the chromium shavings within 120 hours. The analysis of the composition of the collected hydrolysates showed the content of 12% ash and 80% protein, with the main component of the hydrolysate being small peptides with a molecular weight within the range of 3–30 kDa.[74] The effective degradation of protein waste often depends on the enzymatic potential of microorganisms or on the activity of enzymes used for hydrolysing leather waste.

Candida lipolytica, Aureobasidium pullulans and *Yarrowia lipolytica* are among the yeasts reported to produce various proteases.[75, 76] Hydrolysis of solid waste,

71 K. Ławińska, S. Szufa, R. Modrzewski, A. Obraniak, T. Wężyk, A. Rostocki, T.P. Olejnik, (2020), *Obtaining granules…*

72 M.N. Aftab, A. Hameed, I. Haq, C. Run, (2006), *Biodegradation of Leather Waste by Enzymatic Treatment*, "The Chinese Journal of Process Engineering", vol. 6, no. 3, pp. 462–465.

73 P. Pillai, G. Archana, (2012), *A novel process for biodegradation and effective utilization of chrome shavings, a solid waste generated in tanneries, using chromium resistant Bacillus subtilis P13*, "Process Biochemistry", vol. 47, pp. 2116–2122.

74 C. Babu Shanthi, P. Banerjee, N.K. Babu, G. Rajakumar, (2013), *Recovery and characterization of protein hydrolysate from chrome shavings by microbial degradation*, "Journal of the American Leather Chemists Association", vol. 108, pp. 231–239.

75 R. Hernández-Martínez, A. Sancho-Solano, O. Loera-Corral, A. Rojo-Domínguez, C. Regalado-González, S. Huerta-Ochoa, L.A. Prado-Barragán, (2011), *Purification and characterization of a thermostable alkaline protease produced by Yarrowia lipolytica*, "Revista mexicana de ingeniería química", vol. 10, no. 2, pp. 333–341.

76 B. Bessadok, M. Masri, T. Brück, S. Sadok, (2017), *Characterization of the Crude Alkaline Extracellular Protease of Yarrowia lipolytica YlTun15*, "Journal of FisheriesSciences.com", vol. 11, no. 4, pp. 19–24.

generated in various industrial processes, by means of efficient yeast proteases has been widely adopted as an environmentally friendly waste management strategy.[77] The use of *Yarrowia* yeast to the extent of various waste disposal management, including fat waste or hydrocarbon impurities, is known from few literature reports.[78] The research conducted by a team of scientists from the Łukasiewicz Research Network of the Lodz Institute of Technology in 2022 focused on assessing the possibility of biodegradation of chromium shavings contained in the liquid medium by means of isolating *Yarrowia lipolytica* yeast strain. That yeast was isolated from a soil sample contaminated with petroleum hydrocarbons and a high content of sulphates, chlorides, phenols, cyanides and heavy metals. The soil sample was placed in sterile bags and transported to the laboratory. Then, cultivation, isolation and purification of the isolated microorganisms were proceeded. Several microbial isolates were obtained, including the *Yarrowia lipolytica* yeast isolate (IPS21), in result of molecular biology methods that had been applied (Figure 3.1.4.).

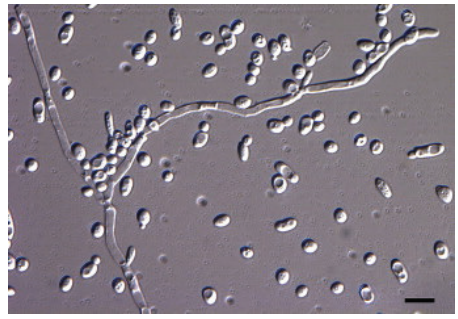

Figure 3.1.4. Single cells and filamentous cell state of *Yarrowia lipolytica*
Source: own elaboration.

The *Yarrowia lipolytica* IPS21 strain has been deposited in the patent deposit at the Institute of Biotechnology of the Agricultural and Food Industry in Warsaw under the number KKP 2089p. It is a strain of wild origin, that was selected for the research purpose out of several others belonging to the collection of the Łukasiewicz – Lodz Institute of Technology. The ability to secrete extracellular proteases had been chosen to be the selection criteria. Subsequently, studies were carried out to the extent of the utilisation of chromium protein waste arising from

77 S. Ariaeenejad, K. Kavousi, A.S.A. Mamaghani, R. Ghasemitabesh, G. Hosseini Salekdeh, (2022), *Simultaneous hydrolysis of various protein-rich industrial wastes by a naturally evolved protease from tannery wastewater microbiota*, "Science of The Total Environment", vol. 815, 152796.

78 A. Domínguez, F. J. Deive, M. Angeles Sanromán, M. A. Longo, (2010), *Biodegradation and utilization of waste cooking oil by Yarrowia lipolytica CECT 1240*, "European Journal of Lipid Science and Technology", 112(11), 1200–1208.

leather production with the use of an isolated strain of yeast. The studies resulted in the submission of a patent application No P.442578, entitled "Method of utilisation of protein waste obtained in leather production". The aim of the invention is to use the *Yarrowia lipolytica* IPS21 yeast strain to obtain a method that allows for easy and one-stage utilisation of protein waste arising from leather production – especially chrome shavings arising from tanning processes, often stored so far at the tannery plant or disposed of at landfill sites. The research outcome also included the publication in 2021, in which the authors proved the yeast used in the study to absorb the source of carbon and nitrogen from collagen. Increased pH values in the medium as well as an increased amount of selected amino acids in the relevant samples resulted from the intensive metabolism of microorganisms.[79] The subsequent publication in this regard is currently in process to confirm that *Yarrowia lipolytica* IPS21 is an ideal candidate for converting protein-rich waste into high-value products.

3.1.3. Activities for the Benefit of the Local Community

Corporate social responsibility is a management strategy according to which enterprises voluntarily take into account social interests, environmental aspects or relations with various stakeholder groups, in particular employees, as far as their business operations are concerned. Being socially responsible means investing in human resources, environmental protection, public relations, and publicity to the extent of those activities, which contributes to the increase of the company's competitiveness and triggers the conditions for sustainable social and economic development.[80] In accordance with this idea, on July 1, 2021, the Ministry of Education and Science announced the Programme titled "Science for Society", the purpose of which is to support the higher education and science system and other institutions working to the extent of the dissemination of science. Co-financing may be granted to projects focusing on the cooperation of scientists with non-governmental and social organisations and the economic operators. The Programme comes forward with financial support within the framework of three priority thematic areas: scientific excellence, science for innovation, humanities. The list of projects approved for funding under this Programme included three projects implemented in whole or in part by the Centre for Footwear Materials, Dyed Products and Food of the Łukasiewicz – Lodz Institute of Technology Research Network.

79 D. Wieczorek, M. Lasoń-Rydel, D. Gendaszewska, (2021), *The influence of the presence of tanning shavings on the growth of yeast from the Dipodascaceae family*, "Technology and Quality of Products", vol. 66, pp. 170–184.

80 https://www.parp.gov.pl/csr (accessed: 07.08.2023).

The first Project entitled „The impact of construction, materials and proper fitting of footwear on the health of children and adolescents" falls into two priority areas, i.e. scientific excellence and science for innovation. The strategic aim of the Project is to tighten cooperation between scientific and research units and the social-and-economic organisations. Accomplishment of this goal will increase the recognition of the Łukasiewicz – Lodz Institute of Technology Research Network and ensure the development of innovative projects in the field of foot prophylaxis for children and adolescents up to 15 years of age, the correct selection of footwear and insoles, and the dependence of the target solutions on the child's physical activity. The operational objective of this Project is to develop attitudes promoting a healthy lifestyle among children, parents, educators and teachers in terms of the selection of footwear by means of developing a scientific monograph as well as recommendations, guidelines and good practices to this end. Within the framework of that Project four tasks are intended to be delivered. The first task will be to carry out anthropometric measurements of the feet of children and adolescents. The second task will be completed through delivery of an educational offer and demonstration lessons as well as a media information campaign. The third task will be to develop a scientific monograph, taking into account social aspects and the relationship between science, innovation and the economy. The Project titled "The impact of construction, materials and proper fitting of footwear on the health of children and adolescents" perfectly fits into the target of the Science for Society Programme. The interdisciplinarity of the research and related outcome will raise the interest in the social concern to improve the comfort of physical activity through the appropriate selection of insoles and footwear.

The second project, that has been awarded with funding from the Ministry of Education and Science, is entitled "Innovative system of distribution of healthy and regional food". That Project, in turn, fits into three thematic areas, i.e. scientific excellence, science for innovation, humanities – society-identity. The Project comes forward with the creation of an economically and organisationally strong agricultural and food industry in Poland through effective cooperation between entities operating in the field of science, society, and economy. The major activities of the Project aim to support the creation of new distribution channels for regional food products to easily reach a wide group of potential customers with them while maintaining the highest quality standards. The Project will be implemented in three stages. The first stage will cover quantitative and qualitative analyses in the field of food along with the development of optimised methodologies as part of the control system and indication of competitive advantage. The second stage will be completed through development of an innovative distribution system for healthy and regional food, together with promotional and information activities. The third stage will encompass the dissemination of the Project deliverables in the form of international publications. In summary, the Project titled „Innovative system of distribution of healthy and regional food" will provide for the complementary

system of protection, quality assurance and promotion of regional products, that will significantly enhance the sustainable development of rural areas. The aim is also to protect and promote the cultural heritage of the countryside, which increases the attractiveness of rural areas and the development of agritourism.

The third Project, that has been implemented by the Centre for Shoe Materials, Coloured and Food Products since 2022, is entitled "Łukasiewicz for children – educational classes and workshops". That Project fits into two thematic areas of the Science for Society Programme, i.e. scientific excellence and science for innovation. The former thematic area is intended to support projects aimed at developing and implementing conceptual framework for the development of the research and teaching staff and the target relevant shape of the public perception of the Polish science. In turn, the latter thematic area, i.e. science for innovation supports projects aimed for instance at improving the effectiveness of the cooperation between science and business and disseminating knowledge about the relationship between science, innovation, and the economy. The aforementioned Project is aimed at establishing the cooperation between the Łukasiewicz Research Network – the Institute of Leather Industry and educational and care institutions in Lodz. Successful delivery of workshops offering fun in the field of ecology and innovative Polish solutions that have been created thanks to science and research as well as the cooperation with industry will allow for efficient time management in an interesting way and help broaden horizons. In addition, soft skills training conducted by employees involved in the Project will contribute to the development of specific interpersonal skills, and above all, qualifications related to presentation and public speech delivery. Four tasks are intended to be delivered within the framework of the Project. The first task will consist in delivery of an educational offer for preschool and early school children. The second task will be completed through a media campaign. Demonstration lessons will be conducted to effectively complete the third task. The fourth task will come forward with a script publicising projects implemented at the Centre for Footwear, Coloured and Food Products as well as a scientific publication. The Project will contribute to the increased recognition of the SBL-Lodz Scientific Institute.

3.2. Unit Processes for Selected Waste Disposal Management Methods in the Tanning Industry

Natural leather is the main product of the tanning industry and an intermediate product used in the consumer goods sector (footwear, clothing, haberdashery, furniture and motor cars). The solid waste generated by the leather industry may be used as a raw material for the production of new and advantageously economical

products, thus ensuring sustainable and environmentally friendly industrial practices.[81] In the leather tanning processes (chemical processes and mechanical operations that shape the leather structure) various forms of solid waste are generated[82] – those are both biologically unstable waste (untanned trimmings, peelings) and waste resulting from the tanning process (shavings, unusable splits) and dust (from dyeing and finishing processes). The related literature indicates that tannery waste is used for producing for instance biogas, biofuels, biocarbons and used as bioabsorbents, soil fertilisers, and even as adsorbents or used for treating wastewater containing dyes.[83, 84, 85, 86, 87]

According to the data of the Statistics Poland,[88] the domestic sector of leather and leather products annually generates approx. 54.5 thousand tonnes of waste, while the estimated amount of solid waste stored so far (on the premises of the plants) equals 32.9 thousand tonnes. From one tonne of rawhide, only about 225 kg accounts for the finished product, and 75% of this weight is made up of production residue. Converted to the final assortment, over 2 kg of waste falls on a square meter of finished leather. Each tannery has its own leather tanning technologies, in which individual processes depend on the selection of products for which the leather is produced.

Leather waste may be considered as a composite material that has an extensive structure due to the collagen fibre it contains.[89] The structure, density (1.30–1.34 g/cm^3) and high strength of collagen fibre (tensile strength 147.1 MPa) as well as the fact that collagen can adsorb water vapour in the amount reaching almost a half of its weight, proves the high potential of reusing that waste in circular economy.

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81 A.K. Singh, A. Raj, (2020), *Emerging and eco-friendly approaches for waste management*, "Environmental Sciences Europe", vol. 32, p. 107.

82 B. Ravindran, J.W.C. Wong, A. Selvam, K. Thirunavukarasu, G. Sekaran, (2016), *Microbial biodegradation of proteinaceous tannery solid waste and production of a novel value added product – Metalloprotease*, "Bioresource Technology", vol. 217, pp. 150–156.

83 C.B. Agustini, F. Spier, M. da Costa, M. Gutterres, (2018), *Biogas production for anaerobic co-digestion of tannery solid wastes under presence and absence of the tanning agent*, "Resources, Conservation and Recycling", vol. 130, pp. 51–59.

84 S. Amdouni, A.B.H. Trabelsi, A.M. Elasmi, R. Chagtmi, K. Haddad, F. Jamaaoui, H. Khedhira, C. Chérif, (2021), *Tannery fleshing wastes conversion into high value-added biofuels and biochars using pyrolysis process*, "Fuel", vol. 294, 120423.

85 X. Huang, F.Yu, Q. Peng, Y. Huang, (2018), *Superb adsorption capacity of biochar derived from leather shavings for Congo red*, "RSC Advances", vol. 8, pp. 29781–29788.

86 N.S.C. Pinheiro, O.W. Perez-Lopez, M. Gutterres, (2020), *Solid leather wastes as adsorbents for cationic and anionic dye removal*, "Environmental Technology", vol. 43, no. 9, pp. 1285–1293.

87 J.A. Arcibar-Orozco, B.S. Barajas-Elias, F. Caballero-Briones, L. Nielsen, J.R. Rangel-Mendez, (2019), *Hybrid carbon nanochromium composites prepared from chrome-tanned leather shavings for dye adsorption*, "Water Air and Soil Pollution", vol. 230, p. 142.

88 Rocznik Statystyczny Przemysłu. Statistical Yearbook of Industry – Poland, Warsaw 2020.

89 G. Bufalo, C. Florio, G. Cinelli, F. Lopez, F. Cuomo, L. Ambrosone, (2018), *Principles of minimal wrecking and maximum separation of solid waste to innovate tanning industries and reduce their environmental impact: The case of paperboard manufacture*, "Journal of Cleaner Production", vol. 174, pp. 324–332.

The amount, structure, and composition of the generated tannery waste were the factors determining the choice of the subject matter of this research. The activities include, in particular, tannery shavings, that have irregular shapes (which causes them to bundle up), are characterised by a very low bulk density of up to 0.1 g/cm^3 (dust over long distance), high humidity of up to 70%, which makes them environmental burden.

3.2.1. Purpose of the Work

The main objective of the research is to extend the scope of recycling of tannery waste (especially its components) and to increase the application potential of the technological solutions developed on the basis of the production residue. In addition, the work is aimed at confirming the hypothesis that individual unit processes allow for the processing of hazardous industrial waste (as exemplified by tannery residue) and increase the possibility of its reuse in other technological operations, obtaining new material as a result.

The following specific objectives have been set out:

- Identification of prospective application areas for tanning residue, given the related properties.
- Optimisation of respective unit processes in the field of waste management (i.e. screening, pressureless granulation, mixing).
- Verification of new solutions based on tannery waste (i.e. composites based on shavings and mineral additives, granules and seed coats based on collagen preparations obtained from tannery waste).

There are numerous literature reports on the potential of using waste biomass of animal and plant origin,[90] including those in the form of various granulates.[91]

3.2.2. Identification of Prospective Application Areas for Tanning Residue, Given the Related Properties

Identification of prospective application areas for tanning residue, given the related properties, was conducted on the basis of the results obtained in the field of analyses of selected (significant in terms of potential use) properties of shavings obtained in domestic tanneries. To this end, the shavings were classified in terms of the grain size and shape (according to the Zingg classification) the specific surface area, chemical composition, and the content of volatile organic compounds (VOC).

90 A. Rostocki, K. Ławińska, R. Modrzewski, G. Siegień, R. Hejft, A. Obraniak, (2022), *Methods for treatment of animal and plant-based biomass waste*, "Fibres & Textiles in Eastern Europe", vol. 30, no. 4, pp. 32–42.

91 A. Rostocki, H. Unyay, K. Ławińska, A. Obraniak, (2023), *Granulates based on bio and industrial waste and biochar in a sustainable economy*, "Energies", vol. 16, p. 56.

Table 3.2.1. Granulometric composition of tannery shavings

Fraction, mm	Weight Share, %
0–0.5	18.0
0.5–1.0	16.0
1.0–1.6	14.5
1.6–2.5	11.0
2.5–4.0	12.0
4.0–8.0	10.0
8.0–12.5	18.5

Source: own research data.

The granulometric composition of tannery shavings (Tab.3.2.1.) was determined based on a sieve analysis (on a laboratory shaker with a set of testing sieves). In order to characterise the shape of shavings, the analysis was carried out according to the Zingg classification (using the Kamik analyser) in relation to four basic grain shapes (Tab. 3.2.2.).

Table 3.2.2. Shape of shavings (according to Zingg classification)

Shape	Volume Share, %
Disc	4.93 ± 0.71
Sphere	70.14 ± 1.02
Wedge	1.17 ± 0.48
Cylinder	23.77 ± 1.52

Source: own research data.

As part of the work carried out, porosimetry testing was carried out using low-pressure gas adsorption of selected fractions of tannery shavings. Structural tests were performed by means of the volumetric adsorption analyzer ASAP 2020 (Micromeritics). On the basis of equilibrium sorption points of nitrogen adsorption, the parameters of maximum sorption capacity and specific surface were determined (the correlation coefficient of 0.999). The Brunauer-Emmett-Teller – BET model[92] was used for characterising pores filling in a multilayer manner.

92 L. López-Pérez, V. Zarubina, I. Melián-Cabrera, (2021), *The Brunauer-Emmett-Teller model on alumino-silicate mesoporous materials. How far is it from the true surface area?*, "Microporous and Mesoporous Materials", vol. 319, 111065.

Table 3.2.3. Structural parameters of the tested shavings

Fraction of shavings	Total sorption capacity cm^3/g STP	Specific surface area BET m^2/g	Adsorption equilibrium constant
< 0.5	0.60	2.63 ± 0.01	23.85
0.5–1	0.61	2.66 ± 0.01	23.67
1–2.5	0.65	2.84± 0.02	19.13
2.5–4	0.59	2.55± 0.02	20.72
> 4	0.81	3.51± 0.02	12.97

Source: own research data.

Using the method of optical emission spectrometry with inductively coupled plasma ICP-OES (spectrometer ICP-OES 5110 Agilent), the chemical composition of tannery shavings was determined in terms of the content of selected elements (metals) (Table 3.2.4.). The content of the tested elements in the samples of shavings was read from the standard curves prepared from the standards of respective metals.

Table 3.2.4. Chemical composition of shavings – content of elements in the sample [mg/kg], ND – below the detection limit

Element	Content [mg/kg]	Element	Content [mg/kg]
Ag	ND	Mn	3.095
Al	47.751	Mo	ND
As	ND	Ni	4.687
Ba	1.697	Pb	ND
Bi	ND	Sb	ND
Ca	2056.97	Se	ND
Cd	ND	Sn	<
Co	ND	Sr	1.193
Cr	10371.6	Ti	ND
Cu	ND	V	ND
Fe	490.561	Zn	6.173
Ge	ND	Zr	ND
Hg	ND	S	3231.75
Mg	1380.45	P	85.806

Source: own research data.

The gas chromatography method with mass spectrometry (GC/MS/HS) at 150°C was used for determining the content of volatile organic compounds (Tab. 3.2.5.). Samples were analysed by means of the Nexis GC-2030 Shimadzu's chromatograph equipped with MS model GCMS-QP2020 and AOC-20i headspace auto sampler.

Table 3.2.5. VOC content in tannery shavings

Substance name	Content [%]	Substance name	Content [%]
3,3-dichloropropene	1.37	triethylene glycol monododecyl ether	0.30
methylhydrazine	0.29	tetradecanal	0.22
formic acid	2.11	myristic acid	0.37
methylphosphine / formic acid	2.78	hexadecanal	2.41
propylene glycol	0.84	pentadecanal	0.26
benzaldehyde	1.04	palmitic acid methyl ester	0.88
carbitol	0.38	palitol acid	0.35
benzosulfonosal	8.75	pentadecanoic acid	3.09
8-methylnonanoic acid	0.32	linoleic acid methyl ester	0.41
4-chloro-m-cresol	16.11	methyl oleate	7.91
2-undecenal	0.29	9-octadecenoic acid methyl ester	2.51
o-hydroxybiphenyl	43.57	methyl stearate	0.41
tridecanal	0.39	cis-10-pentadecenoic acid	0.63
2-methylthiobenzothiazole	0.86	other substances	0.92
2-octylfuran	0.23		

Source: own research data.

Results obtained

- A large variation in the dimensions of respective shaving fractions has been observed (differences in the range of 0.5–12.5 mm).[93]
- The shape of the shavings is varied, but the dominant form is a sphere (70.14%) and a cylinder (23.77%).[94]
- The pore structure of the tested tannery shavings consists mainly of mesopores and macropores. This is evidenced by the relatively low value of the BET specific surface area (SSA), in the range of 2.55–3.51 m^2/g.

93 K. Ławińska, A. Obraniak, R. Modrzewski, (2019), *Granulation process of waste tanning shavings*, "Fibres & Textiles in Eastern Europe", vol. 27, no. 2(134), pp. 107–110.

94 K. Ławińska, (2021), *Production of agglomerates, composite materials, and seed coatings from tannery waste as new methods for its managemen*, "Materials", vol. 14, no. 21, p. 6695.

Comparing the tested samples to natural meso and macroporous matter, such as e.g. carbonate rocks and dolomites, tannery shavings have a similar surface area.[95]

- The analyses carried out indicate that tannery shavings contain significant amounts of elements. They constitute a useful waste from the point of view of elemental composition due to the high content of Ca, Mg, S and P as a valuable source of macroelements, structural elements. High Ca content, and additionally Na content in shavings are also indicated by the authors of the paper.[96] Taking into account the environmental aspect, it is important that there is no Pb or As.[97]
- The compounds obtained in the VOC analysis (e.g. organic acids, preservatives, surfactants, alkanes) are components of chemical preparations commonly used in leather tanning processes. The amount of substances classified (in accordance with Regulation (EC) No 1272/2008 of the European Parliament and of the Council of December 16 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45 /EC and amending Regulation (EC) No 1907/2006) as irritating or harmful to the environment constitutes a small percentage of the analysed waste.[98] In addition, there are solutions to reduce VOCs in tanning processes.[99]

3.2.3. Optimisation of Respective Unit Processes in the Field of Waste Management (i.e. Screening, Pressureless Granulation, Mixing)

The optimisation of the sieving process and non-pressure granulation[100] of tannery waste was carried out. Granulation processes were used for obtaining agglomerates from waste shavings and forming seed shells (of varied size and shape) based on

95 K. Ławińska, R. Modrzewski, A. Obraniak, (2020), *Comparison of granulation methods for tannery shavings*, "Fibres & Textiles in Eastern Europe", vol. 28, no. 5(143), pp. 119–123.

96 A. Pati, R. Chaudhary, S. Subramani, (2014), *A review on management of chrome-tanned leather shavings: a holistic paradigm to combat the environmental issues*, "Environmental Science and Pollution Research", vol. 21, pp. 11266–11282.

97 K. Ławińska, (2021), *Production of agglomerates…*

98 Ibidem.

99 R. Cuadros, A. Solà, I. Ollé, L. Otero, A. Bacardit, (2016), *Reducing the use of volatile organic compoundsin the leather industry*, "Journal of the Society of Leather Technologists and Chemists Journal", vol. 100, pp. 1–7.

100 A. Obraniak, K. Lawinska, (2017), *Spectrophotometric analysis of disintegration mechanisms (abrasion and crushing) of agglomerates during the disc granulation of dolomite*, "Granular Matter", vol. 20, p. 7.

collagen preparations (obtained from tannery waste) in order to increase their drought resistance.

Screening of shavings was carried out on steel mesh sieves with square openings (vibration frequency at 50 Hz and vibration amplitude of 1.0 mm). In the first stage, the input was sieved in a sieve with a mesh opening of 2.5 mm in size (during 20 min), while in the next stage, a fraction of shavings of 0–2.5 mm in size was sieved in a sieve with a mesh opening of 1.0 mm in size (during 10 min). In both series, it was fed to the sieve in such an amount that the initial thickness of the material layer in the sieve did not exceed twice the maximum size of the grains (the length of shavings) in the feed (it had a significant impact on the screening efficiency, which decreased sharply with the increase of the layer thickness in the sieve). The phenomenon of blocking the sieve openings, especially by grains with dimensions similar to the sieve openings (especially those with dimensions equalling or slightly larger than the mesh opening of the sieve), significantly hinders the sieving process. The dependencies in this regard are presented in the related publications[101, 102] that elaborate the description of the phenomenon of screen blocking upon by various model shapes of granular materials and types of laboratory and industrial screens (including vibrating, rotary, with a conical and drum screen), along with a statistical analysis of the obtained results.[103] The graph presented in Chart 3.2.1. shows that the optimal time for screening raw tannery shavings is 20 minutes. After this time, the change in screened and sifted matter is very small and amounts to approx. 1% of the input. Nevertheless, shavings should be considered difficult to sieve because the optimal sieving time of typical granular matter (e.g. mineral aggregates – sharp-edged shape, sand – irregular shape) usually do not exceed 5 minutes.[104] The process of sifting shavings in a sieve with mesh openings of 1.0 mm in size requires much shorter time.

101 K. Lawinska, R. Modrzewski, (2017), *Analysis of sieve holes blocking in a vibrating screen and a rotary and drum screen*, "Physicochemical Problems of Mineral Processing", vol. 53, no. 2, pp. 812–828.

102 K. Lawinska, R. Modrzewski, P. Wodzinski, (2016), *Mathematical and empirical description of screen blocking*, "Granular Matter", vol. 18, no. 13.

103 K. Lawinska, R. Modrzewski, W. Serweta, (2018), *The phenomenon of screen blocking for mixtures of varying blocking grain content*, "Gospodarka Surowcami Mineralnymi – Mineral Resources Management", vol. 34, pp. 83–96.

104 K. Lawinska, R. Modrzewski, P. Wodzinski, (2015), *Comparison of the potential of using drum and vibrating screens for segregating mineral and municipal waste*, "Rocznik Ochrona Środowiska", vol. 17, no. 2, pp. 1365–1388.

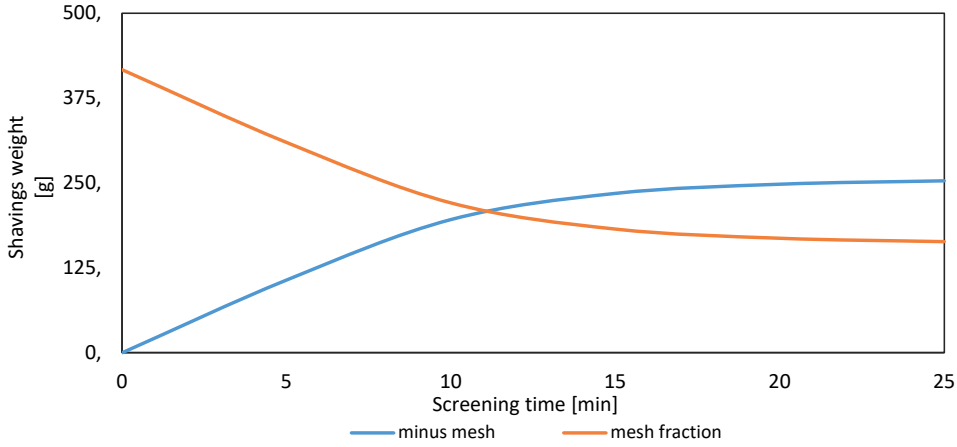

Chart 3.2.1. Determining the time of sifting shavings in a sieve with mesh openings of 2.5 mm in size
Source: own research data

Results obtained

Taking into account the large variation in the dimensions of respective fractions (differences in the range of 0.5–12.5 mm) and their tendency to agglomerate into larger agglomerates (larger fractions), it is recommended to use preliminary screening of tannery shavings for the purpose of other technological processes, especially in respect of fractions of 0–2.5 mm in size, which in total constitutes approx. 60% of total weight.[105] Thus, only approx. 40% of the input (2.5–12.5 mm fraction) requires grinding.

The process of non-pressure granulation results in agglomerates derived from tannery shavings. Three methods of shavings granulation were developed and carried out (Table 3.2.6.). The variable parameters were: the type and amount of mineral additives as well as the amount and concentration of the binding liquid (bed moisture), the method of sprinkling the bed and the sequence of adding respective components to the plate granulator. The graphs presented in Chart 3.2.2. show the granulometric composition obtained by means of the methods 1, 2 and 3 (three selected research series for each method).

105 K. Ławińska, A. Obraniak, R. Modrzewski, (2019), *Granulation process…*

Table 3.2.6. Process parameters of the tannery shavings granulation process

Conditions	Method 1	Method 2	Method 3
Apparatus	Disc granulator, disc of 1 m in diameter, disc rotation speed at 9–15 RPM, disc inclination angle of 0.15–0.3o		Vibrating disc granulator, disc of 0.55 m in diameter, inclination angle of 45o, rotational speed at 30 RPM, vibration frequency at 50 Hz, amplitude of 1 mm
Fraction of shavings, mm	0–12.5; 0–2.5	0–2.5	0–2.5; 0–1
Fine-grained additives	gypsum* (dry and wet), dolomite	gypsum* (dry and wet)	gypsum* (dry and wet), dolomite
Binding liquid	aqueous glass solution R-145 (50–75%)	aqueous glass solution R-145 (75%)	aqueous glass solution R-145 (75%)
Course of granulation processes (stages)	shavings were fed onto the granulator disc, then the mineral additive was sprinkled on the bed through a hydraulic nozzle, shavings were fed onto the granulator disc, the bed was sprinkled and then the mineral additive was applied	shavings were soaked in a binding liquid (pulp), then the granulation process of the moist pulp was carried out with the addition of selected mineral fine material (along with gradual wetting of the bed)	shavings were soaked in a binding liquid (pulp), which followed by draining the pulp, then pulp granulation was proceeded with the addition of selected mineral fine material (without addition of binding liquid/no bed sprinkling)
Other operations	–	dry shavings were mixed in a mixer with 75% glass solution until they were completely wetted (a cylindrical mixer with a low-speed anchor agitator was used)	dry shavings were mixed in a mixer with 75% glass solution until they were completely wetted (a cylindrical mixer with a low-speed anchor agitator was used), then the pulp was drained by placing it on a vibrating sieve (removal of excess moisture)

* waste gypsum, sourced from the Belchatow Power Plant, from a flue gas cleaning system
Source: own research data.

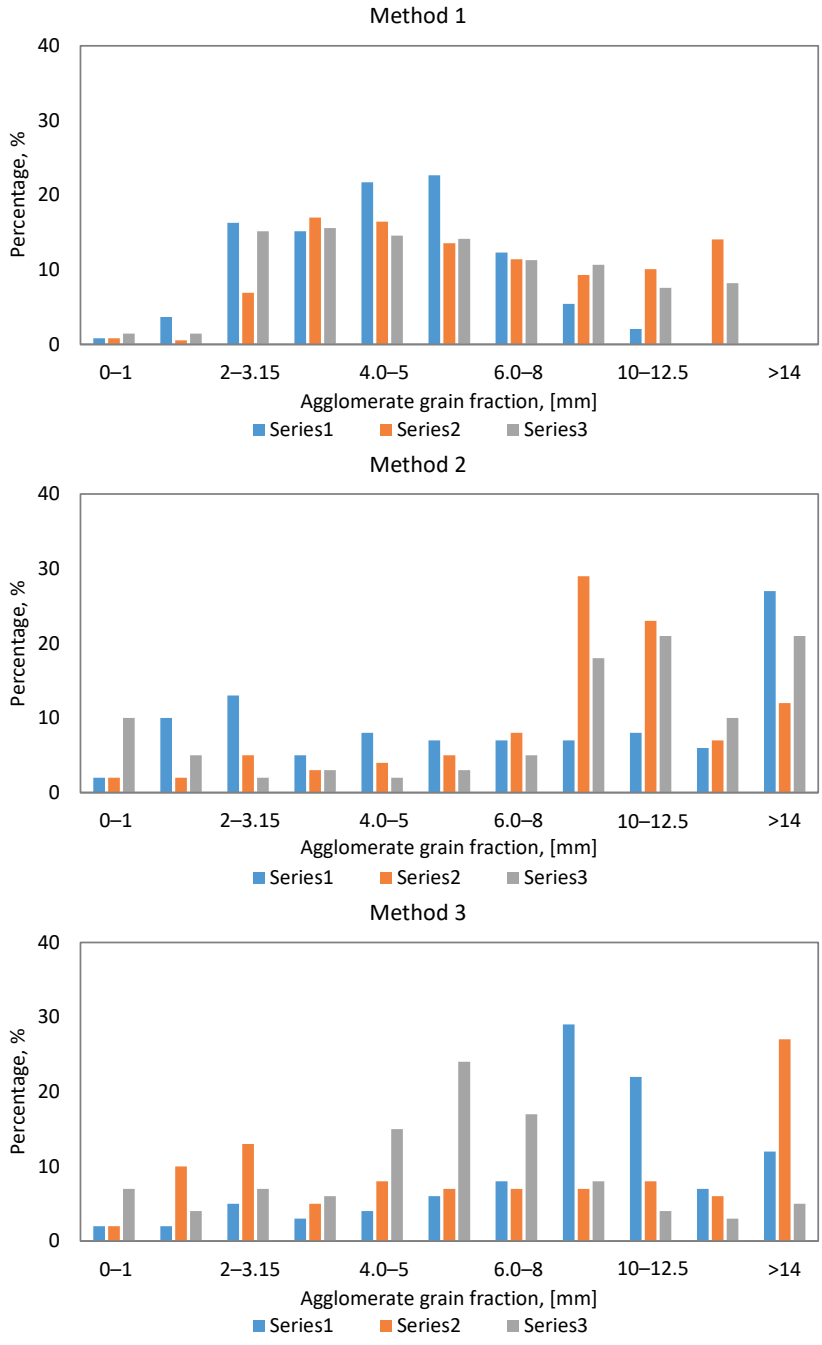

Chart 3.2.2. Granulometric compositions of the obtained agglomerates from tannery shavings (according to methods 1–3)
Source: own research data.

Results obtained

- Non-pressure granulation processes allow for granulation of the entire bed of shavings (0–12 mm fraction). It should be noted that the granules produced according to the developed methods contain a significant proportion of grains with fractions of 2–6 mm in size (especially method 1 and 3), that have the greatest application potential for their use in other processing methods (e.g., composite materials).[106]
- The developed methods of non-pressure granulation of waste allow for minimising environmental burden (related to landfilling and secondary dusting), reducing storage and transportation costs while maintaining potential reuse of processed waste.[107, 108, 109]
- Based on the research, it can be concluded that the best quality pellets are obtained from shavings previously mixed with water glass solution (pulp). Shavings that are too dry do not granulate well.[110]
- The easiest way to granulate tannery shavings is to combine them in a granulator with mineral material after the wetting stage.[111]
- The analysis of the test results indicates that granules with larger diameters were obtained for the tests carried out with higher final moisture content.[112]
- The granulation processes of waste shavings gave them regular, spherical shapes forming a loose granular bed with a bulk density on average about 5 times higher (0.4–0.6 g/cm^3) than that of loose, dry shavings (0.1 g/cm^3).[113]
- Agglomerates from tannery shavings containing both mineral and organic components can be easily stored, transported and dosed in subsequent technological operations.[114]

Non-pressure agglomeration was also used in the processes of forming capsules based on collagen preparations (obtained from tannery waste) of respective seeds. The possibility of using a disc granulator for coating seeds of leguminous plants (pea, field bean, soybean) and rape was assessed. The resulting coatings are designed to increase resistance to drought and pests during seed germination and emergence of seedlings. The characteristics of the collagen preparations used (also in terms of

106 K. Ławińska, (2021), *Production of agglomerates…*
107 K. Ławińska, S. Szufa, R. Modrzewski, A. Obraniak, T. Wężyk, A. Rostocki, T.P. Olejnik, (2020), *Obtaining granules from waste tannery shavings and mineral additives by wet pulp granulation*, "Molecules", vol. 25, no. 22, p. 5419.
108 K. Ławińska, R. Modrzewski, A. Obraniak, (2020), *Comparison of granulation…*
109 K. Ławińska, A. Obraniak, R. Modrzewski, (2019), *Granulation process…*
110 K. Ławińska, R. Modrzewski, A. Obraniak, (2020), *Comparison of granulation…*
111 K. Ławińska, A. Obraniak, R. Modrzewski, (2019), *Granulation process…*
112 K. Ławińska, R. Modrzewski, A. Obraniak, (2020), *Comparison of granulation…*
113 K. Ławińska, A. Obraniak, R. Modrzewski, (2019), *Granulation process…*
114 K. Ławińska, S. Szufa, R. Modrzewski, A. Obraniak, T. Wężyk, A. Rostocki, T.P. Olejnik, (2020), *Obtaining granules…*

a valuable source of nitrogen) were presented in the work output,[115, 116, 117] specifying the physicochemical properties and the content of respective amino acids. The collagen preparations used are transparent liquids with an average density of 1.1125 g/mL (20°C), 67.19% water content, pH 7.5. They are characterised by high contents of glycine, alanine, proline and hydroxyproline.

Optimum conditions for the encapsulation process were determined, including: disc rotational speed at 20 RPM, disc inclination angle of 45°, binding liquid was applied directly to the bed fed with seeds by sprinkling through a hydraulic nozzle. The respective layers of the shell were formed in a specific order (Figure 3.2.1.). The centrally placed seed (1) was first covered with a protective layer, e.g. of fungicides (2). The next layer was a collagen preparation (3). The outer layer of the shell (4) was a fine-grained mineral additive conducive to seed germination (e.g. dolomite, peat, waste soot was used as a source of carbon, etc.). In order to compare the obtained results, yellow dextrin and polyvinyl acid were used as a classic reference liquid[118] for the purpose of collagen preparations. In selected tests, the addition of latex (CAS: 25085-39-6) was also used for improving the stability of the collagen preparation. Output molasses derived from the sugar industry was also used as another type of binding liquid.

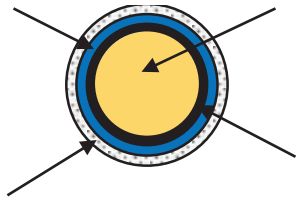

Figure 3.2.1. Layered seed coat produced on a disc granulator
Source: own research data.

As a result of seed coating on a disc granulator, complete, closed coatings were formed on single grains of legumes and rape (no agglomerates were formed) (Figure 3.2.2.). They proved good adhesion to the resulting otoliths (better for

115 K. Ławińska, M. Lasoń-Rydel, D. Gendaszewska, E. Grzesiak, K. Sieczyńska, C. Gaidau, D.G. Epure, A. Obraniak, (2019), *Coating of seeds…*

116 K. Ławińska, D. Gendaszewska, E. Grzesiak, J. Jagiełło, A. Obraniak, (2017), *Use of tanning waste in seed production*, "Przemysł Chemiczny", vol. 96/11, pp. 2344–2347.

117 D. Gendaszewska, M. Lasoń-Rydel, K. Ławińska, E. Grzesiak, P. Pipiak, (2021), *Characteristics of collagen…*

118 M. Domoradzki, W. Korpal, (2005), *Dobór materiałów do otoczkowania nasion rzodkiewki roztworem dekstryny*, "Inżynieria Rolnicza", vol. 11, no. 71, pp. 69–74.

samples in which collagen hydrolysate was the binding liquid). Granules with a homogeneous shape close to spherical were obtained.[119, 120, 121]

Figure 3.2.2. The process of pea seed coating on a disc granulator
Source: own research data.

The analysis of the differences amongst respective samples in terms of the value of the average weight of one pelleted grain and 100 grains with coating indicated the durability of the obtained casings stored with air access. The phenomenon of crushing seed coats during storage was not observed. The largest differences in the average weight of 1 grain were observed in the first days after the pelleting process. In the following days, the matter stabilised. The analysis of the decrease in the weight of the encapsulated grains indicated a greater durability of the coatings with collagen hydrolysate as compared to the durability of coatings made of substances used in studies by other authors (yellow dextrin, polyvinyl alcohol). A smaller decrease in the weight of grains coated with collagen hydrolysate resulted from the specific properties of this preparation (biopolymer, network structure, fibrous structure). The collagen hydrolysate formed a hydrophilic film on the surface of the grain, thanks to which the loss of water was limited. For most of the samples, the average weight of one grain on the day of pelleting was close to the values obtained after 15 days. The initial increase or decrease in the average weight of one grain resulted from the shell composition, including the properties of the materials used.[122, 123] In addition, in order to verify the process, a chromatographic analysis was carried out, which confirmed the presence of amino acids in a randomly selected series of pelleted seeds.

119 K. Ławińska, S. Szufa, R. Modrzewski, A. Obraniak, T. Wężyk, A. Rostocki, T.P. Olejnik, (2020), *Obtaining granules…*
120 K. Ławińska, D. Gendaszewska, E. Grzesiak, J. Jagiełło, A. Obraniak, (2017), *Use of tanning…*
121 K. Ławińska, D. Gendaszewska, E. Grzesiak, M. Lasoń-Rydel, A. Obraniak, (2017), *Coating of leguminosarum seeds with collagen hydrolyzates from tanning waste*, "Przemysł Chemiczny", vol. 96/9, pp. 1877–1880.
122 K. Ławińska, D. Gendaszewska, E. Grzesiak, J. Jagiełło, A. Obraniak, (2017), *Use of tanning…*
123 K. Ławińska, D. Gendaszewska, E. Grzesiak, M. Lasoń-Rydel, A. Obraniak, (2017), *Coating of leguminosarum…*

Results obtained

- It is possible to form durable, stable and complete seed coatings (for grains of varied sizes and shapes) on the basis of waste collagen preparations obtained from tannery waste, using a disc granulator.[124, 125]
- Compatibility of the produced capsule also allows for the use of a layer of fungicides and zoocides protecting the seeds against pathogens and pests.[126]

3.2.4. Verification of New solutions Based on Tannery Waste (i.e., Composites Based on Shavings and Mineral Additives, Granules and Seed Coatings Based on Collagen Preparations Obtained from Tannery Waste)

Verification of new solutions based on tannery waste was carried out by means of creating composite materials and analysing the parameters of the products obtained by pressure-free granulation, i.e. granules and seed coats.

As part of the conducted research, new materials of a composite nature were formed by using a combination of components in the form of tannery shavings and mineral fillers in combination with a suitable adhesive medium, bonding discontinuous, chaotically oriented fibre. The process of pursuing this goal was focused on determining the physical and mechanical properties of the newly created composites, based on a natural polymer, that were fragmented collagen fibre contained in the waste arising from the leather industry. Tannery shavings originating from chrome tanning technology (about 70% of domestic tanneries use chrome tanning technologies) constituted the essential ingredient of the new composite materials. Moisture-free, natural mineral fillers in the amount equivalent to 5% and 10% of the shavings weight were used in the composite moulding process. The mineral additives were readily available powdered mineral raw materials:

- natural calcium-magnesium carbonate (dolomite flour with an average grain size of 0.045 mm),
- kaolin (kaolinite 81%) with a grain size of 0.2–0.002 mm,
- bentonite (montmorillonite > 75%) with a fraction smaller than 0.056 mm.

Tannery shavings with a moisture content of 50% along with mineral additives were mixed using four different types of adhesive medium, that is: Homopolymer (that is an aqueous dispersion of polyvinyl acetate), a modified gelatinous adhesive of animal origin, an adhesive based on low-ammonia natural latex,

124 K. Ławińska, D. Gendaszewska, E. Grzesiak, J. Jagiełło, A. Obraniak, (2017), *Use of tanning…*
125 K. Ławińska, D. Gendaszewska, E. Grzesiak, M. Lasoń-Rydel, A. Obraniak, (2017), *Coating of leguminosarum…*
126 K. Ławińska, M. Lasoń-Rydel, D. Gendaszewska, E. Grzesiak, K. Sieczyńska, C. Gaidau, D.G. Epure, A. Obraniak, (2019), *Coating of seeds…*

and a solvent-free, clear epoxy resin with hardener (for liquid epoxy resins). The optimal weight percentage of shavings in relation to the compatibiliser was determined in the preliminary tests to equal 60:40. The process of forming the composite was proceeded by adding mineral filler and adhesive medium to the shavings in order to combine the components. The mixture of all components was pressed in a heated hydraulic press at the constant pressure of 20 MPa. The moulded composites were dried in a laboratory dryer at 25°C for 24 hours. After another 72 hours of conditioning, the physical and mechanical properties of the obtained composites were tested. The moulded composites were subjected to static tensile tests conducted by means of a Zwick/Roell Z010 type testing machine. The dependence of the increase in the length of the composite specimens on the magnitude of the tensile force applied parallel to the specimen axis was recorded. In the course of the static axial tensile test of the moulded composites, the breaking stress [MPa], breaking force F_{max} [N], sample deformation for F_{max} [mm] were inter alia determined. The strength tests of the moulded composites made it possible to determine the linear deformability modulus (Young's modulus) that assessed their elasticity (Table 3.2.7.). In addition, the water absorption capacity (absorbability, i.e., water content defined as the ratio of the water volume to the weight of the composite specimen in the dry state) and the ability to dewater during the drying process were examined in respect of each of the composites. Taking into account the environmental aspect, the total chromium content (by means of the iodometric titration method) and extracted chromium VI (by means of the spectrophotometric method using 1,5-diphenylcarbazide) in the shavings and produced composites underwent analyses.

Table 3.2.7. Average values of Young's modulus and average density of the produced composites

	Adhesive medium			
	Homopolymer	**Gelatine glue**	**Glue based on low ammonia natural latex**	**Epoxy resin with hardener**
Young's Modulus [GPa]	0.0517 ± 0.00981	0.0365 ± 0.00771	0.000594 ± 0.000136	0.000586 ± 0.0000926
Density [g/cm³]	0.901 ± 0.08	0.699 ± 0.09	0.509 ± 0.07	0.420 ± 0.08

Source: own research data.

The research on composites made from tannery shavings was carried out within the framework of the Project entitled "Determination of optimal composition of collagen fibre composite derived from leather industry waste and mineral additives" funded by the National Science Centre, Miniature 1, DEC 2017/01/X/ST8/01045.

Results obtained

- The obtained values in respect of the properties of the tested composites with mineral additives depend on the specificity of the filler (additive) used. The type of mineral additive used affects e.g. tensile strength, maximum strength and deformation of composites based on tannery shavings. Composites with the addition of bentonite are characterised by the highest tensile strength and the highest breaking strength. The amount of the added natural filler, inter alia, shapes the deformation value due to the maximum force of the formed composites. The formulated conclusions are confirmed by the resulting figures of the statistical significance arising from the conducted analyses.[127, 128]
- The physicochemical parameters are also affected by the apparatus and process conditions for producing composites from tannery shavings, including, among others, ironing temperature. In the case of the homopolymer-bonded composites, the highest values of the maximum force at which the first fracture of the sample occurred were obtained for the highest pressing temperature (80°C). On the other hand, composites formed at lower pressing temperatures (20°C, 40°C) showed better sorption properties.[129, 130, 131]
- The analysis of the values of Young's modulus obtained for the created composites is indicative of the classification of polymer foams (VLD, LD, MD) and some materials within the group of elastomers (IR, CR, EVA), i.e. materials capable of reversible deformation under the influence of mechanical forces without the risk of losing the continuity of their structure, which significantly extends the area of their application.[132, 133]
- The influence of the mineral additive is important in the context of creating an appropriate system in terms of its resistance to water. The source of the increase in the intensity of soaking together with the increase in the percentage content of the mineral additive accounts for the specific properties of the fillers used. In the case of bentonite and kaolin, the characteristic feature of is their high water absorption and swelling capacity. However, the chemical

127 K. Ławińska, R. Modrzewski, W. Serweta, (2019), *Tannery shavings and mineral additives as a basis of new composite materials*, "Fibres & Textiles in Eastern Europe", vol. 27, no. 5(137), pp. 89–93.

128 K. Ławińska, W. Serweta, R. Modrzewski, (2019), *Studies on water absorptivity and desorptivity of tannery shavings-based composites with mineral additives*, "Przemysł Chemiczny", vol. 98/1, pp. 106–109.

129 K. Ławińska, R. Modrzewski, W. Serweta, (2019), *Tannery shavings…*

130 K. Ławińska, W. Serweta, R. Modrzewski, (2019), *Studies on water…*

131 K. Ławińska, W. Serweta, R. Modrzewski, (2018), *Qualitative evaluation of the possible application of collagen fibres: Composite materials with mineral fillers as insoles for healthy footwear*, "Fibres & Textiles in Eastern Europe", vol. 26, no. 5(131), pp. 81–85.

132 K. Ławińska, R. Modrzewski, W. Serweta, (2019), *Tannery shavings…*

133 K. Ławińska, (2021), *Production of agglomerates…*

nature of dolomite (the presence of MgO and CaO oxides) that increases the affinity to hydration, reduces the sorption capacity of composites with this addition. The analysis of the water absorption capacity of the newly developed composite materials showed that the optimisation problem related to the tested property can be steered in many ways. The observed statistically significant differences, due to the differentiating factor – the binding material, allow for the formulation of recommendations as to the type of adhesive medium used.[134]

- The type of adhesive medium significantly affects the ability to absorb and release water. This means that, depending on the purpose of the material, the water absorption capacity can be reduced or increased, as well as the drying rate can be accelerated or delayed. A global comparison of the produced composites indicated the existence of differences due to the proportions of the filler in relation to the weight of shavings. The change in the properties of composite materials also manifested itself in the location of the equilibrium points defined as the intersection points of the drying curves with the soaking curves.[135]
- With regard to environmental tests, composites made of collagen fibre from leather industry waste and mineral additives are safe for the environment, which is confirmed by the lack of Cr(VI) mg/kg content (the determination was made by means of the spectrophotometric method using 1,5-diphenylcarbazide). The total Cr in the tested composites and shavings equalled 3.7%–4.2% Cr_2O_3.[136]

As far as the tannery shavings agglomerates created by non-pressure granulation processes are concerned, their strength properties were defined to prove their potential application (taking into account transport, storage and dosage to other process operations).

The value of the maximum compressive stress causing the produced granules to be destroyed was analysed. The tests were carried out by means of an Instron Tester, measuring the value of the stress in terms of a function of the displacement of the apparatus head that compressed the granules. Each time, the resistance of five granules from each size class was tested, and the arithmetic mean was calculated (Table 3.2.9.). The tests were carried out for selected granules produced by means of the Method 3 (process parameters are shown in Table 3.2.8.).

134 K. Ławińska, W. Serweta, R. Modrzewski, (2019), *Studies on water…*
135 Ibidem.
136 K. Ławińska, (2021), *Production of agglomerates…*

Table 3.2.8. Parameters of tannery shavings granulation processes

Sample	Shavings Fraction [mm]	Water glass Solution [g]	Mineral Additive	Weight of Mineral Additive [g]	Granulation Time [min]
1	0–2	1000	wet gypsum	500	10
2	0–2	1000	wet gypsum dry gypsum	500 285	10
3	0–2	800	wet gypsum	500	10
4	0–2	800	dolomite	1700	13
5	0–2	600	dolomite	1500	8
6	0–1	800	wet gypsum dolomite	400 950	15
7	0–1	800	wet gypsum dolomite	400 1250	18

Source: own research data.

Table 3.2.9. Average destructive force applied to created granules according to the parameters indicated in Table 3.2.8.

Granulate Fraction [mm]	Average Value of Destructive Stress [N]						
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
0–1	1.83	3.5	1.3	2.9	3.5	2.7	0.5
1–2	3.46	5.6	4.8	6.1	8.3	4.1	0.9
2–3	4.07	6.8	5.2	25.1	21.2	5	1.2
3–4	4.34	7.8	6.2	30.6	29.1	5.2	1.6
4–5	6.65	9.7	7.7	60.2	67.2	6.6	2.2
5–6.3	7.02	23.1	8.4	82.5	73.5	7.1	2.7
6.3–8	18.34	29.8	11.6	129.8	126.0	13.8	4.4
8–10	39.97	31.5	26.0	158.8	185.4	27.8	10.3
10–12.5	43.99	40.2	28.6	190.9	198.7	28.8	13.1
12.5–14	65.438	41.9	34.9	200.0	200.0	35.9	17.1
>14	149.838	95.4	96.3	200.0	200.0	48.1	26.2

Source: own research data.

For the selected fractions, the drop resistance (resistance to breakage) of the created granules was also analysed. Out of the granules obtained as the output of the trials 1–7 (Table 3.2.8.), 60 pellets were selected and then dropped onto

a concrete floor from a height of 1 m, counting the number of unbroken pellets[137] (Table 3.2.10.). The resistance to breakage of the granules is crucial with regard to their transport and further processing.[138]

Table 3.2.10. Number of unbroken (drop resistant) granules

Granulate Fraction [mm]	Number of unbroken (drop resistant) granules [unit]						
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
5–6.3	60	60	56	59	60	55	54
6.3–8	59	60	57	60	60	59	59
8–10	59	60	59	58	60	58	59
10–12.5	59	60	58	59	59	59	58
12.5–14	60	60	57	60	59	58	54
>14	60	60	57	60	58	60	58

Source: own research data.

Results obtained

- The highest values of the average stress destroying the granules of respective fractions were obtained for samples 4 and 5 with the highest addition of dolomite. High values were also obtained for samples 1 and 2 with the highest addition of the water glass solution. In those cases, the resistance of the granules to the discharge was also the highest.[139] Those dependencies were also confirmed by granulating fly ashes from hard coal combustion.[140]
- Soluble water glass-based binders are widely used in industry due to their low cost and non-toxicity. They also allow for the production of granules with high strength parameters, high durability and water resistance.[141, 142]

137 T. Dzik, M. Hryniewicz, A. Janewicz, B. Kosturkiewicz, (2017), *Agglomeration of solid fuels in a roll press*, "Przemysł Chemiczny", vol. 96, no. 6, pp. 1852–1855.

138 R.F. Rodrigues, S.R. Leite, D.A. Santos, M.A.S. Barrozo, (2017), *Drum granulation of single super phosphate fertilizer: Effect of process variables and optimization*, "Powder Technology", vol. 321, pp. 251–258.

139 K. Ławińska, S. Szufa, R. Modrzewski, A. Obraniak, T. Wężyk, A. Rostocki, T.P. Olejnik, (2020), *Obtaining granules…*

140 A. Obraniak, T. Gluba, K. Ławińska, B. Derbiszewski, (2018), *Minimisation of environmental efects related with storing fly ash from combustion of hard coal*, "Environment Protection Engineering", vol. 44, pp. 177–189.

141 K. Ławińska, S. Szufa, R. Modrzewski, A. Obraniak, T. Wężyk, A. Rostocki, T.P. Olejnik, (2020), *Obtaining granules…*

142 F. De Castro Dutra, M. Emrich, G. Magela da Costa, A. Dias, (2016), *Influence of drying temperature and atmosphere on the mechanical strength of iron-ore agglomerates and*

- The obtained agglomerates, due to the identity of the mineral additives used, are dedicated to the producers of leather-like materials and composites. On the other hand, binders used for producing secondary, ground leather (eco-leather), e.g. synthetic resins, butadiene-styrene latexes or acrylic latexes may be added in appropriately smaller amounts already at the granulation stage of shredded tannery shavings. In addition, the produced agglomerates may be used as: additives in construction, road construction and as fillers of mining voids.[143, 144, 145, 146]

In order to benchmark the developed method of granulating production residue, waste generated by the food (sugar) industry was also granulated. This waste was selected taking into account, among other things, high moisture content of about 40% (similar to tannery shavings), similar chemical composition especially in terms of high Ca and Mg content (potential use in agriculture). Saturation mud, also called defecation mud, was used, which is a by-product of sugar production (arising from the purification of beet raw juice). On average, more than 12,000 tonnes of that type of waste is obtained during the operation of one factory during the campaign. It is stored in heaps and requires the development of methods for its disposal management.

Agglomeration was carried out using a disc granulator (disc speed at 9.5 RPM). In this case, the additives were dolomite and gypsum (similarly to tannery shavings) as well as lime meal and chalk. Due to the environmental focus of the study, the aqueous glass solution was replaced with an aqueous solution of molasses, which is also a byproduct of food sugar production. 33% and 66% solutions of molasses were used (better results in terms of the granules obtained, as well as strength parameters, were obtained for the 66% solution). For selected fractions of the produced granules, the average values of destructive stress were also determined (Table 3.2.11.). On the other hand, Chart 3.2.3. shows the granulometric compositions of agglomerates produced from shavings and from saturation mud under similar process conditions (with the addition of dolomite).

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sodium silicates for application in sintering processes, "The Canadian Journal of Chemical Engineering", vol. 94, pp. 75–80.

143 K. Ławińska, A. Obraniak, R. Modrzewski, (2019), *Granulation process…*

144 K. Ławińska, (2021), *Production of agglomerates…*

145 K. Ławińska, R. Modrzewski, A. Obraniak, (2020), *Comparison of granulation…*

146 K. Lawinska, R. Modrzewski, W. Serweta, (2018), *The phenomenon…*

Table 3.2.11. The average destructive stress in respect of saturation mud granules containing various mineral additives (forthe 66% solution of molasses)

Average Destructive Stress [N]				
Granulates Fraction [mm]	Additive			
	Gypsum	Dolomite	Chalk	Limestone Powder
4.0	9	13	15	11
5.0	11	16	13	18
6.3	25	21	29	20
8.0	26	24	42	28
10.0	25	46	12	27

Source: own research data.

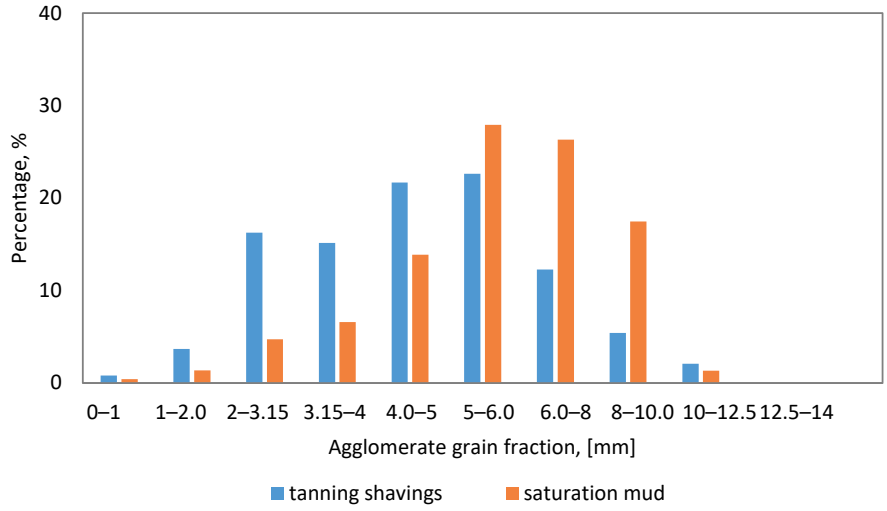

Chart 3.2.3. Granulometric composition of agglomerates made of tannery shavings and saturation mud (samples with dolomite as an additive)
Source: own research data.

Results obtained

- The granulometric compositions of tannery shavings and saturation mud agglomerates clearly indicate that the disc granulation process allows for the processing of the entire material (in both cases).[147]

147 K. Ławińska, S. Szufa, A. Obraniak, T. Olejnik, R. Siuda, J. Kwiatek, D. Ogrodowczyk, (2020), *Disc granulation process of carbonation lime mud as a method of post-production waste management*, "Energies", vol. 13, 3419.

- Non-pressure granulation facilitates the processing of various types of waste (solids, liquids) generated by various industries.[148, 149]
- In terms of application for the agritechnical purposes (as fertiliser additives, soil improvers), the optimal fraction is 2–8 mm in size and the required compressive strength should not be less than 10N (the indicated requirements have been met). In both cases, the maximum activity was obtained from the 5–6 mm fraction for the produced granules.[150, 151, 152]

In further studies, the impact of collagen preparations contained in seed coats created using a disc granulator on the growth and condition of plants was verified. For this purpose, seeds capsules were sown in universal soil, and then the lengths of the obtained seedlings were analysed at certain intervals (Figure 3.2.3.). The related exemplified analyses resulting figures are presented in Table 3.2.12.

Figure 3.2.3. Coating, sowing, seedling length analysis (rapeseed)
Source: own research data.

Table 3.2.12. Average seedling length for seeds of varied seed coatings

Coating Composition	Seed Type	Average Seedling Length, mm
collagen preparation, soot	pea	35.58 ± 1.55, 10 days after sowing
molasses solution, soot	pea	33.28 ± 1.89, 10 days after sowing
reference liquid*, soot	pea	34.46 ± 0.88, 10 days after sowing
collagen preparation	rape	12.1 ± 1.51, 10 days after sowing
reference liquid*	rape	11.56 ± 1.66, 10 days after sowing
collagen preparation, dolomite	rape	11.45 ±1.15, 10 days after sowing
reference liquid*, dolomite	rape	11.075 ± 1.25, 10 days after sowing
collagen preparation, dolomite, peat	rape	11.75 ± 0.35, 10, days after sowing
reference liquid*, dolomite, peat	rape	10.7 ± 0.54, 10, days after sowing

* yellow dextrin, polyvinyl alcohol
Source: own research data.

148 K. Lawinska, R. Modrzewski, W. Serweta, (2018), *The phenomenon…*
149 K. Ławińska, S. Szufa, A. Obraniak, T. Olejnik, R. Siuda, J. Kwiatek, D. Ogrodowczyk, (2020), *Disc granulation…*
150 K. Ławińska, (2021), *Production of agglomerates…*
151 K. Lawinska, R. Modrzewski, W. Serweta, (2018), *The phenomenon…*
152 K. Ławińska, S. Szufa, A. Obraniak, T. Olejnik, R. Siuda, J. Kwiatek, D. Ogrodowczyk, (2020), *Disc granulation…*

Results obtained

- The analysis of the length of the seedlings confirms the effective action of collagen preparations as plant biostimulators – an improvement in the growth and condition of the plants was obtained. Their advantage over the reference liquid and other selected production residue (molasses solution) is also important.[153] [154] [155] [156]
- The developed method provide for the production of multi-component and multi-layer coatings proving a wide range of activity. The type and amount of additives used as well as the order of the layers from which they are formed, also have a significant impact.[157, 158, 159]
- The proposed solution can increase the yields of various plant species by using the by-products of the leather industry.

3.2.5. Overview of the Obtained Results in terms of Application Prospects in Industrial Practice

The results obtained within the framework of the research carried out and the conclusions arrived at on their basis in respect of the unit processes in waste disposal management methods, including tanning, are currently being verified for their potential use in order to raise the level of technological readiness of the developed solutions.

The positive verification of the developed methods in terms of the application of disc granulation for the purpose of producing seed coats (agricultural application) has been confirmed in the framework of the completed two international Projects: Eureka EUREKA/COLL-RAPE/5/2017 (New treatment for rapeseed based on collagen hydrolysates in order to increase the drought resistance of the rape seedling) and Era.Net Rus Plus Innovation 6/RUSPLUS-INNO/2016 (New treatment based on collagen hydrolysates for the purpose of increasing the drought resistance of Leguminosarum seedlings).

Furthermore, application prospects for the output of the research that has been carried out include:

153 K. Ławińska, (2021), *Production of agglomerates…*
154 K. Ławińska, M. Lasoń-Rydel, D. Gendaszewska, E. Grzesiak, K. Sieczyńska, C. Gaidau, D.G. Epure, A. Obraniak, (2019), *Coating of seeds…*
155 K. Ławińska, D. Gendaszewska, E. Grzesiak, J. Jagiełło, A. Obraniak, (2017), *Use of tanning…*
156 K. Ławińska, D. Gendaszewska, E. Grzesiak, M. Lasoń-Rydel, A. Obraniak, (2017), *Coating of leguminosarum…*
157 K. Ławińska, (2021), *Production of agglomerates…*
158 K. Ławińska, D. Gendaszewska, E. Grzesiak, J. Jagiełło, A. Obraniak, (2017), *Use of tanning…*
159 D. Gendaszewska, M. Lasoń-Rydel, K. Ławińska, E. Grzesiak, P. Pipiak, (2021), *Characteristics of…*

- road construction – it is possible to use tannery shavings and their granules in the processes of modifying asphalt binders and as an addition to mineral and asphalt mixtures.
- construction – the research output has indicated the application of shavings (in the amount equivalent to 10, 20 and 30%) in wood-like boards pressed at the temperature of 180°C due to the microbiological resistance (as compared to boards without that additive) (tests according to instruction 355/98).[160] The research was carried out as part of the Project entitled "Materials for the prefabrication of building partitions, agglomerated from secondary raw materials, including demolition wood, textile and leather industry waste" co-funded under the special-purpose subsidy awarded by the President of the Łukasiewicz Centre, Co-financing Agreement 1/Ł-ITD/CŁ/2021.
- composite materials and plastics processing – the possibility of producing biodegradable composites from waste biomass products of animal origin (including shavings and granulates) and plant origin, intended for use in the agri-food, packaging and horticultural industries, has been confirmed. The research was carried out as part of the Project titled "Establishment and launch of the BIO-MAS Research and Development Centre" under the Regional Operational Programme of the Lodzkie Voivodeship, Co-financing Agreement no RPLD.01.01.00-IP.02-10-069/20 (RPLS.01.01.00-10-0002/20-00 of May 10, 2021).
- mining industry – studies have confirmed the possibility of producing agglomerates from flotation waste and fly ashes in the process of non-pressure disc granulation as a method of effective waste disposal management (mitigation of its environmental adverse impact).

The research output indicated above confirms the wide applicability of the developed solutions. The research areas were also selected on the basis of the related literature reports on the leather waste disposal management, and related recycling to be reused, among others, as an additive for acoustic panels,[161] for cement panels (due to mechanical strength as well as insulating properties), for concrete,[162]

160 K. Ławińska, (2021), *Production of agglomerates…*

161 M. Vidaurre-Arbizu, S. Pérez-Bou, A. Zuazua-Ros, C. Martín-Gómez, (2021), *From the leather industry to building sector: Exploration of potential applications of discarded solid wastes*, "Journal of Cleaner Production", vol. 291, 125960.

162 G. Zainescu, (2018), *Polymer Compositions from Leather Fibers (Leather Shavings) for Mortar in Constructions*, In Proceedings of the 18th SGEM International Multidisciplinary Scientific GeoConference SGEM2018, Energy and Clean Technologies Stef92 Technology, Albena, Bulgaria, 2–8 July 2018, pp. 79–86.

and for the manufacture of new composite and biocomposite materials,[163, 164, 165] including packaging materials (e.g. collagen preparation with dialdehyde starch) for packaging pharmaceuticals, food and cosmetics[166] as well as an additive for paper (with improved water resistance and air permeability properties).[167]

163 G. Ramamurthy, B. Ramalingam, M.F. Katheem, T.P. Sastry, S. Inbasekaran, V. Thanveer, S. Jayaramachandran, S.K. Das, A.B. Mandal, (2015), *Total elimination of polluting chrome shavings, chrome, and dye exhaust liquors of tannery by a method using keratin hydrolysate*, "ACS Sustainable Chemistry & Engineering", vol. 3, pp. 1348–1358.

164 J. Zhang, Z. Yan, X. Liu, Y. Zhang, H. Zou, Y. Le, J.-F. Chen, (2020), *Conductive skeleton-heterostructure composites based on chrome shavings for enhanced electromagnetic interference shielding*, "ACS Applied Materials & Interfaces", vol. 12, pp. 53076–53087.

165 C. Ding, M. Zhang, L. Dai, Y. Qi, R. Shi, J. Yang, (2017), *Fabrication and characterization of regenerated leather using chrome shavings raw material*, "The Journal of the American Leather Chemists Association", vol. 112, pp. 145–152.

166 F. Langmaier, P. Mokrejs, K. Kolomaznik, M. Mladek, (2008), *Plasticizing collagen hydrolysate with glycerol and low-molecular weight poly(ethylene glycols)*, "Thermochimica Acta", vol. 469, pp. 52–58.

167 O.A. Mohamed, N.F. Kassem, (2010), *Utilization of waste leather shavings as filler in paper making*, "Journal of Applied Polymer Science", vol. 118, pp. 1713–1719.

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Chapter 4

Lower limbs. Ontogenesis, anatomy, deformations

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4.1. Ontogenetic development of lower limbs in children

In the initial stage of ontogenesis, human lower limbs undergo many changes. In the prenatal period, the limb buds develop beginning from the 3rd week after fertilisation.[1] The 6-week-old embryo already has foot plates that over time are divided into 3 segments. Around the 7th week of embryonic development, primary ossification centres are observed, and the buds of the lower limbs already reach ¼ of the length of the trunk and head.

In the first stage of the postnatal life, complete flexion of the lower limbs is observed, which is a remnant of intrauterine development. This phenomenon persists until about 1–1.5 months of age. Taking into account the growth rate of the lower limbs, the feet dominate until the age of 3. Developmental changes, however, also occur at the level of knee and hip joints and undoubtedly affect the way the foot is positioned in the later period of ontogenesis.

The infant's foot has not yet longitudinal arch, and its plantar part is filled with a soft cushion made of adipose tissue and connective tissue. The role of the fat pad

1 J. Walocha, A. Skawina, J. Gorczyca, (2006), *Anatomia prawidłowa człowieka. Miednica. Podręcznik dla studentów i lekarzy. Wydanie II poprawione*, Wydawnictwo Uniwersytetu Jagiellońskiego, Kraków, pp. 13–19.

is to absorb the shocks caused by the foot hitting the ground. This is especially important in the course of learning to walk, during which the child puts his feet flat and no propulsion is observed.

At this stage of ontogenetic development, ossification of the foot is still poorly advanced. The entire vault of the foot undergoes alterations (both longitudinal and transverse arches), and in children we observe physiological flat feet, which disappear around the age of 6–7 (girls achieve it faster than boys). According to the related literature, the foot of a 10-year-old child is already arched in the same way as the foot of an adult.[2]

Beneath there are scans of the foot of a child aged 2 and 8 years. There are clear differences in the morphology of the foot and the proportions of respective sections of the foot.

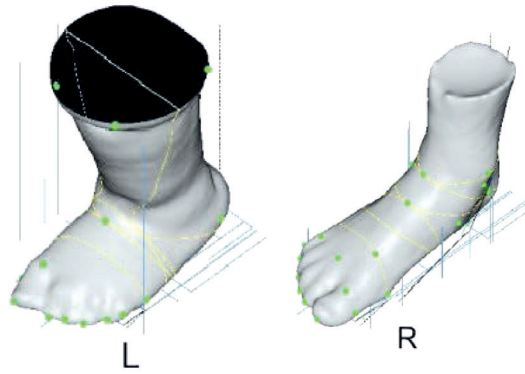


Figure 4.1. 3D scan of the foot of a 2- and 8-year-old boy
Source: own elaboration.

In the related literature, the construct of the "golden age of mobility" can be found. This is a period of particularly dynamic changes in the development of the lower limbs, occurring around 4–5 years of age. It is estimated that at this time the length of the lower limbs exceeds a half of the length of the body.[3]

During the puberty spurt, there is a significant acceleration of foot growth in length. However, the skeletal system grows faster than the muscular system, which is often the cause of foot fatigue at that age and the lowering of the longitudinal arch of the foot again (the muscular system does not keep up with the growing skeletal system). Thus, it is important to maintain the proper function of muscles and control their efficiency.[4]

2 N. Wolański, (2005), *Rozwój biologiczny człowieka*, Wydawnictwo PWN, Warszawa, p. 125.
3 N. Wolański, (2005), *Rozwój biologiczny…*
4 A. Zalewska, K. Średzińska, W. Kułak, (2021), *Postawa ciała a siła mięśniowa u dzieci w wieku szkolnym*, Uniwersytet Medyczny w Białymstoku, Białystok, p. 19.

The formation and development of the foot must be considered strictly in terms of the development of the entire musculoskeletal system. The position of the feet and the arrangement of their long axes in relation to one another, the position of the tarsus closely correlate with the position of the more proximal sections of the lower limb: the knee joint and the hip joint.

During ontogenesis, the position of the axes of the lower limbs also changes. The initial varus position of the knees resulting from the position of the lower limbs in intrauterine development transforms into the valgus position, which disappears around the age of 6–7. It needs to be stressed that we are describing the phenomenon of physiological varus and valgus of the knees.

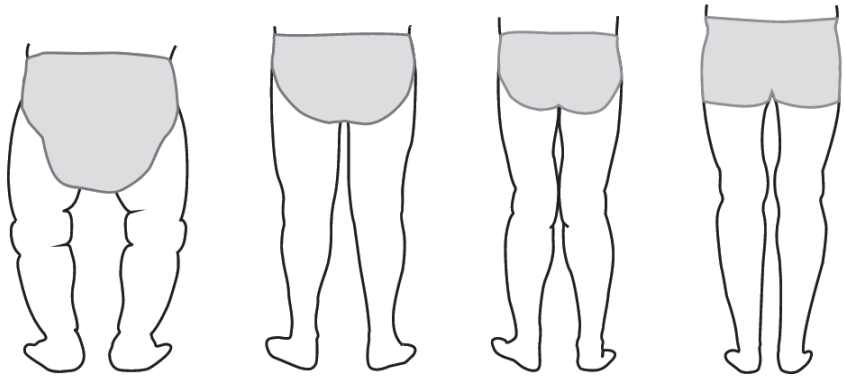


Figure 4.2. Changes in the position of the knees in the process of ontogenesis
Author: Tetiana Paruzel.

4.2. Children's feet deformations

Deformities and other foot ailments are associated with changes in the shape and impairment of the foot function, which have their source in abnormalities of soft tissues or bone tissue.

The moment of formation of foot defects gives rise to the basic classification of them. Foot defects can therefore be divided into congenital and acquired ones.

Lower limb deformities are common pathologies that significantly worsen body statics and lead to posture defects. They are birth defects or develop as a result of deformations of higher parts of the body, or various types of overloads.

The musculoskeletal system is often affected by congenital defects. The causes of developmental distortions can be endogenous and exogenous. Endogenous factors are mainly gene mutations or chromosomal aberrations. Most of the

musculoskeletal system diseases (dysplasia, dystrophy, dysostosis) have a genetic background. They are inherited in an autosomal dominant, autosomal recessive or polygenic manner.[5] Exogenous factors may include: fetal hypoxia, taking medications during pregnancy, maternal diabetes, dietary deficits, ionizing radiation, disease during pregnancy. In recent years, a large role has also been attributed to mechanical factors (oligohydramnios, stronger uterine muscles in primiparous women causing pressure on the hip joints) and the hormonal changes during pregnancy - especially in the last 3 months (increased secretion of oestrogen and relaxin). Significant developmental abnormalities of all organs may develop up to the 3rd month of pregnancy. After this period, the foetus is already a fully formed human. Significant distortions are also called congenital teratological defects and arise during organogenesis, i.e. the formation of organs, and those are the so-called malformations. In turn, fetopathies are developmental disorders that develop in a genetically normal embryo only after the embryonic period (i.e. after the third month of pregnancy when organogenesis is already completed).[6, 7]

The most common birth defects of the feet in children include:

- club foot,
- adducted foot,
- congenital flat – valgus foot,
- heel foot,
- congenital hyperextension of the knee joint,
- congenital tarsal bone coalitions,
- extra navicular bone,
- syndactyly and polydactyly,
- fingers curled and overlapping.

Acquired defects arise in the postnatal stage of ontogenesis. An early start to walking may cause disorders in the proper development of the foot and the whole legs, and thus also the body posture.[8] The most common cause of acquired defects includes mechanical injuries caused by both incorrectly selected footwear and traumatic damage to the musculoskeletal system (fractures, sprains, dislocations).

One of the factors blamed for development of deformations is incorrect footwear. It is comparatively new acquisition in our phylogenesis. Footwear is designed to protect the foot against injuries and adverse weather conditions. When choosing shoes, their basic functions often become secondary, giving way to criteria dictated by fashion. Fashionable shoes are not always healthy. Other

5 D. Kusz, T. Bienek, J. Cholewiński, Ł. Cieliński, K. Czeladzka-Krerowicz, S. Dudko, M. Nowak, P. Wojciechowski, (2009), *Kompendium ortopedii*, Warszawa.

6 Ibidem.

7 W. Dega, K. Milanowska, (1993), *Rehabilitacja medyczna*, Warszawa.

8 M. Borkowska, I. Gelleta-Mac, (2009), *Wady postawy i stóp u dzieci*, Wydawnictwo PZWL, Warszawa.

factors causing distortions may also be diseases (tuberculosis, poliomyelitis, diabetes, rheumatoid arthritis, etc.). The type of occupation and work performed also influences the formation of distortions in adults. Both standing work and continuous performance of the same activities (e.g. walking) can cause distortions. Gender may also be a determining factor in the formation of the defect: the weaker structure of the female foot exposes it to more frequent occurrence of flat valgus foot and hallux valgus.

The acquired defects of feet include, among others:

- flat and flat – valgus foot,
- transversely flat foot (transverse flatfoot, forefoot overload syndrome),
- hollow foot,
- hallux valgus,
- "tailor's bone",
- stiff toe,
- deformities of fingers II–V,
- inflammation of the sesamoids,
- metatarsalgia, including Morton's disease,
- heel spur (inflammation of the plantar fasciitis),
- diseases of the Achilles tendon,
- injuries of the ankle joint,
- calluses and corns,
- Athlete's foot,
- ingrown nails.

4.2.1. Clubfoot (congenital)

Clubfoot has a characteristic shape and its recognition is easy. However, this defect may have a diverse etiological background, which has a significant impact on the choice of a treatment method. There are several hypotheses regarding the aetiologia of the distortion. The oldest of them is the hypothesis postulating the participation of mechanical factors in the formation of the defect (intrauterine compartment, incorrect position of the foot during foetal growth of the limb). The neuromyogenic hypothesis considers changes as minor myelodysplastic disorders within the spinal cord to be the etiological factors of the defect, which causes a difference in the innervation of the foot and lower leg muscles. Recent reports in the related literature suggest the involvement of genetic factors and a complicated way of inheriting the defect.

The image of the defect includes three elements: tarsal equine, tarsal supination and forefoot, forefoot adduction and foot cavities.

There are various degrees of severity of the defect, from small, fully corrective the so-called "soft" clubfoot distortions to non-corrective "hard" with full and intensified individual elements of the defect. For the purpose of treatment planning,

its conduct and comparison of treatment results, it is extremely important to assess and determine the severity of the defect.

It is assumed that the anatomopathological essence of the clubfoot deformity is the displacement of the navicular, calcaneus and cuboid around the talus. As a result of the above, the talus undergoes external rotation, dislocation within the talonavicular joint and internal rotation of the calcaneus. Secondary changes occur in the muscles: contracture of the triceps calf muscle, tibialis posterior, flexor digitorum longus, and hallux. The above-mentioned changes are accompanied by the contracture of joint capsules and ligaments from the posterior and medial side of the foot.

The general rule is to start treatment as soon as possible after birth. It includes conservative treatment involving the application of corrective plaster casts. In the case of a mild defect, this treatment usually leads to full correction. However, in the case of the majority of children, conservative treatment is an introduction to surgical treatment, which is carried out between 2 and 10 months of age. After surgical treatment, immobilisation of the foot in plaster casts lasts about 1 to 3 months. After this period, various types of orthoses are used.

The goal of the clubfoot treatment is to restore the correct anatomical relationship and reconstruct the correct shape of the foot so that the patient can wear standard footwear. In many cases such as the existence of the so-called residual deformations, numerous hypertrophic scars, foot pain, especially after multiple recurrences of the defect, it is extremely important to choose the right insoles or make orthopaedic footwear.

As mentioned, the aetiology of the defect can be diverse. Depending on the causes of the defect, the following types of club feet are distinguished (Table 4.1.).

Table 4.1. Clubfoot Types

Lp.	Type of defect	Cause	Treatment	Risk of recurrence
1	**Habitual**	Incorrect positioning of the foot in the uterine cavity	Use corrective immobilisation or appropriate footwear as early as possible.	Extremely low
2	**Idiopathic**	Most often as an isolated defect. Sometimes it coexists with torticollis or congenital hip dysplasia.	From birth – initially plaster casts, and then surgical treatment with plaster casts	Up to 6 years
3	**Teratogenic**	Neuromuscular diseases in foetal life	Neuromuscular disease in foetal life	Frequent relapses

Source: own elaboration.

Figure 4.3. Clubfoot
Source: https://fizjo-gabinet.pl/stopa-konsko-szpotawa-fizjoterapia/ (accessed: 12.12.2023).

4.2.2. Adjusted foot (congenital)

This is a relatively common defect involving the adduction of the forefoot of varied degrees of severity. It consists in adducting the forefoot, or rather the first radius of the foot, in relation to the rest of the foot at the level of the Lisfranc joint. The foot resembles the shape of a kidney. The rest of the foot is normal, although sometimes there is a valgus position of the heel and dorsiflexion of the foot is normal. The lesion is often bilateral but usually asymmetric. Most likely, it is the result of improper positioning of the feet in the uterus. Spontaneous subsiding of the defect in the case of 85% of children is the proof of such aetiology. In milder cases, in the early childhood, it may go undiagnosed and only the child's gait with turning the eet inwards causes the parents to report to the doctor. The easiest way to recognize this defect is when the child is lying on his stomach with bent knees. In this case, the twisting of the forefoot towards the inside is clearly visible at the level of the Lisfranc tarsi-metatarsal joints. The step is set correctly. Forefoot adduction is corrected passively. The foot has full functional capacity and its movements are free.

In the case of rigid adduction of the forefoot, serial plaster casts are used. Only severe, non-corrective deformities require surgical treatment.

Figure 4.4. Adducted Foot
Source: https://eskulap.olsztyn.pl/leczona-choroba/wrodzona-stopa-przywiedziona/ (accessed: 12.12.2023).

4.2.3. Congenital flat foot

Congenital flat-valgus foot is a rare but difficult-to-treat defect, resulting in a relatively large number of poor treatment results. It occurs on one or both sides. It is characterised by an abolition or even a curvaceous bend of the longitudinal arch of the foot, the lowest point of which on the sole is formed by the head of the talus, dislocation towards the dorsal side in the talo-navicular joint and equine setting of the calcaneus, caused by the contracture of the triceps calf muscle. This deformation is mainly a problem of cosmetic disfigurement and conflict with ready-made footwear, which is quickly deformed when walking. In childhood, this defect is painless, hardly impairing the walking function, while in adulthood, pain occurs due to degenerative changes in the joints of the foot or skin calluses appearing on the most protruding points on the plantar side. The treatment of choice in infancy is surgery followed by plaster casts, insoles and appropriate orthopaedic footwear.

4.2.4. Heel foot

Congenital calcaneal foot – is a mild deformity that is easily subjected to passive correction and does not cause major problems in the treatment of. The foot is set in dorsiflexion and usually valgus (i.e. in pronation). The deformity is caused by the incorrect positioning of the foetus in the mother's womb (the so-called habitual deformity). Treatment consists of manipulative exercises of the foot (i.e. correcting its position) or applying corrective casts for a short period of time.

Figure 4.5. Heel foot
Source: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.bryk.pl%2Fwypracowania%2Fpozostale%2Frehabilitacja%2F18677-wady-wrodzone-w-obrebie-kkd.html&psig=AOvVaw2Xf4oLqogGLEck5vXaxC_R&ust=1681543402919000&source=images&cd=vfe&ved=0CA4QjRxqFwoTCKjXzvfqqP4CFQAAAAAdAAAAABAK (accessed: 12.12.2023).

4.2.5. Congenital extension of the knee joint

This defect is characterised by limited flexion of the knee up to hyperextension of the joint and dislocation of the tibia onto the anterior surface of the femur. Treatment depends on age and degree of deformation. In new-borns, Pavlik Harness is used in order to force knee flexion and plaster casts to correct the position of the joint ends. The surgical method consists in lengthening the quadriceps muscle.[9]

4.3. Podiatry screening of children at preschool and school age

4.3.1. Research method

Children's feet were examined in kindergartens, primary schools, and sports clubs mainly in the City of Cracow.

4.3.2. 3D scanner-based screening

In the course of the screening, the child placed the examined foot inside the scanner, and the other on special stands located on the right and left side of the scanner, respectively. During the scanning process that lasted about 30 seconds, the child stood motionless in an upright position, evenly loading the lower limbs. The device scanned the foot body and the plantar side of the foot, while making anthropometric measurements in accordance with the given algorithm.

The scan files were saved in the .scm format allowing for measurements of the foot body, and in the .stl format providing for reconstruction in 3D programs in order to modify the image later (the so-called point cloud).

Occasionally, multiple foot scans were required due to an incorrect image generated by the computer.

After performing the correct foot scan and measurement, test reports were generated.

9 D. Kusz, T. Bienek, J. Cholewiński, Ł. Cieliński, K. Czeladzka-Krerowicz, S. Dudko, M. Nowak, P. Wojciechowski, (2009), *Kompendium ortopedii…*

Figure 4.6. Placing the foot in the 3D scanner
Source: own elaboration.

4.3.3. Anthropometric measurements of the feet

To assess the dimensions of the feet, in addition to the 3D scanner, the traditional technique of anthropometric measurements was also used by means of a diameter compass, a shoe measuring tape and an altimeter.

During the examination, the child stood with the feet slightly apart, evenly loading the feet.

After the tests, the obtained results were converted into the length and width dimensions of the footwear.

The test procedure is shown in the pictures below:

Figure 4.7. Measuring the length of the foot by means of a diameter compass
Source: own elaboration.

Figure 4.8. Measuring the width of the forefoot by means of a diameter compass
Source: own elaboration.

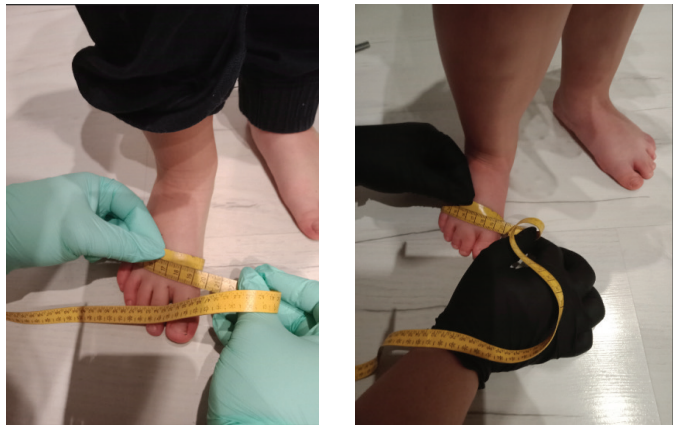


Figure 4.9. Measuring the circumference of the forefoot by means of a shoe measuring tape
Source: own elaboration.

The obtained results were entered into a database and subjected to statistical analyses.

4.3.4. Orthopaedic assessment

The next stage of the preliminary examination was the orthopaedic assessment of the health condition of the children's lower limbs. This is a key element of research in terms of monitoring foot deformation changes in the developmental age.

In accordance with the developed procedure, in the subsequent stages of the examination, the position of the knees, forefoot, toes (during the examination of

the patient from the front) and the position of the tarsus during the examination of the patient from the back were assessed.

During the assessment, attention was also paid to deformities of fingers 2–5, ingrown nails and skin changes. In the next stage, the longitudinal arch of the foot was assessed. The results of the assessment were recorded in the patient's examination card. Photographic documentation of the examinations of selected patients is presented below.

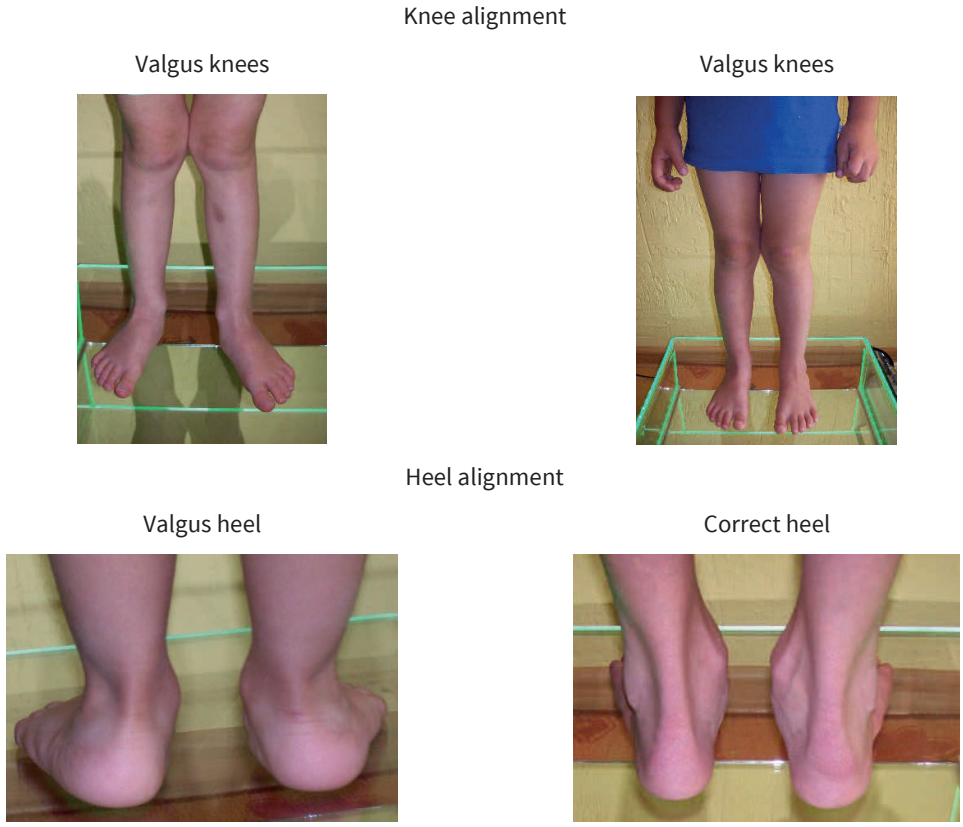


Figure 4.10. Evaluation of knee and tarsus alignment in selected patients
Source: own elaboration.

Flat feet

Hollow feet

Correct feet

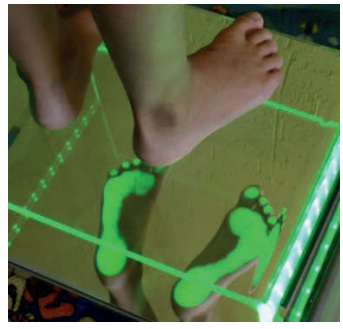
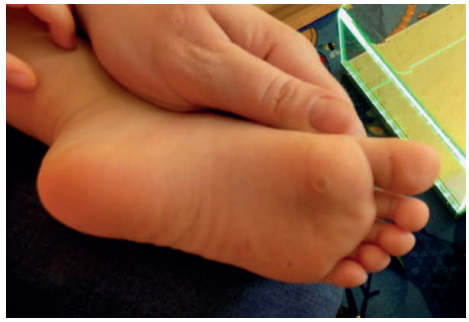


Figure 4.11. Sample images of the plantar side of the foot visible on the podoscope
Source: own elaboration.

The next stage of the examination was the assessment of the child's skin condition. Particular attention was paid to the presence of moles, warts, fungal lesions, ingrown nails or improperly shortened nail plate.

Photographic documentation of selected cases is presented below.



Virus wardon the plantar side of the foot

Birthmark on the dorsal side of the foot

Figure 4.12. Photographic documentation of skin and nail condition assessment
Source: own elaboration.

4.4. Test results and data analysis

4.4.1. 3D scanner-based screening

4.4.1.1. Characteristics of the population

As part of the task, 2,560 foot scans of children aged 3–15 were performed. The children were classified according to age and sex criteria. Table 4.2. presents the number of children in respective age groups, taking into account the breakdown by gender.

Table 4.2. The number of children in respective age groups, taking into account the breakdown by gender

Age	Girls	Boys	Totals
1	2	3	4
3	18	22	40
4	22	36	60
5	32	50	82
6	32	60	92
7	84	98	182
8	132	224	356
9	216	238	456

1	2	3	4
10	162	194	356
11	176	118	294
12	120	140	260
13	108	98	206
14	46	82	128
15	14	20	34
Totals	1162	1380	2546

Source: own elaboration.

4.4.1.2. 3D scanner-based screening – results of anthropometric measurements by gender

Below are the results of anthropometric measurements made by means of a 3D scanner. Three basic anthropometric parameters indicating foot length, width and circumference of the forefoot were analysed. The analysis was carried out in age groups, taking into account the division into sex.

Table 4.3. Results of basic anthropometric measurements for girls

Age	Foot length				Forefoot width				Forefoot girth			
	Av.	Min	Max	S.dev	Av.	Min	Max	S.dev	Av.	Min	Max	S.dev
2	135.4	133.4	139.1	2.6	62.4	59.9	65.1	2.1	158.0	156.0	160.2	1.7
3	149.3	136.2	164.7	9.4	62.4	55.6	68.8	3.8	155.4	141.5	168.7	7.5
4	160.7	152.1	174.8	7.0	65.2	60.3	73.3	3.7	163.6	148.8	182.5	9.1
5	166.8	149.9	183.6	8.5	66.5	58.8	72.0	3.8	164.2	146.4	176.8	8.7
6	178.8	164.4	198.4	8.0	71.1	62.7	77.1	3.6	174.1	154.4	191.0	9.0
7	192.0	168.2	221.2	11.1	73.4	64.1	89.4	5.0	181.1	161.5	217.9	12.0
8	199.4	175.3	241.7	11.6	77.2	64.6	88.4	4.9	190.1	159.9	219.0	12.0
9	208.9	174.1	239.8	11.6	80.1	69.8	96.2	4.9	195.7	169.2	229.9	11.4
10	217.7	190.0	246.1	12.4	83.4	68.9	102.6	6.8	204.3	168.5	247.9	15.8
11	226.1	187.7	259.2	13.5	86.5	68.5	103.0	7.1	211.1	168.0	252.1	17.0
12	233.2	205.2	258.8	12.1	89.6	81.1	100.7	4.6	218.1	199.4	249.0	11.1
13	241.1	202.7	260.8	11.7	92.8	78.0	104.5	5.4	225.5	187.2	249.9	11.8
14	238.8	213.1	260.7	11.3	92.5	82.5	105.6	6.3	224.3	199.9	252.1	12.3
15	233.8	225.2	248.5	7.3	89.6	83.7	95.2	3.5	217.2	202.8	230.4	8.2

Source: own elaboration.

As it results from the presented data, periods of acceleration and retardation of growth are observed in the course of ontogenesis within all the examined parameters. Lower values of anthropometric parameters were observed only in the group of 15-year-old girls. Such results are related to the small number in the group of 15-year-old children. However, taking into account the fact that at this age parents have little influence on the child's fashion and preferences regarding shoes, the result should be considered an indicative value.

Table 4.4. Results of basic anthropometric measurements for boys

Age	Foot length				Forefoot width				Forefoot girth			
	Av.	Min	Max	S.dev	Av.	Min	Max	S.dev	Av.	Min	Max	S.dev
2	151.3	132.3	175.2	12.30	64.00	57.9	71.7	4.10	159.2	147.2	177.5	9.20
3	160.6	143.9	180.0	7.90	65.60	57.9	71.3	3.40	161.4	137.7	175.8	9.40
4	172.5	157.4	191.9	7.604	74.86	63.9	166.8	20.47	173.1	158.1	196.5	10.85
5	183.6	155.1	202.9	10.25	74.51	61.8	85.6	5.664	183.3	153.7	210.2	13.80
6	197.1	175.3	234.3	11.45	77.48	68.1	95.8	5.281	189.9	166.8	243.3	13.33
7	203.6	178.5	232.0	11.73	79.76	66.7	91.6	5.199	196.0	165.6	224.0	12.08
8	213.3	185.2	243.6	11.47	82.79	71.5	99.1	5.622	203.5	178.0	241.3	13.48
9	221.1	192.0	259.8	13.64	85.15	74.5	103.6	5.851	209.2	183.1	255.0	14.29
10	228.0	202.5	248.8	10.16	88.92	76.9	104.9	6.161	217.6	189.9	253.7	14.20
11	237.9	209.0	271.2	13.19	92.34	76.2	110.6	6.988	224.3	22.4	270.9	23.71
12	248.8	217.8	275.1	12.76	97.30	85.6	116.2	7.386	235.8	206.7	280.2	17.52
13	254.0	220.1	279.0	13.11	97.89	81.8	109.1	5.954	238.0	199.3	262.4	13.61
14	256.7	242.5	279.5	12.60	97.43	5.954	115.0	12.23	236.7	13.61	275.7	29.36
15	264.5	258.6	276.9	6.64	100.00	90.7	108.3	7.316	244.8	223.7	263.4	16.73

Source: own elaboration.

A similar growth rate of foot parameters is also observed in the population of the surveyed boys. Individual parameters show periods of growth acceleration and its slowdown.

4.4.2. Orthopedic assessment

4.4.2.1. Characteristic of the population

As part of the task, the orthopaedic assessment was performed for 1727 children aged 4–15.

Table 4.5. The number of children in respective age groups, taking into account the breakdown by gender

Age	Girls	Boys	Totals
4	12	15	27
5	10	21	31
6	20	30	50
7	16	32	48
8	70	67	137
9	150	132	282
10	137	151	288
11	137	119	256
12	111	80	191
13	107	89	196
14	23	59	82
15	97	42	139
Totals	890	837	1727

Source: own elaboration.

4.4.2.2. Data analysis

The collected data was subjected to statistical analyses, calculating the percentage share of children with specific deformities. The analyses were performed in age and sex groups.

A tabular summary of the obtained orthopaedic assessment results is presented below.

4.4.2.2.1. Knee alignment

Table 4.6. Knee alignment

Knee alignment [% of girls group]				
Age	**n**	**Varus**	**Correct**	**Valgus**
1	2	3	4	5
4	12	0	33	67
5	10	0	60	40
6	20	0	75	25
7	16	0	94	6
8	70	0	94	6
9	150	0	91	9
10	137	0	96	4

Table 4.6 (cont.)

1	2	3	4	5
11	137	0	91	9
12	111	0	91	9
13	107	1	95	4
14	23	0	91	9
15	97	0	97	3

Source: own elaboration.

As it can be seen from the above data, 67% of girls aged 4 have valgus knees. Valgus declines with age, reaching 40% in 5-year-olds and 25% in 6-year-olds, respectively.

Table 4.7. Knee alignment

Knee alignment [% of boys group]				
Age	**n**	**Varus**	**Correct**	**Valgus**
3	15	0.0	60.0	40.0
4	21	19.0	52.7	47.3
5	30	0.0	83.3	19.6
6	32	0.0	93.8	6.2
7	67	0.0	97.0	3.0
8	132	0.8	93.9	5.3
9	151	1.3	92.1	6.6
10	119	0.0	95.8	4.2
11	80	0.0	96.3	3.4
12	89	2.3	92.1	5.6
13	59	0.0	98.3	1.7
14	42	0.0	97.1	2.9
15	11	0.0	97.1	2.9

Source: own elaboration.

In the case of boys, the phenomenon of physiological knee valgus is also noticeable. The highest percentage share of boys with physiological valgus was noted – similarly to girls – at the age of 4 (47.3%). Amongst girls, varus of the knees at school age is more often the case, which may be caused by more frequent football practice by boys than girls.

According to the stages of shaping the lower limb in the course of ontogenesis, knee valgus is a physiological phenomenon that replaces the earlier physiological varus (positioning of the knees in the case of non-ambulatory children). When you start walking, the lower limbs are loaded with body weight. Then the so-called physiological valgus is observed to reach its maximum between 2 and 4 years of age. By about 6–7 years of age, the knee valgus should decrease, and the lower limbs should be placed in an increasingly correct position.

4.4.2.2.2. Heel alignment

Table 4.8. Heel alignment

Heel alignment [% of girls group]				
Age	**n**	**Varus**	**Correct**	**Valgus**
4	12	0.0	16.7	83.3
5	10	0.0	50.0	50.0
6	20	0.0	60.0	40.0
7	16	0.0	75.0	25.0
8	70	0.0	81.4	18.6
9	150	0.0	80.0	20.0
10	137	0.0	82.2	17.8
11	137	0.0	82.5	17.5
12	111	0.0	82.9	17.1
13	107	0.0	90.1	9.9
14	23	0.0	87.0	13.0
15	97	0.0	97.1	2.9

Source: own elaboration.

As it results from the presented data, there were no cases of clubfoot in the study population. On the other hand, valgus heel position constitutes a higher percentage share of the population in the group of 4-year-old girls (83.3%).

With age the walking posture improves in favour of correct positioning. Among 7-year-old girls, valgus of the tarsus occurs in 25% of them. This proves the disappearance of the physiological valgus of the tarsus, which correlates with the valgus position of the knees.

In the studied group of girls, cases of valgus were noted in every age group – up to 14 years of age but it should be borne in mind that for those over 7 years of age incorrect tarsus setting should already be under the control of an orthopaedist or a physiotherapist.

Table 4.9. Heel alignment

Heel alignment [% of boys group]				
Age	**n**	**Varus**	**Correct**	**Valgus**
3	15	0.0	6.7	93.3
4	21	0.0	19.0	81.0
5	30	0.0	46.7	53.3
6	32	0.0	53.1	46.9
7	67	0.0	55.9	43.6
8	132	0.0	70.1	29.9
9	151	0.0	73.5	26.5
10	119	0.0	73.9	26.1
11	80	0.0	77.5	22.5
12	89	1.1	76.4	22.5
13	59	0.0	79.7	20.3
14	42	0.0	97.1	2.9
15	11	0.0	97.1	2.9

Source: own elaboration.

In the population of boys, a similar trend of changes in the position of the tarsus is observed, which confirms the direction of physiological changes during the development of the lower limbs.

Physiological valgus remains at a high level until about 6–7 years of age (and therefore slightly longer than in the case of girls), and moreover, the percentage share of boys tested in a given age-sex group is higher as compared to the corresponding group of girls. However, this conclusion should be treated with caution because the number of children in particular age and sex groups is different.

4.4.2.2.3. Forefoot alignment

Table 4.10. Forefoot alignment

Forefoot alignment [% of girls group]			
Age	**n**	**Correct**	**Adducted**
1	2	3	4
4	12	100.0	0.0
5	10	100.0	0.0
6	20	100.0	0.0
7	16	100.0	0.0
8	70	100.0	0.0

1	2	3	4
9	150	100.0	0.0
10	137	99.3	0.7
11	137	100.0	0.0
12	111	100.0	0.0
13	107	96.3	3.7
14	23	100.0	0.0
15	97	97.1	2.9

Source: own elaboration.

In the studied population of girls, in most age and sex groups, forefoot adduction was not observed. Cases of deformity were recorded in a maximum of 3.7% at the age of 12, which can be considered insignificant due to the size of the groups. On the basis of the gathered data, it is difficult to unambiguously determine the periods of changes taking place.

Table 4.11. Forefoot alignment

Forefoot alignment [% of boys group]			
Age	**n**	**Correct**	**Adducted**
3	15	93.3	6.7
4	21	100.0	0.0
5	30	100.0	0.0
6	32	100.0	0.0
7	67	98.5	1.5
8	132	99.2	0.8
9	151	99.3	0.7
10	119	98.3	1.7
11	80	97.5	2.5
12	89	98.9	1.1
13	59	100.0	0.0
14	42	97.0	3.0
15	11	97.1	2.9

Source: own elaboration.

A similar phenomenon is observed in the population of boys, although here in the case of 3-year-olds as many as 6.7% of boys had adduction of the foot in the Lisfranc joint.

4.4.2.2.4. Positioning the first toe andothers toes

Table 4.12. Positioning the first toe

Positioning the first toe [% of girls group]			
Age	**n**	**Correct**	**Valgus**
4	12	100.0	0.0
5	10	100.0	0.0
6	20	95.0	5.0
7	16	100.0	0.0
8	70	98.6	1.4
9	150	98.6	1.4
10	137	95.6	4.4
11	137	97.8	2.3
12	111	96.4	3.6
13	102	94.1	5.9
14	23	95.6	4.4
15	97	97.1	2.9

Source: own elaboration.

Table 4.13. Positioning the first toe

Positioning the first toe [% of boys group]			
Age	**n**	**Correct**	**Valgus**
3	15	100.0	0.0
4	21	100.0	0.0
5	30	100.0	0.0
6	32	100.0	0.0
7	67	100.0	0.0
8	132	98.5	1.5
9	151	100.0	0.0
10	119	98.3	1.7
11	80	98.8	1.2
12	89	100.0	0.0
13	59	100.0	0.0
14	42	97.1	2.9
15	11	97.1	2.9

Source: own elaboration.

Deformities of the other fingers were very rare. They concerned mainly the 2nd toe that was deformed due to wearing shoes that were too short (especially the Greek-type foot, in which the 2nd toe is longer). The varus alignment of the fifth toe, that had until recently been considered a deformity, has been observed frequently, but is now recognised as an evolutionary change.

4.4.2.2.5. Shape of the longitudinal arch

Table 4.14. Shape of the longitudinal arch

Shape of the longitudinal arch [% of girls group]					
Age	**n**	**Correct**	**Low**	**Flatfoot**	**Hollow**
4	12	0.0	75.0	25.0	0.0
5	10	30.0	60.0	10.0	0.0
6	20	35.0	50.0	15.0	0.0
7	16	62.5	25.0	12.5	0.0
8	70	77.1	21.4	1.5	0.0
9	150	82.7	16.7	0.6	0.0
10	137	82.5	12.4	5.1	0.0
11	137	81.8	17.5	0.7	0.0
12	111	78.4	16.2	5.4	0.0
13	99	84.8	10.1	5.1	0.0
14	23	82.6	8.7	8.7	0.0
15	97	97.1	2.9	0.0	0.0

Source: own elaboration.

Table 4.15. Shape of the longitudinal arch

Shape of the longitudinal arch [% of boys group]					
Age	**n**	**Correct**	**Low**	**Flatfoot**	**Hollow**
1	2	3	4	5	6
3	15	13.3	60.0	26.7	0.0
4	21	19.0	57.1	23.9	0.0
5	30	40.0	40.0	20.0	0.0
6	32	62.5	34.4	3.1	0.0
7	67	62.7	23.9	13.4	0.0
8	132	64.4	27.3	8.3	0.0
9	151	66.2	28.5	5.3	0.0
10	119	78.2	16.8	5.0	0.0

Table 4.15 (cont.)

1	2	3	4	5	6
11	80	78.8	15.0	6.2	0.0
12	89	85.4	13.5	1.12	0.0
13	59	88.1	10.2	1.7	0.0
14	42	97.1	2.9	0.0	0.0
15	11	97.1	2.9	0.0	0.0

Source: own elaboration.

The arch of the foot develops until about 6–7 years of age. As mentioned in the introduction, we initially observe the phenomenon of physiological flat feet, which, according to the related literature, disappears at school age (more quickly in the case of girls).

The presented data analysis shows that among girls up to about 6–7 years of age we observe a lowering of the longitudinal arch with a tendency to flat feet. In the case of 7-year-old girls, 62.5% of the study population have properly arched feet. Among older girls (9–14 years), about 18% have low-arched feet or flat feet.

In the studied population of boys, the dynamics of changes in the morphology of the arch are similar, however, feet with a physiological lowering of the longitudinal arch and physiologically flat feet are observed in a larger group of boys than in girls (given the analysis of the corresponding age groups).

The obtained research results are confirmed by the related literature.

4.5. Principles of selection and assessment of children's shoes

4.5.1. Adjusting the shoes to the length of the foot

Wearing shoes that are too short is one of the causes of acquired foot defects. Shoes that are too small deform children's feet, aggravate ailments in adults, and are simply uncomfortable. On the other hand, shoes that are too big make it difficult to walk and force you to move unnaturally. So, a seemingly simple thing has a significant impact on the health of our legs and thus on our well-being. This issue is more complicated in the case of footwear for children but also footwear for adults plays an important role. Of course, one can say that adults are "adults" and decide for themselves and also decide for their children, namely what shoes they and their

children wear. However, a part of the responsibility falls on the manufacturers of the lasts and shoe manufacturers.

When discussing this problem, it is necessary to pay attention to several aspects, namely:

- the influence of the method of measurement on determining the length of the foot;
- foot length growth rate;
- change in the length of the foot while walking;
- difference in foot dimensions under load;
- foot length with different heel heights.

It is obvious that the dimensions of the feet increase with age. In the case of children, they grow about 10 mm in length per year but there are periods of faster and slower growth, different among girls and boys. Significant individual differences are also observed. For most girls, the length of the foot reaches its "adult" dimension by the age of 13, while for boys it takes a little longer – until the age of 16–18. Then we observe that the feet become wider and thicker.

The highest growth rate is observed between 5 and 6 years of age, both in boys and girls, in the case of whom this rate clearly decreases after the age of 11. Due to the much smaller number of children measured in the Cracow and Nowy Sącz studies,[10] the distribution of values is uneven but it is clear that the growth rates over the period under consideration are very high.

Table 4.16. Foot length increase (mm) in various children populations

Research	Sex	Age									
		3,4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Poland	**Boys**	9,7	7,7	10	9	7,9	8,4	7,7	7,8	7,4	9,6
	Girls	8,8	9,9	9,1	9,7	7,5	8,9	7,3	8,2	6,2	5,1
N. Sącz	**Boys**	7,4	10,5	9,8	6,9	9,1	9,8				
	Girls	10,6	8,1	10,5	6,1	9,3	7,2				
Cracow	**Boys**	11,2	7,2	9,9	10,2	4,1	16,4	6,4	9,8	6,9	12,7
	Girls	7,8	11,9	6,7	9,4	10,7	10,8	2,4	10,8	5,7	4,4

Source: own elaboration.

10 A. Malinowski, T. Lewicki, Z. Śniegowski, (1975), *Antropometryczne pomiary stóp i możliwości ich zastosowania w przemyśle ortopedycznych*, „Przegląd techniki ortopedycznej i rehabilitacyjnej", vol. 3.

Table 4.17. Foot length increase (mm) in Cracow children (semi-longitudinal examinations)

I group		
Avarage age Year.Month	Increase	
	Boys	Girls
7.7		
8.3	1.8	1.6
8.8	2.2	2.8
9.3	6.6	5.5
9.8	4.4	4.5
10.2	4.8	5.7
10.7	3.9	3.3
11.2	4.4	4.2
11.7	4.0	3.0

II group		
Avarage age Year.Month	Increase	
	Boys	girls
10.30		
10.11	2.0	2.4
11.50	4.4	3.0
12.00	3.2	4,4
12.50	5.2	3.5
13.10	6.1	1.8
13.50	3.3	1.6
13.11	5.1	1.5
14.30	0.9	0.0

III group		
Avarage age Year.Month	Increase	
	boys	girls
13.3		
13.1	3.0	0.0
14.4	2.2	0.0
15.0	4.7	0,7
15.2	1.0	0.8
15.1	3.5	0.3
16.5	18.4	0.0

Source: own elaboration.

Łukasiewicz-ŁIT also measured the feet of the same children attending one of the schools in Cracow, every six months. Those studies were commenced in three age groups – children aged 7, 10 and 13 (those were semi-longitudinal studies). Table 4.17. presents the results of those studies. Analysing the data contained in it, it should be noted that in boys, throughout the period at issue, the increments are about 5 mm – that is half a number in the metric sizing system and almost one number in French (Continental) sizing system, i.e. the sizing according to which almost all footwear models in Poland are made.

"Change in foot length" while walking

In addition to the increase in the length of the foot with age, the changes in the shape of the foot during walking should also be taken into account when choosing footwear. Observed in slow motion, can the image of body weight transfer during walking be presented in the following stages: the weight rests on the heel, it is transferred to the outer edge of the foot in the metatarsal area, it is transferred to

the metatarsal heads (just behind the toes towards the heel), followed by a bounce from the toe to the next step. In this stage, due to the direction of foot movement and the energy with which the foot moves, we observe the movement of the entire foot towards the tip of the shoe. How big is this shift? Łukasiewicz-ŁIT carried out tests by means of making a foot print in static (standing) and dynamic (walking) conditions, using a set for mapping foot pressure called Ortho-track by Otto Bock. The differences between the two measurements ranged from 8 to 16 mm.

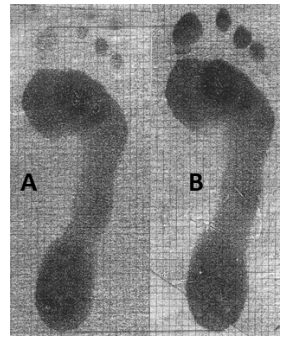


Figure 4.13. a) Static test; b) Dynamic test
Source: own elaboration.

This difference probably results not only from the movement of the foot in the shoe while walking, but also from the change in the shape of the foot under the influence of load, therefore it must be taken into account when selecting and making footwear.

Based on the research results elaborated upon above, regarding the correct adjustment of the length of shoes to the length of the user's feet, it must be remembered that the following factors must be taken into account when making or selecting footwear:

- in the case of footwear intended for children, the increase in foot length over a certain period of time should be taken into account – the length of the foot increases by 10 mm on average per year;
- due to the movement of the foot in the shoe, the shoe must be longer than the foot when walking. The Polish standard regarding last dimensions recommends that the foot length allowance, called the "functional allowance", should be from 7 to 5% of the foot length (higher percentage for smaller feet).

In order to determine the size of the foot, one can use professional rulers (Figure 4.15.) on which the foot size is automatically converted into a size number. As part of the Project, a leaflet was developed to provide information on the rules of footwear selection as well as a measuring device (Figure 4.18.).

The measurement can also be made using measuring instruments such as a calliper or a diameter compass. However, it should always be remembered that

regardless of the measurement method, the data obtained is only auxiliary, and the degree of foot fit should be verified in the footwear. In this case, it is recommended to use removable insoles, that, after having been taken out of the footwear and having placed the foot into them, show how much allowance is left in the footwear. It is also useful for the purpose of an ongoing control during the use of footwear, which prevents the use of footwear that the child has already "grown out of".

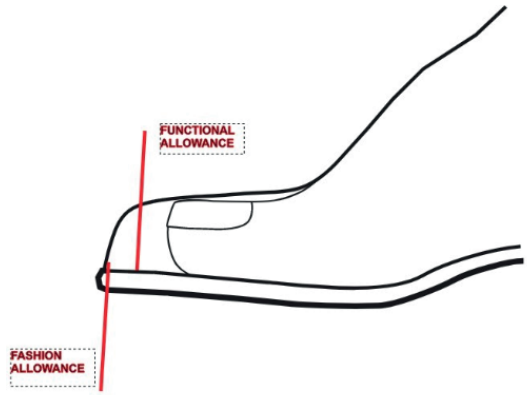


Figure 4.14. Foot length allowances
Author: Tetiana Paruzel.

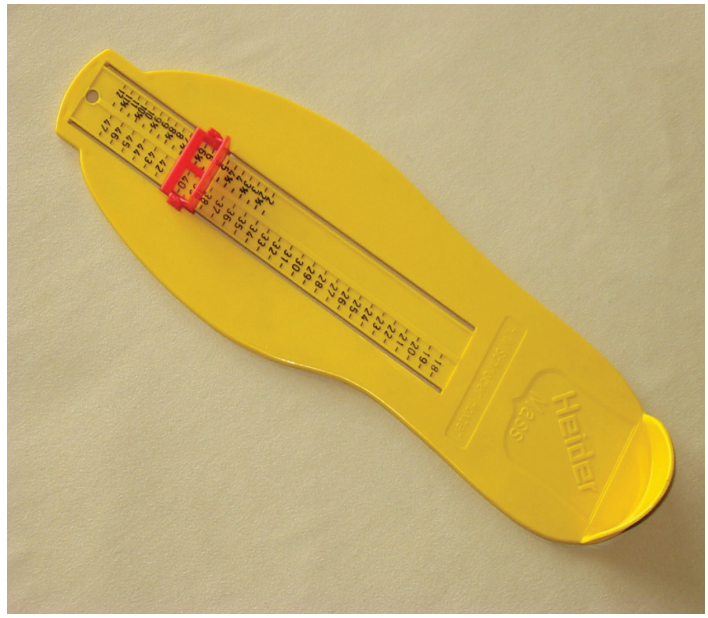


Figure 4.15. A specialist measuring instrument for determining the size of the foot (foot length metre)
Source: own elaboration.

Figure 4.16. The leaflet with a measuring tape
Source: own elaboration.

Figure 4.17. The leaflet with a measuring tape
Source: own elaboration.

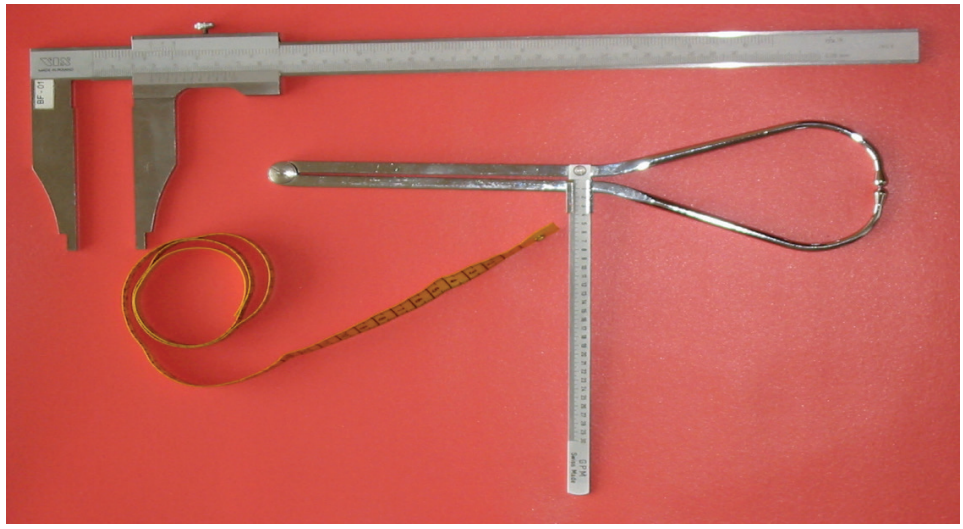


Figure 4.18. A Calliper, diameter compass, measuring tape
Source: own elaboration.

4.6. Evaluation of children's shoes

The basic criterion for evaluating the correct children's footwear is the degree of protection against deformations and other foot diseases (mycoses, allergies, ingrown toenails) as followed by durability and aesthetic qualities.

The correct children's footwear must first of all:

- take into account the shape, dimensions and activities of the feet, and thus ensure free positioning of the fingers and proper adjustment to the shape and width of the feet;
- protect against the adverse effects of a hard substrate and protect against external factors (cold, moisture, sharp elements);
- ensure an appropriate microclimate inside the footwear by securing the appropriate parameters of temperature and humidity inside the footwear, that do not create conditions for excessive growth of fungi and bacteria.

When evaluating the children's footwear and determining their suitability for use by children, the following should be considered:

- last desing,
- selection of raw materials,
- shoe design.

4.6.1. Control of the last dimensions and shape

The last is a geometric form of the foot, that is also a manufacturing item. The last design is closely related to the type of footwear for which the last is intended. In turn, the dimensions of the last and its structure determine the dimensions of the inside of the footwear, being responsible for the degree of fitting the footwear to the foot.

Figure 4.19. Children's lasts
Source: own elaboration.

Since the last is a reflection of the human foot, it is divided into 4 basic components: a heel, metatarsal, forepart and toetip. The most distal part of the last, that is the toetip, may be subject to the greatest modifications in accordance with new fashion trends. This is where the so-called fashion allowance is taken into account, which can be small in the case of wide tips or very large in the case of highly elongated, pointed tips (extremely elongated tips of lasts had a 6-centimetre fashion allowance).

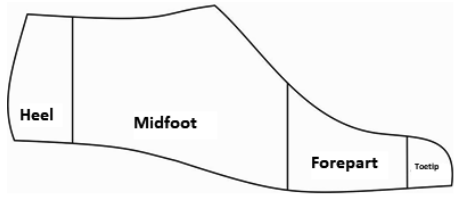


Figure 4.20. The last components
Source: own elaboration.

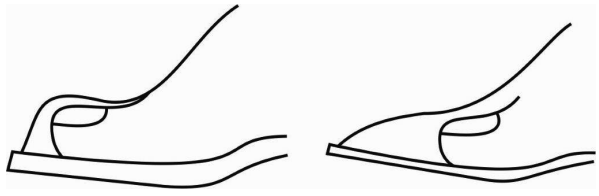


Figure 4.21. Allowances in footwear with different toe shapes
Source: own elaboration.

In the last, we distinguish specific places related to the plastic structure of the last and basic structural elements.

Depending on the purpose, we distinguish:

Low shoe lasts – the characteristic feature of those lasts is the height of the heel and the shape of the back arch of the heel. Lasts are intended for manufacturing shoes with a low (or medium) heel. The correct height of the boot quarter should be marked on the last. The posterior heel arch adduction is relatively slight. The upper arch shaped on this last must not compress the Achilles tendon;

Ankle Boot lasts – the characteristic feature of those lasts is the height of the step and the shape of the rear arch of the heel. That last is intended for manufacturing low-heeled and high-top shoes. The rear part is higher as compared to the last intended for manufacturing low shoes. The rear arch of the heel is abducted, i.e. its upper part deviates slightly backwards;

Sandal lasts – the characteristic of those lasts is the width of the base of the last. It is generally assumed that in lasts intended for manufacturing shoes with an open heel, the width of the footbed in the heel should be 2 mm wider, and in the case of shoes with an open toe, the width of the footbed in the forepart should be 2 mm wider. In those lasts, the total allowance should be 5 mm. The shape of the heel arch is adducted, and in addition the heel can be bulged within the last's base.

Children's feet are especially demanding. It is susceptible to all kinds of pressure, the "effect" of which may be acquired deformities of the feet. Shoes intended for children must therefore have high and wide foreparts. The dimensions of the correct lasts intended for manufacturing the footwear for children are set out in the standard "Footwear for children under 15. Material and construction requirements for lasts and footwear and test methods (PN-O-91015)".

The dimensions determining the shape of the tip are:

1. First toe angle (α)
2. Fifth toe angle (β)
3. Toetip height.

The following parameters should be used for individual size groups:

Table 4.18. Basic parameters of lasts for children's shoes

Age group	**1**		**2**	**3**	**4**	**5**	**6**
Parameter	**10**	**13**	**16**	**18½**	**21**	**23½**	**24**
α angle	92°	91°	89°	89°	87°	84°	87°
β angle	90°	89°	87°	87°	86°	83°	86°
Toetip height, not less than:	15	16	17	18	19	20	21

Source: PN-O-91015:2000 Obuwie dla dzieci do lat 15 – Wymagania materiałowe i konstrukcyjne kopyt i obuwia oraz metody badań.

In order to control the dimensions and shape of the base (bottom) of the last, special control templates can be used. They are applied to the last bedding to check that the bedding "fits" on the last.

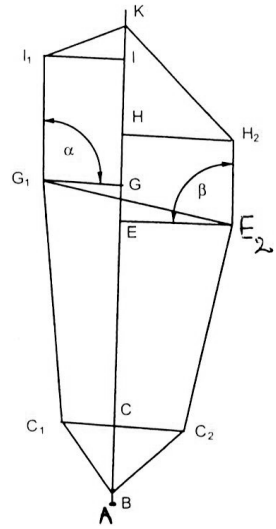


Figure 4.22. Control template for base of the last for children's shoes
Source: own elaboration.

Furthermore, the width of the last must be determined by measuring the length and circumference of the last and then comparing it with the data set out in the standard. The following are used to control the dimensions and shapes of the last: shoemaker's measuring tape, calliper.

Control measurements include:

- Length of the base of the last
- Forepart circumference
- Heel height
- Toetip lift
- Toetip height
- Heel height

The total length of the base of the last – measured after the so-called "wave", i.e. along the longitudinal axis of the last from the starting point of the bedding B, taking into account the curvature of the lower plane of the last.

Forepart circumference – wrap the last with a measuring tape so that it passes through points W1 and W2, W3 (markers on the last). In the absence of markers, apply the control template to the base of the last and, according to it, mark point E2 on the last, and then draw a line from this point perpendicular to the longitudinal axis of the last and mark point E1.

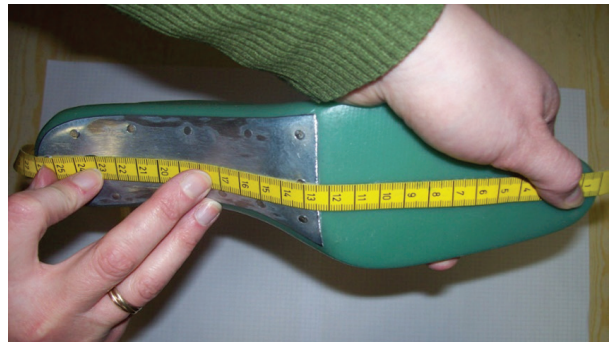


Figure 4.23. Method of measuring the length of the base of the last
Source: own elaboration.

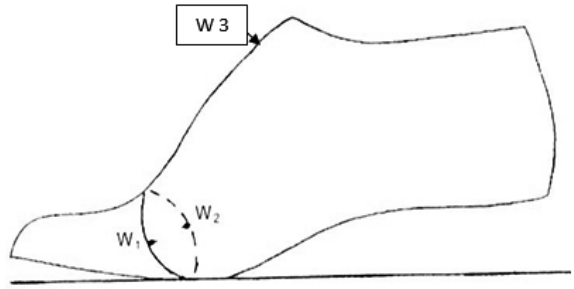


Figure 4.24. Method of measuring the circumference of the forepart
Source: own elaboration.

4.6.2. Verification of footwear design

When assessing the correctness of the performance of children's shoes, the following should be taken into account:

Connections of the upper elements – they should avoid the area of the big toe joint and the fifth toe. The location of those points should be determined in accordance with the "Foot Parameters Grid". Joining the elements stiffens the upper, which may compress and rub the foot.

Height and shape of the heel – the height should not exceed 0–20 mm for younger children, and for girls with feet from 22 to 25 cm–35 mm. In moulded soles, the actual heel height is the difference between the thickness of the sole in the heel and at the thinnest point in the forefoot area.

Easy to put on shoes – the design that facilitates putting on shoes, such as lacing, Velcro fastening, fastening straps – the farther towards the toe the lacing or fastening reaches, the easier it is to put on shoes (Figure 4.25.). Zippers in booties and boots should be sewn diagonally 15–20 mm from the edge of the sole. The diagonal sewing of the zipper makes it easier to put it on.

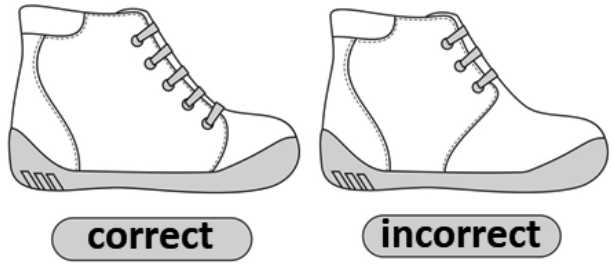


Figure 4.25. Ankle boots with correct and incorrect lacing
Source: own elaboration.

Soft upper materials – uppers of footwear should be made of soft materials, easily adapting to the shape and dimensions of feet;

Upper edges of the uppers – properly finished so that they do not have sharp edges and do not rub feet during use. Indicated finishes, e.g. by wrapping, binding or by using the so-called "shock absorbers" in the upper part of the upper and on the tongue in the form of collars filled with foam;

Figure 4.26. The upper edge of the upper finished with a soft collar
Source: own elaboration.

Lace ends – in shoes for small children, the ends of the laces should be sunk or knotted. Metal or plastic tips are hazardous because a child can swallow them;

Decorative and functional elements – such as discs, buckles, hooks, ornaments, buckles must not have sharp edges and must be fixed in such a way that a small child cannot tear it off and swallow it or put it, for example, into the nose;

Sole texture – anti-slip elements of various heights and shapes, particularly important in winter footwear, but also important in everyday and home footwear, especially for children starting to walk at preschool age. Smooth, slippery soles cause injuries;

Thickness of the soles – thinner soles for everyday and home footwear (optimal thickness of about 4 mm) and for winter shoes to protect against the cold. Thicker soles are recommended to be minimum 6 mm in width. Sole thickness is measured with a thickness gauge or calliper at the midpoint of the forefoot. When assessing the thickness of the sole, it should be remembered that the stiffness of the sole increases with the thickness of the sole, which is not recommendable;

Weight of outsoles – in order to reduce the weight of shoes in moulded soles, various types of relief should be used: holes, grids, etc. (Figure 4.27.);

Figure 4.27. Relief grid in the sole for children's shoes
Source: own elaboration.

Flexibility – a highly flexible sole that bends easily (using little force) at the metatarsophalangeal joints, which makes it easier to roll the foot while walking. In the case of winter footwear, in which, due to the need to use thick soles to protect against the cold and with a deep tread, the footwear may be less flexible. However, in this case, the sole should be profiled in such a way that it facilitates the foot roll without the need to bend the sole (the soles have an arch shaped profile).

The key element in the assessment of children's footwear is the assessment of the inside of the footwear – unevenness and thickening inside the footwear, which may pinch, are unacceptable, and even hurt children's feet. Particular attention should be paid to the sensitive areas of the feet. Sensitive places of the foot are anatomical areas that are particularly exposed to excessive pressure and overload, and are prone to disease and painful deformations:

- the metatarsophalangeal joint of the big toe
- the metatarsophalangeal joint of the fifth toe
- the highest raise point
- the place where the foot passes in the lower leg (joint)
- medial ankle
- lateral ankle
- the rear arch of the heel (around the Achilles tendon).

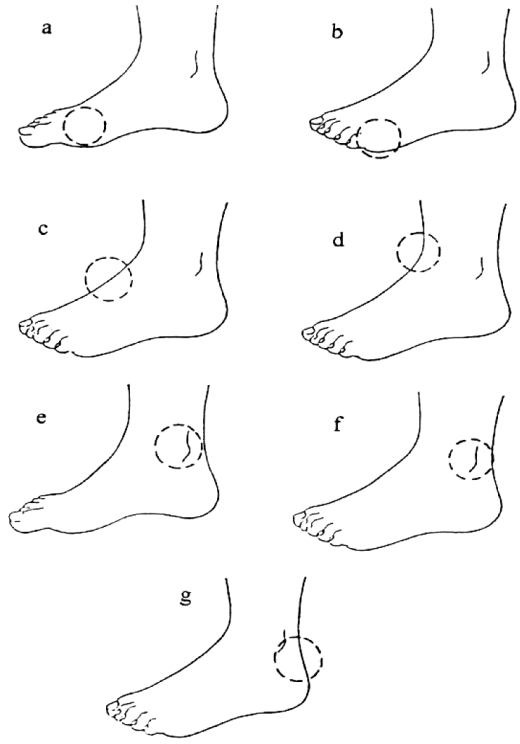


Figure 4.28. Sensitive places of the foot
Source: own elaboration.

The inspection should include:

- joining materials – there must be no thick seams connecting several layers of materials that may hurt the feet;
- the method of attaching small elements – various types of discs, rivets, eyelets, hooks, ornaments should be flattened and fastened in such a way that they do not hurt the foot;
- technological defects – wrinkling of linings, linings, glue residues, embossing of the sole material, sharp ends of threads, nails, clips remaining after attaching the insole to the last, etc.;
- footwear reinforcement elements:

Toe cap – if used in footwear, it must be thinned to "disappear" towards the back of the foot. The length of the toecap should not exceed the bending line of the foot. Poorly thinned and too long toecap can compress the foot in the place where the footwear bends during use. It will also affect negatively the aesthetics of top of the shoes;

Counter – properly developed and formed, it must be consistent with the shape of the heel of the last and elastic enough not to be deformed (not deformed) under

the pressure of the foot. The length of the tab wings – in shoes made with a glued system, it should be 2/5 of the length of the last bedding.

Linings – an element in direct contact with the foot, that should be characterised by good hygienic properties. The linings should be glued pointwise so that the adhesive layer does not reduce the hygienic features. It is advisable to use replaceable insoles, especially in winter and rain boots, that are easily removed from the shoes and can be dried, washed or disinfected. Such linings should be additionally stiffened, for instance, glued with cardboard;

Innersoles – have a large impact on the flexibility of footwear. The excessive thickness of the material used for the insoles increases the stiffness of the entire bottom system. It is advisable to use:

- two-part innersoles: the rear part is rigid, the front part is soft;
- innersoles cut in the front part (in the area of metatarsophalangeal joints);
- innersoles sewn in from fabric double-plywood or needled non-woven fabric in footwear made with a direct injection system.

Heel caps – if they consist of two parts, they cannot be connected with a seam that will rub the foot. The leather heel counter should be sewn with the fleshy side to the foot to prevent the foot from slipping out of the footwear, and in insulated footwear to additionally protect against abrasion of the insulating fabric.

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Chapter 5
Social and Economic Benefits Assessment in Terms of Social Innovation

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5.1. Assessment Benefits Derived from Social Innovation in the Polish Economic Reality

The assessment of the studied socio-economic phenomena poses many methodological problems, mainly due to their high degree of complexity and the multitude of approaches to the researched area. However, taking into account the results of the survey, it should be noted that the knowledge of the average Polish participant in social life in this area is small. However, this is not due to the lack of social interest but the lack of credible and reliable feedback from the creators or owners of the innovation. There is nothing to prevent some part of the Polish budget from being spent on social campaigns promoting a healthy lifestyle, etc. There are no objections to promoting the most innovative solutions in particular areas of social life. Social innovation stems from a long-term study of social needs combined with a dialogue between specialists in a given field, entrepreneurs, and society. The role of the authorities is also indispensable here, as they play an important role in creating the business environment, for example through legislation. The lack of knowledge about the benefits arising from social innovation or its role in the economy is not conducive to promoting positive behaviour among society. As a result, the Polish economy is perceived as ineffective and non-innovative.

Social innovation may be defined in various aspects. By and large, it is understood as new, more effective methods and tools for solving social problems in various areas of social life. The nature of social innovation is not uniform, either. The related implementation may take the form of new solutions or improvements. The same applies to the subject of innovation itself as it may relate to manufactured

products, processes, methods of optimising the consumption of production factors. At this stage, it is necessary to indicate what kind of social innovation has recently been implemented in the Polish economic reality. The European Union has been supporting the development of innovative projects for years, also in social terms. Currently, social innovation is financed both at the national and pan-European level. The European Social Fund under the Operational Programme Knowledge Education Development 2014–2020, Priority Axis IV Social Innovation and Transnational Cooperation, Measure 4.1 Social Innovation serves as one of he funding sources. The specific objectives for the priority axis are as follows:

- increasing the use of social innovation to improve the effectiveness of selected aspects of public policies in the area of ESF impact;
- strengthening professional competencies and key people with the use of transnational mobility programmes;
- implementation of new solutions, in particular in the field of professional activation, lifelong learning and creation and implementation of public policies, thanks to cooperation with foreign partners.

The financial contribution for this purpose is EUR 659,591,124.

The exemplary set of social innovation elaborated upon above contributes to the process of solving key social problems, thus constituting the so-called social entrepreneurship. Aspects of this entrepreneurship are stimulated by the European Commission through various types of financial models. In the 2014–2020 budget perspective, social innovation was included in the regulations on structural funds – both the European Social Fund and the European Regional Development Fund. Programmes supporting social innovation include: the Programme for Employment and Social Innovation combining the three existing Progress Programmes, EURES and the European Progress Microfinance Mechanism, the URBACT Programme and Horizon 2020.[1] Social innovation, due to its experimental nature, is often burdened with a high implementation risk, therefore public funds should be the funding source of such initiatives. Social innovation has been implemented and disseminated in Poland to the extent of the following areas: activities for sustainable education, sustainable transport, supporting active and healthy ageing, supporting disabled and unemployed people in the protection of their physical and mental health.

1 B. Skubiak, (2016), *Innowacje społeczne w teorii i praktyce*, "Barometr Regionalny. Analizy i Prognozy", vol. 14, no. 1, Wydawnictwo Akademii Zamojskiej, Zamość, p. 33.

Table 5.1. Examples of social innovation financed with the EU funds and other sources (Poland and the world)

Name/title of social innovation	Brief description of the innovation	Who is the innovation aimed at?
1	2	3
Innovative shopping bag for a rehabilitation walker	Multifunctional bag with attachments for a rehabilitation walker.	The product is dedicated to the elderly with limited mobility and people with disabilities who move with the use of a walker/ rehabilitation walker.
Innovative system for detecting epilepsy attacks, bradycardia, tachycardia and falls	Open Seizure Detector is an application that is configured with digital equipment. Its task is to detect seizures during tonic-clonic seizures in the case of epilepsy, arrhythmias and falls. In addition, it alerts caregivers about the occurrence of an attack or fall.	The innovation is addressed to elderly people with limited mobility and/or perception and to people with disabilities.
A website with information on how to adapt a home to people with disabilities, along with a database of potential contractors	The website is available at: https://brakbarrier.pl. The website collects architectural and functional information on how to adapt the living space for people with disabilities. The website contains a database of potential contractors.	The target group of the website includes: elderly people with limited perception and/or mobility as well as people with disabilities, members of their families.
A mobile application for seniors for smartphones with a simple and clear interface: Mobi Seni App	The application contributes to the increase in activity, establishing and maintaining contacts and provides the ability to call for help in an emergency with an indication of the location of the person calling for help.	Social innovation is intended for elderly people with limited mobility and/or perception as well as for people living alone or spending time alone as well as carers and family members of these people.
Leisure without barriers – fishing without barriers	It is a model of safe location marking for independent pursuit of fishing passion by people with disabilities and elderly people with limited perception and/or mobility.	The solution is dedicated to people with disabilities and seniors with limited perception and/or mobility – interested in fishing. An indirect target group includes the Polish Angling Association and regional and local fishing associations.

Table 5.1 (cont.)

1	2	3
Tool Eloquently Available	Social innovation consists in developing a tool for alternative communication (www.spektrumkomunikacji.pl). In this alternative form of communication, graphic symbols and photos are used in communication processes in everyday life by non-speaking people affected by autism as well as other people with speech dysfunctions.	The innovation is dedicated to non-speaking people and to representatives of non-governmental organisations and institutions working in the environment of non-speaking people who, thanks to the use of developed tools, have easier communication with people with disabilities.
Polish Institute of Sensory Accessibility	It is a developed set of guidelines for creating places adapted in terms of accessibility for sensory sensitive people (people with sensory integration disorders/SI disorders). The effect of innovation is available on the website www.instytutdostepnosci.pl along with a database of sensory accessible places.	The solution is addressed to people on the autism spectrum with sensory integration disorders and other people with disabilities who have been diagnosed with sensory disorders.
Mutual support telephone	The innovation consists in the use of conscious laughter as a therapeutic method based on mutual cooperation of seniors using the telephone. Innovation involves the use of developed methods of consciously evoking laughter.	The innovation is addressed to seniors with limited perception and/or mobility who, due to their psychophysical condition caused by their personal and/or health situation, require the use of innovative therapeutic methods.
Expedition education available to everyone	It is an innovative, comprehensive model of improving accessibility for people with various disabilities to education, culture, and art through experience in contact with monuments, attractions, and tourist services. The model is based on the preparation and development of programmes for visiting and experiencing a place based on the matrixes of verification of the availability and adequacy of attractions and services for various groups of people with special needs.	The innovation is dedicated to: people with disabilities, in particular people with physical disabilities, and visually impaired, with hearing impairment, intellectual disabilities, with mental disorders or diseases, with communication difficulties and elderly people with limited perception and mobility.

1	2	3
FiveApp	A smartphone application that facilitates communication for people with hearing impairment.	The innovation facilitates communication for people with hearing impairment, who can communicate in American Sign Language (ASL).
Dressing	Raincoat for people in wheelchairs.	Uniclothing is a universal, waterproof and innovative rain cover, designed taking into account the needs of people with physical disabilities, moving in a wheelchair.
Device supporting the function of the upper limb for people after a stroke with its permanent dysfunction	The tested product is a „glove" for people after a stroke, with consequences in the form of upper limb contracture. Thanks to the use of a set of mechanical and elastic elements connected together in a specific way, the device facilitates the mapping of the lost limb function and the performance of activities previously inaccessible without the help of a caregiver.	Innovation for people with disabilities in result of strokes.
b-Link software	The aim of the b-Link project is to provide people with physical disabilities with a tool in the form of a program that allows them to work on a computer and use the Internet by blinking their eyelids. With this program installed on the computer, the user can display and navigate the web pages, control the mouse cursor, type on the keyboard, operate a package of office or e-mail programs and turn off the computer.	The program dedicated to people with physical disabilities is available on the TP and Orange websites. It is available in the Polish, English and French language versions.
Reducing the weight of PET bottles by Coca Cola	Reducing the weight of the bottle contributes to reducing the amount of waste, and thus to preserving raw material resources for future generations and improving the cleanliness of the environment.	Social innovation for every use. The aim of the implementation is to build awareness of waste management in households by making the public aware of waste recycling and mitigating the adverse impact on the natural environment.

Table 5.1 (cont.)

1	2	3
Integrated reporting – Grupa Lotos	Thanks to integrated reporting, Lotos enables its stakeholders to make a comprehensive, measurable, objective assessment of its overall involvement in sustainable development issues through an integrated and user-friendly presentation of financial and non-financial statements on business operations and activities in the financial year.	Social benefits: building trust and credibility among the company's stakeholders, thanks to data transparency; supplementing the company's financial data with ESG data for investors interested in SRI investments; responding to the needs and expectations of stakeholders; opening to dialogue and social consultations through the use of new communication channels; mitigating the adverse impact on the environment due to paperless reporting.
Rondo 1 building	Rondo 1 is the first building in Europe with an implemented DALI lighting control system.	Social benefits: mitigating the adverse impact on the natural environment; increasing employees' awareness of environmental issues; responding to stakeholders' expectations in the context of care for the environment.
Mitigating the environmental impact in the supply chain – Raben Group	In terms of the car fleet, an eco-driving culture has been implemented, the purpose of which is to limit and monitor the amount of fuel consumed. The truck fleet has been replaced with the natural environment in mind (300 vehicles). The Group also has its own petrol stations, thanks to which it monitors the quality of fuel and emissions of exhaust gases into the atmosphere. Drivers have been offered eco-driving training, which has reduced the average fuel consumption from 31.2 to 30.76 litres per kilometre.	Social benefits mitigating the adverse impact on the natural environment; improving the living standards of local communities.

1	2	3
Samsung Hope Relay – Go Help	An application used while walking, cycling or jogging, giving you the opportunity to add your kilometres travelled to the general pool. For every kilometre travelled, Samsung has donated 1 Pound Sterling (PLN 1 in Poland) to organisations supporting children and young people. In Poland, the aim has been to subsidise summer camps for children from SOS Children's Villages.	Social benefits: opportunity to get involved in supporting those in need for whom the company operates; promoting the idea of volunteering among customers; additional motivation to undertake physical activity.
Proof Glasses	Proof is a company that makes sunglasses by hand. It has been the social innovation to base the production of glasses on natural raw materials, primarily wood.	Social benefits: respect for natural environment resources; obtaining raw materials from sustainable sources; donating part of the profit to social purposes (eye surgery in India, tree planting in Haiti).
tarbucks™ Shared Planet™	Shared Planet™ is a campaign aimed at expanding customers' knowledge of the origin of coffee, its ethical cultivation and purchase, and thus the supply chain of the product to Starbucks coffee shops. It is to make customers aware that coffee beans obtained in coffee shops are grown with care for the natural environment, and the purchase itself is based on the Fair Trade Standard.	Social benefits: support for local communities; mitigation of the adverse impact on the natural environment and combating climate change; transparent communication with the environment thanks to the GRI guidelines; consumer education on the supply chain of products offered by Starbucks.
Management of waste from the leather industry in agrotechnics – Łukasiewicz – Institute of Leather Industry (currently Łukasiewicz – Lodz Institute of Technology)	The implementation of the projects included activities aimed at increasing the yield of various plant species using the by-products of the leather industry.	The results of the conducted research will be applicable in many sectors of the economy, especially in agriculture. Among other things, a new material based on collagen preparations and seed coating technology has been developed in order to increase resistance to drought and the use of waste biomass to develop a new foliar preparation containing a fungicide and plant biostimulators.

Table 5.1 (cont.)

1	2	3
Environmental responsibility – Łukasiewicz – Institute of Leather Industry (currently Łukasiewicz – Lodz Institute of Technology)	Tools have been developed to calculate the carbon footprint in the footwear sector, which allows to estimate greenhouse gas (GHG) emission during the production of footwear.	The aim of the project has been to provide footwear companies with a tool that will allow the industry to identify the most important aspects of production for the purpose of reducing greenhouse gas emission.
Unit operations in the field of processing tannery waste for re-use – Łukasiewicz – Institute of Leather Industry (currently Łukasiewicz – Lodz Institute of Technology)	Work carried out in the field of methods of collecting tannery shavings derived from chromium and chromium-free tanning processes, for the purpose of which mineral additives are used. As a result of the conducted work, a loose, agglomerated granular bed containing both mineral and organic components is obtained, that is easy to store, transport and dose.	The developed methods make it possible to process and change the physical properties of the waste output – shavings derived from chromium and chromium-free tanning processes, often stored at the tanning plant and sent for disposal.
DOM model	The innovation focuses on carers of children with cancer in order to provide new tools that will enable them to use the resources of their own family and the closest environment in handling childhood cancer, and consequently also help the child. The main element is to enhance the knowledge and awareness of local employees of social welfare institutions, psychologists, educators, therapists, social partners, and teachers about the possibilities and ways of supporting families struggling with this problem.	Support for families taking care of children undergoing cancer therapy or after cancer treatment, taking into account the local institutions.

1	2	3
Your way	This is a modern program created by Altix company in cooperation with the Chance for the Blind Foundation. The application developed in 2017 helps the people with visual impairment to move independently, which makes it easier for them to remain mobile in public space. YourWay works by connecting to small transmitters (so-called beacons) that are found in various places or on devices. After connecting to the beacon, it will transmit information and the application will read what it receives. There is also a version in which a speaker tag will play information in the form of audio instead of the application.	This is a solution that supports people with visual impairment in moving around the city successfully.
Together you can do more	It is a model of supporting sports activities of visually impaired people based on engaging them in Nordic walking in the company of professionally prepared sports guides (assistants). This is a new form of rehabilitation and leisure, which significantly mobilises people with visual impairment to: be active, increase the degree of independence, improve self-esteem, optimism of life, overcome physical disabilities and learn to interact with the environment, and even take up new family and social roles, including professional.	Nordic walking for people with visual impairment
You_good_eat	The model of workshops in the field of natural nutrition for parents of disabled children contains a guide and a related dossier as well as an educational film and measurement tools that support healthy eating for the whole family.	For parents of disabled children

Table 5.1 (cont.)

1	2	3
ONCO-Yoga	The activities undertaken as part of the project consist in development of a program and organisation of the Integrated Support Course for Chronically Ill People and their Carers, which covers the areas crucial for the well-being of the patient, including the closest relatives and/or carers.	The project is addressed to people professionally caring for chronically ill people as well as volunteers, social workers, animators and family carers.
EasyMove	The mobile caterpillar platform for wheelchairs allows you to move without leaving your own wheelchair on surfaces inaccessible to wheelchairs (e.g. beach, forest paths).	Innovation dedicated to people with disabilities in wheelchairs.
Szu on the trail of memory and Gates of memory	The game facilitates spending time to the satisfaction of people with neurological disease. The book for preschool and early school children makes it easier for the youngest family members to live with people suffering from neurological disease.	Innovation dedicated to people with neurological disease.
Less loneliness	Improving the well-being of seniors in their relationship with students is an innovation that serves older people who live independently for various reasons and suffer from loneliness and a sense of isolation. The licence includes recruitment and verification procedures for people associated within the solution, templates of contracts and survey announcements for employees of non-governmental organisations and social workers.	Innovation dedicated to lonely, elderly and rejected people.

1	2	3
Gynaecology available	The solution not only makes it easier for the disabled to find a gynaecology clinic that meets the accessibility requirements but is also aimed at making doctors and medical staff aware of this important issue. This innovation is a website with a search engine for available gynaecological clinics along with an educational section for women with disabilities and for health care personnel: www.dostepnaginekologia.pl.	It is a solution for gynaecological care, obstetrics and motherhood addressed to women with disabilities.
MedInterview	It is a platform for conducting a pre-anamnesis (preliminary medical interview) using a website containing questions and suggested answers available in the Polish and the Polish Sign Language (PJM). The aim of the project is to increase the accessibility of medical facilities in Primary Health Care.	Innovation dedicated to various groups of patients, but above all, to patients with hearing impairment.
Lagging of Health	It is a guide for conducting a conversation between an oncologist and a patient and a binder for a cancer patient.	Innovation dedicated to adults with disabilities that have developed as a result of cancer and related cancer therapy.
Childbirth of a Woman with Hearing Impairment	It is an educational platform with a tutorial for a woman with hearing impairment within the framework of the childbirth course, from the beginning of labour to the delivery itself – http://porodgluchej.pl. The priority of the project is to raise the awareness of a patient with hearing impairment and her safety as far as the labour and delivery is concerned. The project is also to prevent undesirable obstetric complications that may be hazardous to life and health of patients with hearing impairment and their offspring.	The direct target group of the Project „Childbirth of a Woman with Hearing Impairment" includes women of reproductive age – between 15 and 49 years old, with disabilities, i.e. hearing impairment (from birth or those who developed hearing impairment in the prelingual period, i.e. before acquiring the phonic language), using the Polish Sign Language.

Table 5.1 (cont.)

1	2	3
Dentistry without barriers – adaptation and admission qualification of patients with disabilities	The main objective of social innovation is to improve access to dental care for children, adolescents and young adults with disabilities, especially those with intellectual disabilities, by adapting and defining the rules of qualification for prophylaxis and treatment procedures already in the place of education. As part of the project, a model for conducting an adaptation session to a visit to the dentist's has been developed to be used during classes at school. A mobile dental station has been arranged for (a chair, lamp, small dental equipment, personal protective equipment as well as disinfectants). The developed model facilitates the initial admission/treatment qualification and adaptation of students to dental procedures in well-known school conditions, with the participation of people assisting students/pupils in everyday life (pedagogues, psychologists, nurses).	The innovation is dedicated to pupils/students with intellectual disabilities and other dysfunctions and/or chronic disease, who are educated in special schools.
Everyone can save!	This is a first aid course dedicated to people with mild and/or moderate intellectual disabilities, who will know how to respond in the event of Sudden Cardiac Arrest (SCA) and the need to perform Cardiopulmonary Resuscitation (CPR).	The target group includes adult people with mild or moderate intellectual disabilities.
On wheels at the hairdresser's	The innovation consists in tailoring the services offered by hairdressing salons to the needs of people in wheelchairs by developing prototypes of devices that allow to serve a person in a wheelchair in the salon.	The target group includes the people with disabilities moving by means of various types of wheelchairs.

1	2	3
The neighbour can	It is a method of building an aware local community in which people with dementia and their carers are supported and included in its everyday life. The innovation aims to improve the opportunities of this social group in terms of using such areas as trade, services and cultural life in the local environment.	The solution is aimed at elderly people with disturbed perception, and more specifically, patients with neurodegenerative disease.
AR	It is an application-aided therapeutic methodology for people with autism and their carers/families in therapy, the aim of which will be to improve the opportunities for those people to be activated in various areas of everyday life. The application is based on augmented reality technologies, which is currently a very dynamically developing area in the digital world. It is widely used in education, training, medicine, services, etc.	The target group includes children and teenagers with a high-functioning autism certificate, aged 7–18 years.
Passion Incubator	The innovation consists in the integration of sports and artistic activities and the related methodology aimed at social inclusion of the participants in the classes, in opposition to the focus on individual results and achievements. As part of the Innovation, a comprehensive model for organising and conducting additional sports and artistic activities has been developed in the form of a textbook enriched with an incentive system for participants of classes and places friendly for people with disabilities marked with special stickers in order to increase the availability of additional activities for children and the youth.	The target group of the project includes children with mobility, intellectual and/or multiple disabilities.

Table 5.1 (cont.)

1	2	3
„KanGur +" Universal Transport Cocoon	It is a universal Transport Cocoon that is a „connector" between a disabled person and e.g. a wheelchair, bus seat, etc. It will allow you to carry out an ordinary safe walk without fear of slipping the person from the wheelchair or passenger seat when going on a trip by bus. The intention of the creator has been to incorporate solutions available in the market (carriers and stabilising pillows) but insufficient for the needs of a person who has problems with muscle tone into the innovation that allows to carry a disabled person while maintaining stability.	The target group of the innovation includes people with disabilities, mainly people who are dependent, in a vegetative state, after strokes, with paralysis – unable to independently maintain a stable position during transport.
On the path available	This innovation consists in developing a standard for marking Nordic Walking routes for people with visual disabilities and the elderly.	The target group of the innovation includes people with visual disabilities.
Alone on the road	It is a developed and tested model for conducting classes for visually impaired people who have partially lost their sight as a result of diseases or accidents, for the purpose of facilitating their return to independent use of a car (adults) and learning to ride a bicycle (children and adolescents).	The main target group of the solution includes visually impaired people who have partially lost their sight as a result of diseases or accidents, both adults and children/young people.
SIMNEY – carrier for carrying disabled people on the go	The main objective of the social innovation, under which the transport sling has been created, is to improve mobility of people with disabilities. The transport carrier will improve the mobility of physically disabled people by facilitating their movement from the stroller to the chair in means of transport such as cars, coaches, planes, etc.	The target group includes all people who use a wheelchair on a daily basis.

1	2	3
Read me a book	The innovation is a combination of volunteer service with the opportunities offered by the mass media – radio. It consists in combining 3 well-known activities, i.e. reading books on the radio, reading books by volunteers for the elderly and dependants, interviews with authors of books on the radio. The innovation of the idea stems from the fact that the elderly, in addition to access to literature and contact with volunteers, gain the opportunity to actively engage in interviews with the authors of books in their own homes.	The implementation of the project will allow the elderly with limited mobility not only to read the book but also to go a step further – to attend a meeting with authors, which will be broadcast on the radio.
siphonophores	It is a method dedicated to visually impaired people to allow them to proactively view art and cultural exhibits displayed in galleries/museums. The aim of the project has been to solve the problems related to the lack of sufficient accessibility of the public space in museums and art galleries – the paintings and sculptures contained therein – for visually impaired people, so that they could experience this art through their own eyes.	The target group includes the disabled people with specific visual impairments, i.e. people with a central field of vision with a narrowed field of 10 to 20 degrees, able to distinguish colours.
Art Available	The innovation comes forward with an art creation method for children with disabilities, that consists of: development of technological solutions that facilitate the participation of children with special needs in the event, and development of innovative workshop and artistic work with a disabled child.	The target group includes children and the youth with disabilities and developmental disorders from 5 to about 13 years old.
The Multisensory Dictionary of Art	It is an educational tool dedicated to children and young people with visual disabilities, that is to teach the history of art in an attractive way. This allows them to better understand the culture around them.	The target group of the innovation includes the visually impaired youth who are 12–18 years of age, 6th – 8th grade pupils/students at primary school and secondary schools.

Table 5.1 (cont.)

1	2	3
„Counteracting Digital Exclusion in Lubelskie Voivodeship" implemented under the contract No POIG.08.03.00-06-049/10-00 of 2011, co-financed by the EU under the European Regional Development Fund and implemented under the Innovative Economy Operational Programme for the years 2007–2013, Priority Axis 8 Information Society – increasing the Innovativeness of the Economy, Measure 8.3 Counteracting digital exclusion – eInclusion.	The project totally valued at PLN 18,445,445 in its outcome provided for free access to the Internet and the purchase of necessary devices and software for households in 47 boroughs and two districts of the Lubelskie Voivodeship at risk of exclusion from active participation in the information society due to difficult financial situation or disability.	Innovation addressed to all inhabitants of the Lubelskie Voivodeship. The implementation of the project has contributed to improvement of the quality of life of the residents thanks to the access to computer hardware and the Internet.
Lublin Vocational Qualifications Framework – a model of effective cooperation between vocational schools and employers	The innovation has given rise to an innovative model of effective cooperation between vocational schools and employers in the Lubelskie Voivodeship based on the accreditation system „Lubelskie Framework of Vocational Qualifications". As part of the project, a model of vocational education has been delivered in accordance with the suggestions and proposals of employers. The aim has been to adapt the curriculum to the expectations of the labour market.	The innovation addressed to young people and employers has allowed for the creation of a youth education model in accordance with the needs of the labour market in the region.
Innovative Integral Programs of Early Social Intervention	An innovation project counteracting social exclusion of young people in the Lubelskie Voivodeship.	The main target group of the innovation includes young people with educational difficulties and problems of social maladjustment.

1	2	3
Brilliant Woman	The aim of the innovation has been to increase the activity of women in the face of the problems posed by the labour market in 2011–2015.	Social innovation addressed to women from Świdnica District, that has come forward with advisory and training support as well as financial assistance for 35 women in the amount of PLN 40,000 zloty for setting up their own business.
Success in your hands	The aim of the project has been to develop entrepreneurship in Chełm and Włodawa Districts by means of developing the skills of running a business and self-employment with the capital support in the form of subsidies and training and consultancy/ advisory support. In effect of those activities, new businesses have been set up.	Innovation addressed to the local community interested in support for the purpose of starting their own business.
Science for business, business for science	The innovation project covering the knowledge transfer between scientific institutions and enterprises in the area of technology, process, IT, energy and marketing. Mutual exchange of employees through the organisation of internships has allowed for the transfer of experience in the sphere of practical and scientific and didactic activities.	All stakeholders have been the beneficiaries of the innovation.
Lifelong learning for adult mobility in the labour market	The aim of the project has been to support public schools for adults from the Lubelskie Voivodship in adjusting the educational offer to the changing socio-economic conditions through the use of innovative teaching methods and the forecast of factors influencing lifelong learning in the region.	Innovation addressed to schools.
Friendly office, new quality of services	The aim of the project has been to improve the quality and accessibility of public services provided by the local municipality office.	Innovation addressed to the entire local community.

Table 5.1 (cont.)

1	2	3
Support and Activation Programme for Seniors in the City of Lublin for 2013–2015	The aim of the innovation was to equalise opportunities and prevent social exclusion of seniors, organise activities in the field of health protection and preventive health care, social activation of seniors, creating a positive image of the elderly in the local community.	Social innovation addressed to seniors in the programme area.
Ambitious and enterprising	The aim of the project has been to boost professional engagement through training, internships and financial support, which contributes to improvement of the professional qualifications of unemployed people with a varied age structure.	Social innovation addressed to the local community interested in boosting professional engagement.
I-Cane: mobility solutions for the visually impaired, for global use	The innovation has come forward with a touch interface for visually impaired people, that leads a person along an unfamiliar route.	A social innovation aimed at the visually impaired community.
DAIN: digital activist integration network	DAIN is based on the philosophy of inclusion through community-based learning. The basic idea is that digitally excluded people can best reach out and train their fellow citizens who live in the same locality and have a similar social background.	Social innovation addressed to the digitally excluded community.
Innovativeness of the public sector – immigration policy in Portugal	Social innovation stemming from the need to facilitate communication between public administration in Portugal and immigrants. National Immigrant Support Centres (CNAIs) have been established to respond to a number of challenges identified by immigrants in the field of communication. Mediators have been recruited, trained, certified to be included in the process of providing administrative services.	Social innovation addressed to public administration in Portugal and immigrants struggling with communication problems.

1	2	3
North Rhine-Westphalia State Programme „Social Integration City": District Renewal Support	The government of North Rhine-Westphalia has developed an integrated policy supporting 80 urban regeneration programmes in its state. The Integrated Local Action Plan defines how the development, reorganisation and modernisation of a given area is to take place. Integrated Local Action Plans (LAPs) are implemented in districts. 55 Municipalities are responsible for the preparation and implementation of the LAP, e.g. applying for funding and ensuring that the local plan meets the needs of the city as a whole.	A social innovation aimed at the public administration of North Rhine-Westphalia.
An integrated action plan for Pongrác housing estate in Köbánya District in Budapest	The Pongrác estate is an isolated area of Köbánya surrounded by non-residential areas. The strategy aims to eliminate the causes of land segregation, making it a better place to live. Activities focus on: strengthening the residential function of the estate, renovation of buildings, strengthening the urban functions of the district by improving streets and parking lots; improving safety through road signs and speed bumps, new streetlights and cameras, renovation of playgrounds; the creation of a new football field; the creation of small gardens and open spaces between houses, a new public agora for outdoor recreation and other community building activities.	Social innovation addressed to the community living in an area excluded in terms of access to basic infrastructure.

Table 5.1 (cont.)

1	2	3
Supporting social entrepreneurship at the regional level: Yorkshire Key Fund and Social Enterprise Support Centre	The Yorkshire Key Fund was launched in 2007 under the ERDF South Yorkshire Objective 1 Programme for the period 2000–2006. The Start and Grow Fund supports small start-up social enterprise projects with loans of up to €25,000 and grants of €2,000 to €5,000. There is a preparation fee of 1% and interest at a fixed rate of 6.5%. Loans are granted for a maximum of five years. Social enterprises in Yorkshire also benefited from the Social Entrepreneurship Support Centre (SESC), which provided non-financial support for business planning and strategic development.	Social innovation addressed to the community wanting to start their own business.
Using public procurement in an innovative way: the City of Nantes	The city of Nantes in north-west France is known as a leading innovator in the use of social clauses in public procurement to provide jobs for the long-term unemployed. France revised its public procurement rules in 2006, allowing for the condition that part of the work must be carried out by a specific target group in need of professional involvement. Nantes Metropole and the surrounding suburban administrations (Chantenay, Vannes, Doulon and Malakoff) awarded contracts using this clause. The works included swimming pools, roads, bus lines and a media centre. Types of occupations include bricklayers' helpers, carpenters, painters, construction workers, pavers, landscaping staff, plumbers.	A social innovation aimed at the community of the Nantes region, in particular the long-term unemployed.

1	2	3
New forms of social services – STEP Migrant one-stop shop	STEP is based in the small town of Dungannon in Northern Ireland. It was founded in 1997 to work with local communities and was initially funded under the EU's PEACE programme. In the early 2000s, Northern Ireland has gone from a no-migrant zone to a labor-intensive place. Employment agencies brought migrants from Portugal and East Timor, and after accession to the EU in 2004, from Poland and Lithuania. STEP started working with these marginalised communities and gradually expanded its services using a combination of EU funds, provincial contracts and grants. The public bodies in Northern Ireland did not have the experience to work with such a wide variety of clients or to provide the language support to make this possible. STEP currently assists over 6,000 migrants a year with one-on-one advice on legal, health, employment, housing, social services, immigration and more from specialist advisers. Their work has led to improvement of the conditions imposed by unscrupulous employment agencies.	Social innovation addressed to public administration and immigrants wishing to work in Ireland.

Table 5.1 (cont.)

1	2	3
Kiút programme, self-employment and microcredit for Roma in Hungary	Kiút aims to support Roma to work in the formal economy by setting up a business. The microcredit programme provides assistance by lending start-up money to small businesses to generate enough income to service the loan and generate additional income for Roma families. Clients receive constant advice and administrative, financial and business assistance. A clear and important goal of the programme is to encourage women to participate in the programme.	Social innovation addressed to Roma families living in Hungary, running or wanting to run their own business there.

Source: https://innoes.pl/innowacje/2 (accessed: 22.12.2022), joint responsibility. *Wspólna odpowiedzialność. Rola innowacji*, edited by N. Ćwik, (2013), Forum Odpowiedzialnego Biznesu, pp. 115–130; https://www.gov.pl/web/fundusze-regiony/innowatorzy-spoleczni (accessed: 06.01.2023); https://www.szansadlaniewidomych.org/index.php/yourway/ (accessed: 01.06.2023); https://emidruk.nazwa.pl/kopiainkubator/razem-mozna-wiecej/ (accessed: 06.01.2023); https://www.psychesomapolis.org/onco-joga (accessed: 06.01.2023); http://www.inkubatorwielkichjutra.pl/zwiekszenie-dostepnosci-do-uslug-medyczny/ (accessed: 06.01.2023); Z. Wacławski, (2017), *Rola innowacji społecznych w rozwoju regionu województwa lubelskiego – przykłady dobrych praktyk*, "Nierówności Społeczne a Wzrost Gospodarczy", No 50 (2/2017), Uniwersytet Rzeszowski, Rzeszów, pp. 463–368; *Guide to Social Innovation 2013,* European Commission, pp. 30–36.

One of the widely known measures of innovation is the Summary Innovation Index (SII) – developed by the Maastricht Economic and Social Research and Training Centre on Innovation and Technology (UNU-MERIT) and the Joint Research Centre (JRC). The information on the state of innovation in the surveyed countries aggregated in the SII includes a number of indicators in the field of research and innovation, divided into inputs (inputs) and effects (outputs). The SII is a weighted average of 25 Innovation Union Scoreboard (IUS) indicators divided into three groups:

- innovation potential, i.e. factors conducive to innovation, such as: human resources, an open and attractive research system, funding and support;
- innovative activity of enterprises, i.e. investments of enterprises and their entrepreneurship, links between enterprises, intellectual assets;
- the results of enterprises' activities presented in two dimensions: innovators and economic effects.[2]

The SII indicator is used for synthetically assessing the level of innovation in the EU countries. Eight dimensions of innovation and 25 indicators make it possible to analyse the achievements of the European Union's innovation system. As part of measuring innovation, the Innovation Union Scoreboard studies distinguish 3 main types of indicators: enablers, activities, outputs and 8 dimensions of innovation, taking into account a total of 25 various indicators.

The research results contained in the latest study show that, as compared to the previous ones, the level of innovation changes both between countries and within four groups:

1. Innovation leaders.
2. Catching up countries.
3. Moderate innovators.
4. Humble innovators.

Table 5.2. *Summary Innovation Index* (SII). Comparison of the indicator level for the EU countries in 2022 and 2015

Country	Value 2022	Level	Country	Value 2015	Level
1	2	3	4	5	6
Sweden	149.32	Innovation Leader	Sweden	138.77	Innovation Leader
Finland	149.17	Innovation Leader	Denmark	136.87	Innovation Leader
Denmark	148.19	Innovation Leader	Netherlands	132.33	Innovation Leader
Netherlands	142.26	Innovation Leader	Finland	129.63	Innovation Leader

2 A. Masternak-Janus, M. Rybaczewska-Błażejowska, (2013), *Analiza efektywności innowacyjnej przedsiębiorstw przemysłowych w Polsce z wykorzystaniem metody DEA*, "Ekonomia i Zarządzanie", no. 4**,** Oficyna Wydawnicza Politechniki Białostockiej, Białystok, p. 494.

Table 5.2 (cont.)

1	2	3	4	5	6
Belgium	141.67	innovation Leader	Luxembourg	129.11	Strong Innovator
Ireland	130.66	Strong Innovator	Austria	125.46	Strong Innovator
Luxembourg	130.47	Strong Innovator	Belgium	124.86	Innovation Leader
Austria	130.07	Strong Innovator	Ireland	123.58	Strong Innovator
Germany	129.16	Strong Innovator	Germany	121.73	Strong Innovator
Cyprus	117.64	Strong Innovator	France	116.88	Strong Innovator
France	115.87	Strong Innovator	Slovenia	100.85	Moderate Innovator
Estonia	110.24	Strong Innovator	Spain	88.93	Moderate Innovator
Slovenia	102.80	Moderate Innovator	Portugal	88.45	Moderate Innovator
Czechia	101.60	Moderate Innovator	Malta	86.12	Moderate Innovator
Italy	100.62	Moderate Innovator	Estonia	85.85	Strong Innovator
Spain	97.54	Moderate Innovator	Italy	83.13	Moderate Innovator
Portugal	94.83	Moderate Innovator	Czechia	81.82	Moderate Innovator
Malta	92.79	Moderate Innovator	Cyprus	79.47	Strong Innovator
Lithuania	91.81	Moderate Innovator	Lithuania	71.96	Moderate Innovator
Greece	88.25	Moderate Innovator	Hungary	69.39	Emerging Innovator
Hungary	76.58	Emerging Innovator	Slovakia	65.97	Emerging Innovator
Croatia	73.03	Emerging Innovator	Greece	64.04	Moderate Innovator
Slovakia	70.49	Emerging Innovator	Croatia	57.51	Emerging Innovator
Poland	66.54	Emerging Innovator	Poland	55.21	Emerging Innovator
Latvia	56.13	Emerging Innovator	Latvia	51.41	Emerging Innovator
Bulgaria	49.66	Emerging Innovator	Bulgaria	48.03	Emerging Innovator
Romania	35.69	Emerging Innovator	Romania	35.61	Emerging Innovator

Source: own study based on: https://ec.europa.eu/research-and-innovation/en/statistics/performance-indicators/european-innovation-scoreboard/eis# (accessed: 06.01.2023).

Comparing the SII results in 2015 and 2022 presented above, it can be seen that in 2022 Belgium was separated from the most innovative countries, while in the previous edition it was among the Innovation leaders. The following economies are still at the top of the ranking: Sweden, Finland, Denmark and the Netherlands. The lowest SII level in 2022 was demonstrated by: Romania, Bulgaria, Latvia, Poland, Slovakia, Croatia and Hungary. Therefore, there are no significant changes in this respect as compared to 2015.

Table 5.3. Comparison of selected SII indicators for Poland and Slovenia in 2022

Country	R&D expenditure in the public sector	R&D expenditure in the business sector	SMEs introducing product innovation	Employment in innovative enterprises	Top R&D spending enterprises	Innovative SMEs collaborating with others	PCT patent applications
Poland	64.52	64.34	55.05	50.79	0.88	64.81	35.61
Slovenia	70.97	117.83	170.50	98.58	8.01	144.69	62.77

Source: own study based on: https://ec.europa.eu/research-and-innovation/en/statistics/performance-indicators/european-innovation-scoreboard/eis# (accessed: 06.01.2023).

In order to become a Moderate Innovator in the coming years, Poland must effectively change its approach to innovation. In the table above, Poland has been compared with Slovenia that currently is a Moderate Innovator, and has achieved the highest level of the SII index in its group. The above data shows that in Poland the percentage share of public funds in financing innovation is still too high, and the percentage share of private sector funds is too low, which translates into significantly lower values of partial indicators in the SII innovation assessment. Innovation is also expressed through patent activity. In this respect, Poland is at the end of the list, far behind, for example, Slovenia. The partial index for Poland is 100% lower than the one displayed by the best Moderate Innovator. The greatest disproportions between the surveyed countries result from the differentiated level of implementation of product innovation by the SME sector and the cooperation of the SME sector with other entities to the extent of innovation development and implementation. Poland differs significantly from Slovenia in those two areas, thus overcoming those disproportions may be difficult to achieve.

Another indicator used for assessing innovation at the national level is the Global Innovation Index (GII) – developed by Cornell University, INSEAD and the World Intellectual Property Organisation (WIPO). Published annually since 2007, the Global Innovation Index shows the advancement of countries and economies in terms of their innovation. On the basis of 80 indicators, such as e.g. the number of patent applications, the level of education, the quality of scientific publications (number of citations), or the involvement of the economy in the development of innovation The World Intellectual Property Organisation calculated innovation indicators for 131 countries around the world. The report published in 2022 shows that the most innovative European countries include: Sweden, the Netherlands, Germany and Finland. Thus, a similarity with the classification developed by SII may be noted. The least innovative economies included: Romania, Slovakia, Greece and Croatia. Poland was ranked 38th in the ranking, which gives it one of the last positions among European countries. The report shows that in 2022

Poland fared better in terms of innovative products than in the case of expenditure on innovation.[3] Slovenia, with which Poland was compared by the level of the SII index in 2022, was ranked 33rd.

Table 5.4. Comparison of selected GII indicators in 2022 for Poland and Slovenia

Indicator	Poland	Slovenia
Researchers, FTE/mn pop	29	16
Gross expenditure on R&D, % GDP	31	17
GERD performed by business, % GDP	27	14
GERD financed by business, %	28	13
GERD financed by abroad, % of GDP	38	10
Patent families/bn PPP$ GDP	36	25
Patents by origin/bn PPP$ GDP	23	19
PCT patents by origin/bn PPP$ GDP	42	27

Source: own study based on: https://www.globalinnovationindex.org/analysis-comparison (accessed: 07.01.2023).

GII serves as another ranking that, through synthetic indicators of innovation, shows how big the disproportion between Poland and other European countries in terms of innovation is. One of the main sources of concern for the Polish government should be the structure of financing innovation and improvement of the institutional management efficiency in terms of implementation (commercialisation) of various types of innovation, primarily those of a social nature.

5.2. Description of Research Methodology and Tools

The purpose of the research conducted in the period from October to December 2022 was to diagnose social and economic needs and the effects of social innovation in the opinion of Polish participants in social life. Although the research on the social effects of innovation has a long standing tradition, the constant changes in this area make the results quickly outdated. Poland's accession to the European Union, globalisation, the development of information technologies, and the recent pandemic or social unrest have significantly influenced the development and

3 https://www.globalinnovationindex.org/analysis-economy (accessed: 07.01.2023).

various applications of social innovation. The increase in social awareness regarding a healthy lifestyle or maintaining the right balance between work and family life has contributed to a new approach to social innovation that is increasingly perceived as an essential sphere of social life. The topic of social innovation is still inherent in social sciences and continues to be a challenge for researchers, as the explication of the genesis of new trends in the area of innovation or R&D may merely contribute to further development of the indicated research topic.

The research objective adopted in the project obviously translated into the criteria for selecting the research sample. The study on the perception of social innovation in the current economic reality demanded that the participants of the Polish socio-economic ecosystem be included in the study. The study used a non-random (non-probability) sample selection. Those are sampling techniques that do not use sampling procedures, but other procedures, based primarily on subjective decisions, based on known objective data, relating to the knowledge of the structure of the studied population. During the survey period, complete responses were obtained from 408 respondents.

The statements of people who are participants in social life constitute an important source of information in the conducted empirical study on the perception of social innovation by the society. In theoretical terms, the form of those statements may vary, for example: it may be a free, formalised interview or a survey questionnaire. From the point of view of this study and its objectives, the most appropriate research tool seems to be a questionnaire. The development of technology, primarily including information technology, and the easy availability of various electronic communication channels have made survey research one of the most willingly used methods of obtaining information in the information society. The answers obtained in this way will provide knowledge on how the participants of social life perceive social innovation, in which areas the aforementioned social innovation is most expected by the society or what factors limiting and stimulating development of such initiatives in the economy are the most important.

This study was conducted via an electronic survey sheet. The selection of the research sample was based on purposive sampling – this is the most typical case of non-random sampling. It involves a completely subjective selection of surveyed units for the sample, in the hope of obtaining the broadest and most complete information. Currently, electronic methods of survey research are more and more widely used. Research carried out by means of an electronic questionnaire is completed by a respondent (CAWI – Computer Assisted Web Interviewing). With the advent of computers, the process of collecting survey responses has become much simpler and faster. An important factor determining the choice of a research tool is the time-consuming and cost-intensive nature of the research process. An electronic survey is finalised much faster than in the case of a traditional form, in addition, in the case of an electronic survey, it is not necessary to print the questionnaires and process the data into an electronic version. The CAWI survey

is an online survey technique that fits into the quantitative methodology of market and opinion research. Obtaining data from respondents is ensured by electronic questionnaires available via web browsers, and supervision over their completion is ensured by dedicated research software – it inter alia controls the degree of examination of the sample under consideration, the appropriate sequence of questions asked as well as the verification and correct recording of the answers obtained. In this study, it has been decided to use the CAWI method to conduct a survey using the surveyeo.pl tool. The advantage of this method is its multimedia nature, speed of obtaining results, lower cost, and the ability to reach various types of recipients. In addition, it should be noted that the use of the CAWI research method enables the researcher to independently carry out survey research, thanks to which it is possible to reduce research costs and speed up the implementation time. Contrary to appearances, independent implementation of online research is fast and intuitive. The researcher retains full control over the course of the study and can track the results in real time.

The survey questionnaire included closed-ended questions, single-response and multi-response questions as well as questions with the use of a scoring scale. In total 14 questions were supposed to be responded by the respondents (including the metric). Closed questions contained predetermined answers. Based on the answers collected as part of closed questions, it is possible to calculate the distribution of answers, determine the central tendency in the answers and the correlations between them (85% of questions). The closed questions also included questions that differed in the number of answers provided by the respondent (single-response and multi-response). As the name suggests, single-response questions can be answered only once (75% of closed questions), while multi-answer questions involve a multi-part list of alternatives, out of which a respondent chooses the most adequate answers (25% of closed questions). The last group of questions consisted of questions using interval scales. The analysis of data obtained using this type of a scoring scale is vector-related in nature and focuses on determining the direction and intensity of recognised attitudes and assessments. They have a polarised form, divided into positive or negative attitudes and evaluations. The most frequently used scoring scale in this type of questions is the five-point Likert scale, the numerical values of which express the following assessments:

- negative assessment;
- rather negative assessment;
- neutral assessment;
- rather positive assessment;
- positive assessment.[4]

The research tool was constructed in such a way that the questions using the Likert scale (accounting for 15% of the questions in the survey) were extensive. On

4 Ł. Błuszkowski, D. Midler, (2007), *Wywiad jako metoda badawcza*, [in:] K. Kuciński (ed.), *Doktoranci o metodologii nauk ekonomicznych*, Szkoła Główna Handlowa, Warszawa, p. 211.

average, 10 partial answers were matched to each question, to which a respondent had to assign a numerical answer. The scoring scales created in this way not only made it possible to determine the possession of certain competencies, but also made it possible to examine the intensity of selected features.

5.3. Perception of Social Innovation – Surveying Outcome

The statistical analysis of the results of the survey conducted in respect of a group of 408 respondents presented in this part of the work was performed using an Excel spreadsheet. The analysis of the survey results is a synthetic summary of the collected statistical figures in the form of resulting tables, charts and conclusions. The survey was divided into two parts – one referred to the demographic and social characteristics of a respondent, and the other – substantive content.

Chart 5.1. Composition of respondents
Source: own study.

The respondents were dominated by women (251 people). They accounted for 62% of the total group under consideration.

The respondents in the study were mostly people aged 19–49 years. They constituted 68% of the total group under consideration. From the second age group including those between 50–59 and over 60 years of age, 26% of respondents participated in the survey. The smallest group was represented by people under 18 (7%). On this basis, it is plausible to conclude that the people most interested in participating in this study were young and middle-aged people. There is a high probability that the interest in social innovation was the major motivation to participate in the study. The graph shows a clear difference in the development of this feature among the study participants.

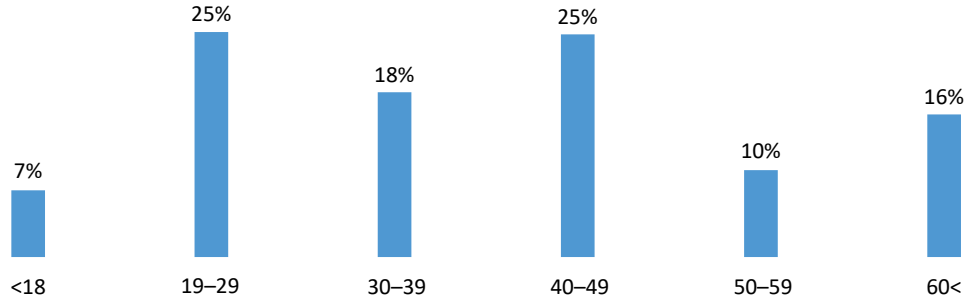

Chart 5.2. Age of Respondents
Source: own study.

Chart 5.3. Family Background of Respondents
Source: own study.

The diversity of the origin of the respondents is also noteworthy. The dominant group of respondents was represented by inhabitants of a city (73%). In this context, it should be noted that the differences in the family background of the study participants did not result from the availability of the Internet. Currently, approximately 92% of Polish households have access to the Internet. It can therefore be assumed that the interest in the study was higher among city dwellers, who had greater access to various types of information, which has been one of the benefits of spatial concentration of entities.

The structure of the respondents in terms of education indicates that the dominant group was represented by people with vocational or secondary education (56%), followed by the participants of the study, who were graduates of master's studies (27%), bachelor's studies (15%) and persons with the academic title of doctor (2%).

Summing up the part of the research outcome to the extent of the characteristics of the surveyed respondents, it should be noted that the dominant group was represented by women, aged 19 to 49 years, living in the city, with secondary or vocational education.

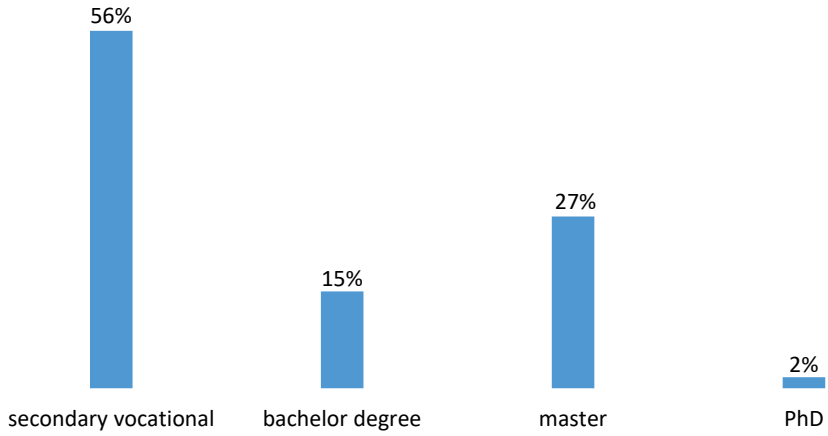

Chart 5.4. Educational Background of Respondents
Source: own study.

Table 5.5. Structure of the answers: Question no 1: Which statement according to Which country is most defined by social innovation?

Statement / Scoring Scale	1. – I strongly disagree,	2. – I rather disagree,	3. – I have no opinion,	4. – I rather agree,	5. – I strongly agree
1	2	3	4	5	6
serve to improve the quality of life of society	3%	6%	29%	32%	30%
use interdisciplinary knowledge to develop new social solutions	3%	8%	38%	31%	20%
bring together specialists from various fields	3%	9%	35%	30%	23%
solve problems that have never existed before solutions in the social area	3%	8%	41%	29%	19%
improve the comfort of life	3%	7%	33%	29%	28%
fill the market gap in the field of new products/services of a social nature	3%	8%	36%	33%	20%

Table 5.5 (cont.)

1	2	3	4	5	6
have nothing to do with social development – these are products / services for which we pay more when we are tempted by product marketing and social fashion	16%	15%	41%	18%	10%

Source: own study.

Attempting to examine how social innovation is perceived, the respondents indicated that in the vast majority, this dimension of innovation serves to improve the quality of social life (30%). Next, the indication concerning "improvement of the comfort of life" was rated the highest (28% of respondents). It should be noted that respondents who perceived social innovation in a negative way accounted for approx. 3% of indications. Therefore, it can be unequivocally stated that the dominant belief among the respondents was that social innovation constitutes an added value for society, mainly in the form of an increase in the comfort of living. It can therefore be concluded that the participants of the study had sufficient knowledge and hand been familiar with the subject matter.

Table 5.6. Structure % of answers: Question no 2: Please indicate (max. 3) factors that favour the implementation of social innovation in the economic reality

Factor	**Transparent legislation**	**Increased availability of financing for SMEs, local government units, business-related institutions,**	**Greater financial outlays on R&D by the Government,**	**Organization culture**	**Tax incentives for entrepreneurs**	**Initiating the implementation of social innovation by the Government through various types of government programs**	**Others**
Number of responses	194	135	133	157	181	133	4
%	48%	33%	33%	38%	44%	33%	1%

Source: own study.

Answering the question about the factors stimulating the development of social innovation, respondents most often indicated transparent legislation (48%) and tax incentives for entrepreneurs (44%). The survey did not ask the respondents about their occupation, therefore it is not known whether there were entrepreneurs among the respondents. Nevertheless, the answers indicate an important and significant participation of entrepreneurs in creating social innovation. Entrepreneurs, in order to be able to develop by offering socially innovative products and services, should, according to the respondents, be encouraged by tax reliefs and the law and legal regulations. Among other factors, there was a statement that the demand for development and innovation arose from people who were becoming more and more indulgent and needed newer and simpler solutions. It can therefore be concluded that lifestyle is an additional factor stimulating innovation.

Table 5.7. Structure % of answers: Question no 3: In what areas, according to Your social innovation are most needed? (max. 3)

Factor	New technologies	Natural resources and their protection	Sustainable agriculture	Mobility	Health and safety	Education and training	Media, technology and mobile systems	Others
Number of responses	185	201	119	94	204	148	4	5
%	45%	49%	29%	23%	50%	36%	1%	1%

Source: own study.

The structure of the respondents' answers indicates that social innovation is most expected by society in the area of health and safety (50%). Next, the survey participants indicated the need to create social innovation in the area of natural resources (49%) and new technologies (45%). On the other hand, innovation in the field of mobile technologies and systems turned out to be the least popular among the respondents (1%). The results of the study show that the interest in social innovation in the area of health care may result from the change in the age structure of the Polish society. This causes serious economic and social challenges for the entire Polish health care system. This means more expenses to ensure adequate living comfort and work efficiency. Social innovation in the area of health care is becoming one of the most important areas of financial and institutional support by the state administration in Poland.

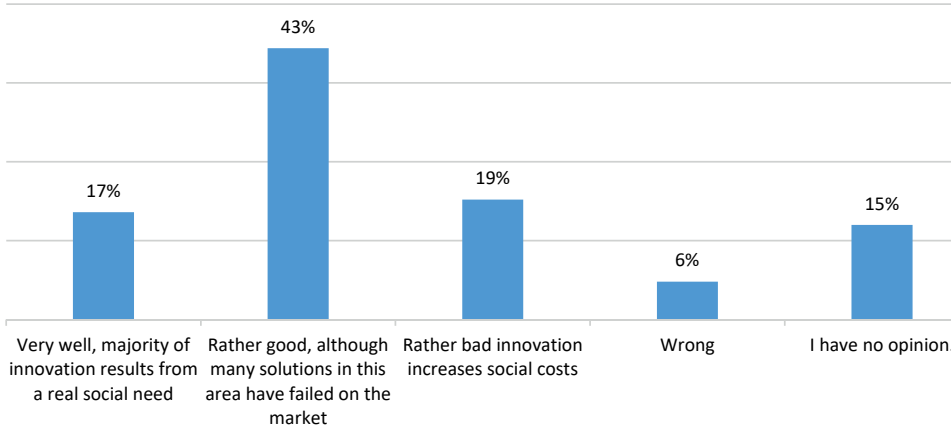

Chart 5.5. Structure % of answers: Question no 4: I assess the effects of social innovation (in Poland and in the world) in the area of health care…
Source: own study.

The structure of answers to the question concerning the perception of the effects of social innovation is diversified. More than a half of the respondents assess social innovation favourably. As many as 43% of the respondents answered that this type of innovation was an added value, although they were aware that many solutions of this type had not been used in social life. Social innovation in the area of health and safety was rated very well by 17% of respondents. In this part, the respondents strongly emphasised the fact that they believed in the effectiveness of social innovation in the area of health care. Probably those are the respondents who are also users of innovative solutions in reality. Social innovation was negatively assessed by 25% of respondents, and 15% have no opinion in this regard.

Table 5.8. Structure % of answers: Question no 4: Please refer to the following statements…

Statement / scale	1. – I strongly disagree,	2. – I rather disagree,	3. – I have no opinion,	4. – I rather agree,	5. – I strongly agree
1	2	3	4	5	6
Social innovation in the field of health care should be a priority in the development policy of every society	4%	4%	28%	31%	33%

1	2	3	4	5	6
I am not aware of any social innovation in the area of health protection and improving the safety of its functioning	9%	15%	46%	18%	13%
I know numerous examples of social innovation in the field of health care and improving the safety of its functioning	11%	14%	44%	19%	12%
Podiatric prophylaxis is an important element of public health protection	6%	10%	46%	24%	15%
Innovation in the field of podiatry is an important category of social innovation	6%	10%	46%	25%	13%
We should pay more attention to social innovation in podiatric prevention	3%	10%	45%	29%	13%
There is a lack of social awareness regarding the possibility of improving the comfort of using footwear	4%	11%	39%	28%	18%
Problems of a subological nature are underestimated by society	3%	9%	40%	29%	19%
I prefer to pay more for shoes that have certificates of conformity. I am sure that the shoes I have sneered at will have a positive effect on my health	6%	10%	39%	30%	15%

Table 5.8 (cont.)

1	2	3	4	5	6
Podological prophylaxis should be an element of parental education in educational institutions	4%	10%	42%	28%	15%
Certification of each type of footwear should be mandatory	4%	10%	42%	27%	18%

Source: own study.

The dominant belief among the respondents was that social innovation in the field of health care should be a priority in the development policy of every society (33% of the respondents strongly agreed). At the same time, this confirmed the answers of the respondents to question no 3. Additionally, 19% of the respondents marked "5" in the Likert Room, expressing the view that podiatric problems are underestimated by the society. It proves that the Polish society has no expectations in terms of innovation that would improve the comfort of using footwear because podiatric problems are regarded as a minor common inconvenience. On the other hand, as many as 11% of respondents strongly disagreed with the statement that examples of social innovation in the area of health care were commonly known to them.

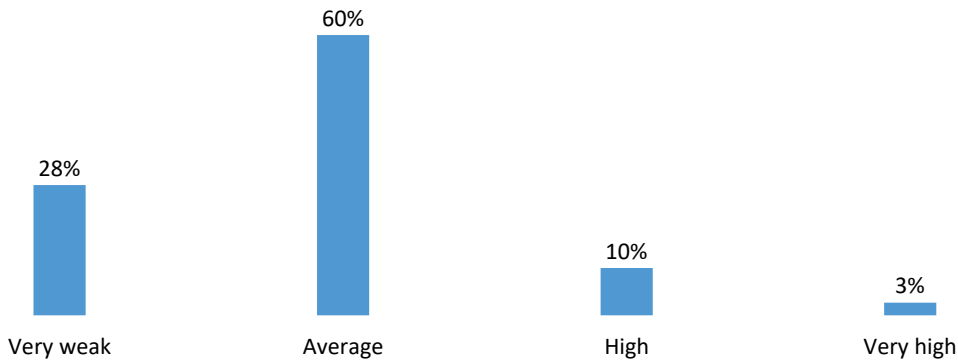

Chart 5.6. Structure % of answers: Question no 6: How do you assess your knowledge in the field of podiatric prophylaxis?
Source: own study.

Respondents assessed their knowledge in the field of podiatric prophylaxis at an average level (60%) and very low (28%). This proves that knowledge in this field is not promoted in Poland. The only source of information in the field of podiatry is the Internet, but an awareness-raising campaign targeted at

specific social groups would most likely change the proportions indicated on the chart. This is evidenced by the structure of the respondents' answers in the next question.

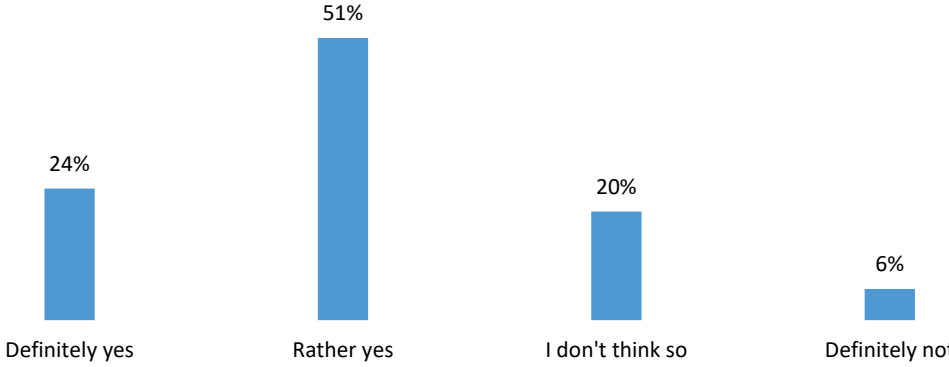

Chart 5.7. Structure % of answers: Question no 7: Do you think that increasing social awareness, e.g. through social advertising, free preventive campaigns in the field of podiatry, would contribute to increasing the rationality of shoe purchases?
Source: own study.

Respondents in 75% of cases answered that the increase in social awareness in the field of podiatry prevention would contribute to increasing the rationality of footwear purchases. It can be assumed that social campaigns in the above-mentioned scope would influence the development of social knowledge in the field of podiatric problems.

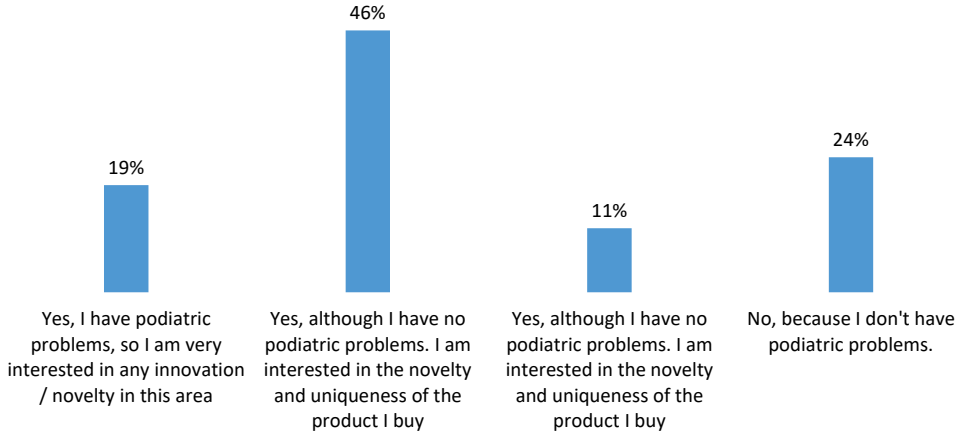

Chart 5.8. Structure % of answers: Question no 8: Are you interested in innovation to improve the functionality of footwear?
Source: own study.

The next question concerned the respondents' interest in innovation in terms of improving the usable functionality of footwear. As many as 65% of respondents expressed interest in this type of innovation in footwear products, out of which 19% stated that it resulted from podiatric problems. Among the respondents there were people (46%) who were interested in innovation in this field, despite the fact that they did not have podiatric problems. The study shows that 24% of respondents are definitely not interested in innovation to the extent of footwear due to the lack of podiatric problems.

Table 5.9. Structure % of answers: Question no 9: Please indicate what innovation in terms of increasing the comfort of using footwear would you be interested in (please indicate the 3 most important ones)?

Factor	Eco-friendly footwear manufacturing materials, biodegradability	Implementation of IT tools that would measure various types of parameters of footwear use and their impact on foot health	Specialist innovation in footwear, e.g. for people who practise active sports, resistant to weather conditions	Innovation that increase the safety of use, e.g. the use of anti-slip materials or lining materials inside the shoe	Innovation in the field of shoe inserts, e.g. foot-shaped, cooling, eliminating the effects of sweating	Innovation in the construction of footwear, e.g. reducing the load on the spine in the joints when walking	Others
Number of responses	163	94	141	139	133	128	7
%	40%	23%	35%	34%	33%	31%	2%

Source: own study.

Respondents, when answering the question about the types of innovation that increase the comfort of using footwear, were not unanimous. Most respondents were in favour of ecological and biodegradable materials that footwear should be made of. Next (35%), the respondents pointed to specialist innovation, e.g. in footwear for athletes. Only 1% fewer respondents emphasised the importance of innovation that increased the safety of footwear use. The fewest respondents (23%) reported interest in implementing IT tools that would measure the parameters inside the footwear. It can therefore be concluded that the dominant view among the respondents was that innovative solutions in footwear should concern structural elements.

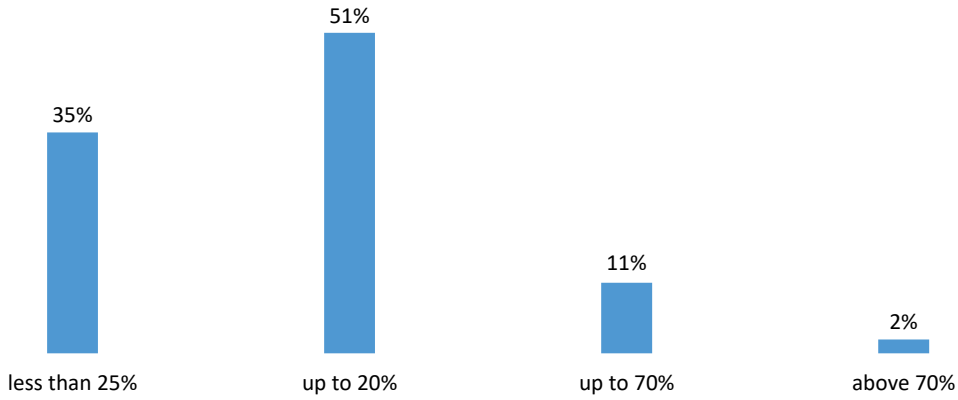

Chart 5.9. Structure % of answers: Question no 10: What price increase would you accept for footwear with one of the previously marked innovation?
Source: own study.

The last question, that the respondents had to face, concerned the acceptable level of price increase for footwear that would have one of the previously indicated types of innovation. Most respondents (51%) would be able to accept an increase in the price of their favourite footwear up to 20%. Only 11% of respondents are able to pay more for shoes – up to 70%, and 2% – over 70%. Probably, the highest footwear price rise for the footwear that has the desired type of innovation affects people suffering from podiatric disorders. From earlier statements, it can be concluded that 77 (19%) of the respondents have podiatric problems.

5.4. Social Innovation Development Prospects until 2050

In recent years, the role of social innovation in the development of society has been increasing, which is also due to the increase in the innovativeness of society. The ending financial perspective, including the Europe 2020 strategy, has been conducive to the development of social innovation mainly by launching financial streams supporting the competitiveness of the European economy by creating social networks conducive to creativity and innovation. It is therefore important in the current financial perspective to ensure the creation of institutional and financial foundations for the development of social innovation. Effective use of the opportunities generated by the European Union is possible only in the case of establishing cooperation between state, business, and civil society institutions in

order to develop the best – and accepted by stakeholders – solutions in the field of implementing social innovation. First, however, the strengths and weaknesses of the development of social innovation in the current economic reality should be indicated. Since social innovation is boosted by societal immediate needs and requirements and expectations, the business sector expenditure on innovation in terms of a percentage share of the GDP and the expenditure incurred on R&D activity by all economic operators conducting this activity in a given year in a given country (GERD – Gross expenditures on research and development.) constitute most frequently used indicators to assess the innovativeness of enterprises.

Table 5.10. Expenditures (GERD) on R&D by sectors in the years 2004–2020 (average share %)

Country	Business enterprise sector	Government sector	Higher education sector
1	2	3	4
Belgium	61%	23%	2%
Bulgaria	30%	40%	0%
Czechia	41%	39%	1%
Denmark	60%	28%	0%
Germany	66%	29%	no date
Estonia	43%	43%	1%
Ireland	52%	28%	1%
Greece	35%	48%	2%
Spain	46%	42%	4%
France	54%	36%	2%
Croatia	39%	46%	3%
Italy	47%	40%	1%
Cyprus	22%	56%	4%
Latvia	30%	36%	2%
Lithuania	31%	43%	2%
Luxembourg	42%	36%	1%
Hungary	48%	38%	0%
Malta	51%	30%	1%
Netherlands	53%	33%	0%
Austria	49%	33%	0%
Poland	38%	50%	3%
Portugal	44%	45%	3%
Romania	40%	49%	2%
Slovenia	61%	29%	0%

1	2	3	4
Slovakia	38%	46%	1%
Finland	62%	26%	0%
Sweden	61%	26%	1%
Iceland	43%	36%	2%

Source: own elaboration based on data from Eurostat.

The innovativeness of the economy, apart from other factors, is influenced not only by the size of the related expenses, but also by their subjective structure. Data for the period 2004–2020 presents the course of this phenomenon for the EU countries according to individual sources of financing this type of activity. The structure of the total expenditure on R&D in the analysed period was as follows: the private sector provided 46% of funds on average, the government sector supplied 38% of funds on average, and the higher education sector provided 2% of funds on average. In the context of the analysis presented above, it is noteworthy that the sectoral structure of expenditure reflects the relative state of innovation systems in respective economies. In most economies, the private sector accounts for the largest percentage share of R&D funding. In the most innovative economies, i.e. the economies of Denmark, Germany, Slovenia, Finland and Sweden, the private sector funded 62% of innovation volume on average. In the case of the most innovative countries, a small percentage share of public funds in overall funding sources for the total R&D activity is noticeable. The indicated trend can be seen in the above-mentioned economies, where the average percentage share of public expenditure in financing innovation is equivalent to 27%, and in the higher education sector it is less than 1%. The situation is different in less innovative countries, where high expenditures from public funds may be the result of small expenditures of enterprises on research and development activities. Romania, Poland, Cyprus are the examples of such countries.

Table 5.11. Average expenses incurred by enterprises on innovation in the breakdown by the number of employees in the EU in terms of the percentage share of the GDP in 2004–2020

Country	Average 1–9	Average 10–49	Average 50–249
1	2	3	4
Belgium	3%	13%	19%
Bulgaria	2%	4%	5%
Czech Republic	1%	5%	14%
Denmark	5%	15%	10%
Germany	1%	4%	5%
Estonia	4%	9%	17%

Table 5.11 (cont.)

1	2	3	4
Ireland	2%	11%	6%
Greece	1%	3%	3%
Spain	2%	9%	14%
France	2%	8%	10%
Croatia	0%	2%	6%
Italy	2%	6%	9%
Cyprus	2%	3%	3%
Latvia	2%	2%	4%
Lithuania	1%	5%	7%
Hungary	2%	5%	8%
Malta	2%	9%	12%
Netherlands	7%	11%	15%
Austria	3%	11%	14%
Poland	1%	2%	6%
Portugal	2%	7%	13%
Romania	0%	1%	2%
Slovenia	4%	13%	21%
Slovakia	0%	2%	6%
Finland	6%	15%	22%
Iceland	13%	21%	13%
Sweden	no data	15%	10%

Source: own elaboration based on data from Eurostat.

The above data indicates a significant diversification of enterprises in terms of expenditure on innovation incurred by them. The average percentage share of expenditure on innovation in the GDP among micro-enterprises is dominant in Iceland (13%). Other EU countries record it below 10% of the GDP, from which it can be indicated that a significant role of the smallest enterprises in financing innovation is noticeable in the Netherlands (7%) and Finland (6%). In the case of the Netherlands, the data in the Eurostat database is not complete, hence it can only be stated that the financing of innovation by micro-enterprises is at a higher level than the European average. The group of countries where micro-enterprises do not finance innovation with their own funds includes: Croatia, Romania and Slovakia. The next group consists of small enterprises that prove the percentage share in financing innovation in the analysed period to be higher than in the previous group. Among the countries with the highest percentage shares in financing are:

Iceland (21%), Sweden (15%), Finland (15%) and Denmark (15%), while medium-sized enterprises from Romania (1%), Poland (2%), Slovakia (2%), Latvia (2%) and Croatia (2%). In the case of Poland, however, the higher dynamics of expenditure of medium-sized enterprises on innovative activity should be noted, in contrast to the other countries in this group. Since 2016 this kind of spending has been on a rise by an average of 1 pp. In 2020 Polish medium-sized enterprises spent up to 5% of the GDP on innovation. The countries, where spending on innovation by large enterprises was the highest, include: Finland (22%), Slovenia (21%) and Belgium (19%). This is a significant difference as compared to the previous lists because Belgium and Slovenia are not found in any of the previous ones. Moreover, in terms of participation in financing innovation by small and medium-sized enterprises, those countries oscillate around the EU average. When analysing the presented average data in detail, it can be pointed out that throughout the research period (2004–2020) those countries were characteristic of a high percentage share of expenditures incurred by large enterprises on innovative activities. In Slovenia, the highest percentage share of this type of spending was recorded in the years: 2011–2015 (max. 30% in 2011), while in Belgium those are the years: 2013–2019 (max. 35% in 2019). In Finland, the maximum level of that indicator was reached in 2020 (29%) but it should be noted that the financing of innovation by the largest enterprises was evenly distributed over the period under review.

Table 5.12. Patent applications to the European Patent Office (EPO) per capita by priority year in the years 2006–2017

TIME	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1	2	3	4	5	6	7	8	9	10	11	12	13
Belgium	147	148	141	132	140	138	136	138	138	140	140	146
Bulgaria	4	2	2	2	2	4	5	5	7	4	4	4
Czech Republic	15	18	20	17	18	21	22	24	26	28	30	34
Denmark	210	241	239	218	233	264	236	242	245	241	240	247
Germany	293	296	282	286	287	281	268	261	257	259	245	229
Estonia	16	21	26	34	29	21	18	21	18	29	25	28
Ireland	69	76	74	77	71	81	68	72	72	82	77	78
Greece	10	9	9	8	6	8	9	10	11	9	9	8
Spain	31	31	32	33	33	32	32	32	33	35	35	36
France	135	136	137	135	131	137	136	137	139	144	143	142
Croatia	8	7	7	5	7	4	5	4	3	4	5	5
Italy	87	85	81	75	76	74	73	72	70	72	70	68
Cyprus	9	14	14	19	9	7	3	9	9	10	11	11

Table 5.12 (cont.)

1	2	3	4	5	6	7	8	9	10	11	12	13
Latvia	7	7	10	9	7	9	13	33	42	13	11	11
Lithuania	3	3	5	3	5	6	11	14	17	8	7	8
Luxembourg	228	155	193	151	153	136	128	121	111	116	107	94
Hungary	16	19	18	18	20	22	21	22	23	21	20	20
Malta	17	17	13	19	8	1	13	12	13	17	15	14
Netherlands	229	205	211	210	185	207	203	201	206	207	203	204
Austria	212	208	196	205	212	215	222	226	231	233	233	231
Poland	4	5	6	8	10	10	13	14	16	15	17	18
Portugal	10	12	11	9	9	11	11	11	12	13	13	14
Romania	1	2	2	2	2	3	4	4	5	5	5	5
Slovenia	50	60	69	61	52	55	62	62	66	58	54	55
Slovakia	8	7	7	5	9	10	8	9	9	8	10	10
Finland	257	242	239	247	260	251	303	322	342	253	240	236
Sweden	292	313	304	284	302	301	325	339	350	300	294	283
Iceland	101	81	79	81	57	71	87	88	98	no date	no date	no date

Source: Elaboration based on Eurostat data.

The table above shows how patent activity in respective EU countries has developed over the last few years. The data shows that the largest number of patent applications per capita were submitted in such countries as: Sweden, Finland, Austria, Denmark and Germany.

Throughout the period under review, the highest patent activity is proven by three European countries: Sweden, Finland and Germany. Over the period under review in Sweden min. the number of patent applications is 285 per capita (2017) and the maximum is 350 per capita in 2014. In the case of Germany min. the rate equalled 229 notifications per capita in 2017, and the maximum one equalled 296 notifications per capita in 2007. Finland, on the other hand, recorded the largest number of applications in 2014 (342) and the least one in 2017 (236). The fewest patent applications per capita in the analysed period were recorded by: Romania (3 on average), Bulgaria (4 on average) and Croatia (5 on average).

Innovation is developed by innovators, i.e. people who lead to the application of new and improved ways of producing products, rendering services, etc., in practice. Therefore, an important factor determining the development of innovation in the economy is to create an environment where innovators can develop and implement their ideas. One of the basic indicators of the level of innovation development in the country is the structure of employment and its changes.

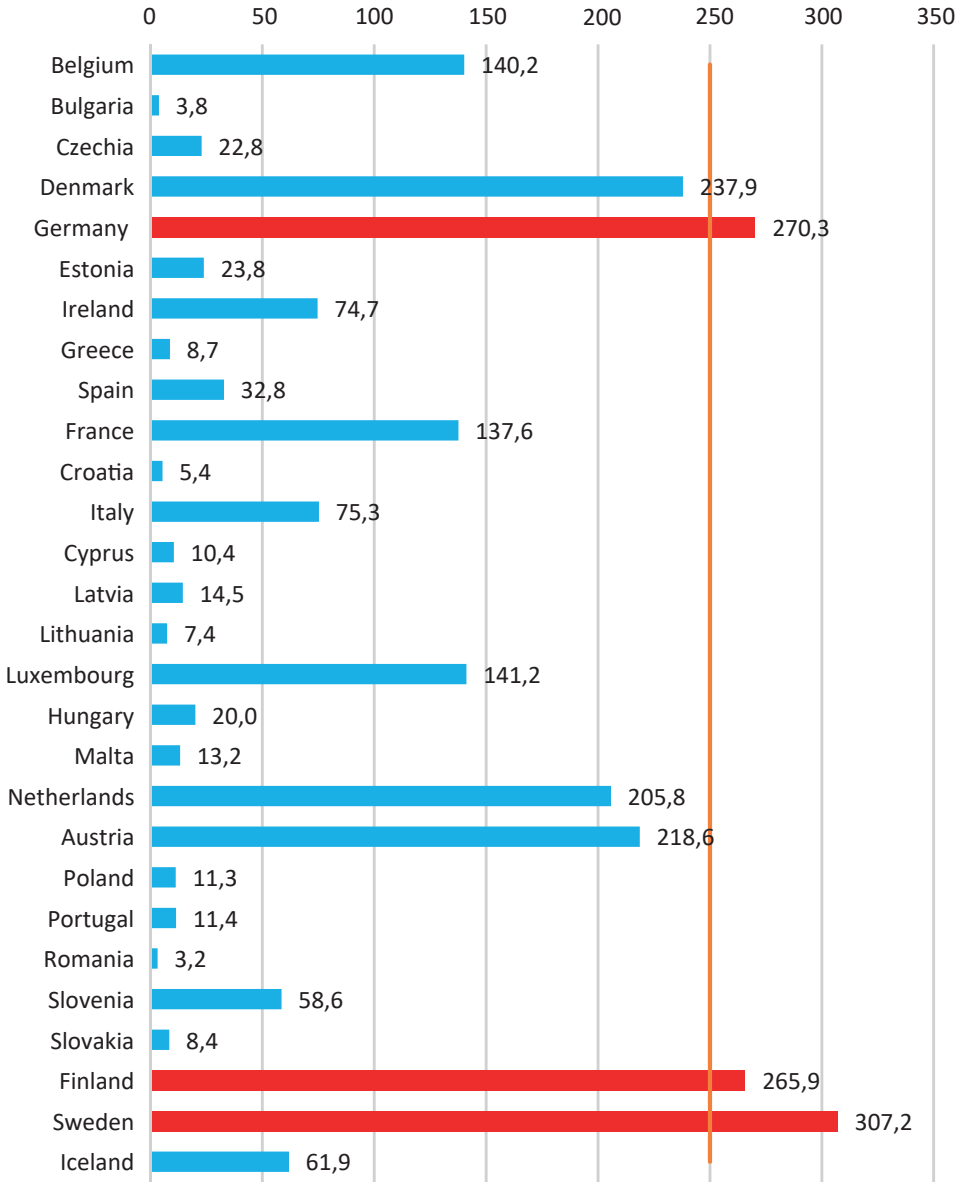

Chart 5.10. Patent applications to the European Patent Office (EPO) per capita by priority year in the years 2006–2017 (average)
Source: own elaboration based on Eurostat data.

Table 5.13. Percentage share of employees in the sector: enterprises, government, higher education in the years 2004–2020 in the EU countries (average values in terms of %) of total employment in the R&D sector

Country	Enterprise sector	Government sector	Higher education sector
Belgium	51%	6%	42%
Bulgaria	26%	41%	32%
Czech Republic	47%	19%	34%
Denmark	56%	4%	39%
Germany	50%	13%	37%
Estonia	30%	11%	58%
Ireland	51%	3%	49%
Greece	16%	20%	61%
Spain	38%	16%	46%
France	57%	10%	32%
Croatia	19%	26%	55%
Italy	47%	13%	38%
Cyprus	22%	20%	48%
Latvia	18%	16%	66%
Lithuania	17%	16%	67%
Luxembourg	68%	20%	16%
Hungary	36%	18%	45%
Malta	43%	3%	54%
Netherlands	66%	9%	25%
Austria	54%	6%	39%
Poland	26%	14%	59%
Portugal	34%	8%	52%
Romania	29%	26%	44%
Slovenia	54%	17%	29%
Slovakia	20%	19%	61%
Finland	52%	10%	37%
Sweden	53%	8%	38%
Iceland	43%	17%	38%

Source: own elaboration based on Eurostat data.

Based on the data presented in the table above, it can be concluded that in the countries that are characterised by the highest level of innovation (e.g. according to the *European Union Innovation Scoreboard*), the percentage share of people employed in R&D in the enterprise sector is dominant. In countries such as Luxemburg[5] and

5 *Strong Innovators*, European Innovation Scoreboard 2022.

the Netherlands,[6] the average level of this indicator was 68% and 66%, respectively. The analysis carried out at the level of consecutive years shows that in the case of Luxemburg this percentage share had been successively decreasing since 2004 (in 2004 – 83%, in 2014 – 61%, and in 2020 – 57%), which is the opposite trend in relation to the Netherlands (in 2004 – 56%, in 2014 – 74%, and in 2020 – 75%). The smallest percentage share of innovators employed by the private sector concerns such countries as: Latvia (18%) or Lithuania (17%). In those countries, the vast majority of innovators are employed by universities, which is 66% and 67%, respectively. As far as the percentage share of the government sector in employing R&D personnel is concerned, only Bulgaria has a dominant tendency in this respect (41% on average), although this indicator in the analysed years shows a clear downward trend (2004 – 61%, 2014 – 36%, 2020 – 25%) in favour of the rising percentage share in the private sector. In the case of higher education, apart from Latvia and Lithuania, the ranking is dominated by countries such as: Greece (61%), Slovakia (61%), Poland (59%) and Estonia (58%). It should be noted that in countries where the percentage share of employment of R&D personnel in academia is dominant, the innovation potential is not effectively used. Many ideas and solutions developed by academics employed at universities are not commercialised. The difficulty in establishing the cooperation between universities and entrepreneurs and the costs of creating innovation are the factors that limit the implementation of innovation.

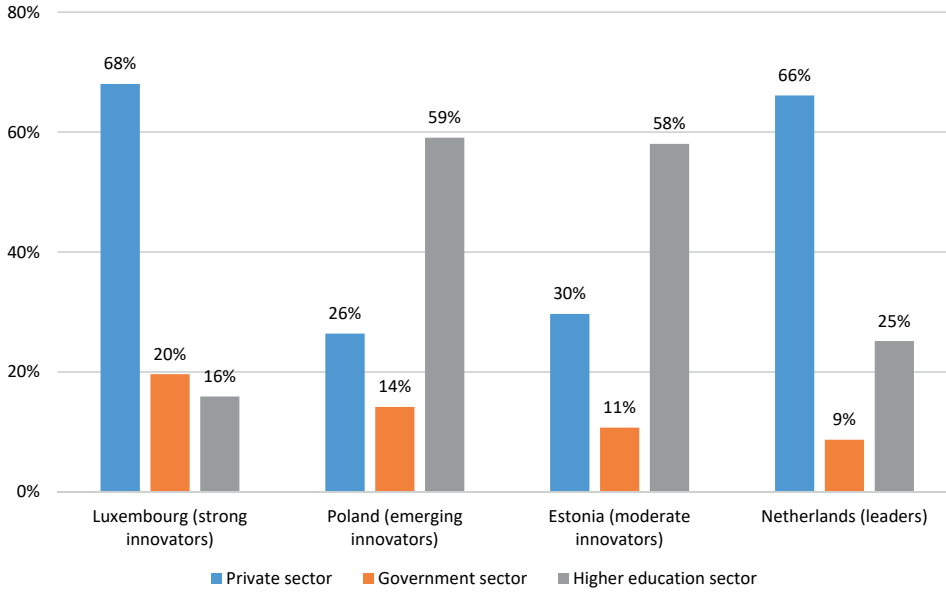

Chart 5.11. Comparison of the selected EU countries and the R&D employment in respective (average values in 2004–2020)
Source: own elaboration based on Eurostat data.

6 *Innovation Leaders*, European Innovation Scoreboard 2022.

The chart above shows clear differences between countries that represent different levels of innovation in recent rankings. Poland, regarded by the European Innovation Scoreboard[7] 2022 as emerging innovators, has a similar employment composition to Estonia (moderate innovators). Both countries are characterised by a dominant percentage share of R&D employment at universities, and therefore a "frozen" ability to boost and implement innovation in economic practice. The situation is different in the group of the most innovative countries.

Poland, despite the innovation-related potential (including social ones), is not considered to be one of the economies that can effectively take advantage of this potential. Still, in the Polish economic reality, there is no effective cooperation between entrepreneurs and institutions that have all the conditions to successfully launch a new product or service in the market. Despite many years following the European Union accession, availability of the EU financial assistance, the opportunity to enjoy the know-how transfer from more developed economies, Poland does not have a well-developed innovation booster policy. Although it should be emphasised that the willingness of entrepreneurs to create social innovation that would meet the needs of specific social groups is becoming more and more visible. Entrepreneurs have become aware that social innovation is less likely to fail. This is due to the fact that social innovation is "tailor-made" to social needs. Furthermore, this type of innovation should be particularly "taken care of" by government institutions that have the greatest capacity to stimulate pro-innovation processes and initiatives.

- In the coming years, the support for the development of social innovation in Poland should boost innovation that may combat emerging economic shock.

The crisis caused by e.g. a pandemic or armed conflicts will certainly affect innovation over the next decade. When determining aid packages, state authorities should make decisions based on social needs resulting from emerging turmoil. In the era of COVID-19, the potential for new breakthroughs and technologies has definitely increased – especially in the field of information technology or biotechnology. Unleashing this potential, however, will depend to a large extent on the appropriate support that should be provided by the State.

- The support for the development of social innovation in Poland should also aim at pro-investment policy.

Poland is ranked last place in the innovation rankings due to problems with funding sources for innovation. Currently, due to the recent economic shock, investors have started investing in larger enterprises – at the expense of start-ups. Healthcare, robotics and online education have become popular areas of investment. It should therefore be expected that technological innovation will be massively generated by the largest companies located in such countries as the United States, Singapore or China.

7 European Innovation Scoreboard 2022.

- The support for the development of social innovation in Poland should also build the potential of science and technology clusters.

Innovation is concentrated in scientific and technological centres in selected high-income countries with extensive experience in cooperation with entrepreneurs. In Poland, this topic is still neglected. There is a lack of financial resources for innovation support centres and a reliable system of the related financial clearance. This year, the ranking of the largest scientific and technological centres in the world has been for the first time prepared on the basis of the total number of patents and scientific publications n the breakdown by the size of the centre. The new financial perspective has given rise to the greater intensification of undertakings carried out by the centres located in the US and Europe, as compared to their Asian counterparts. This proves the growing potential of European innovation support centres. Within the next decade, there may be a significant shift of enterprises interested in innovation from different parts of the world to take advantage of the knowledge and technology of the European science and technology clusters.

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Conclusion

In recent years we have been dealing with the accumulation of social concerns of various types such as demographic issues related to social exclusion or the labour market. Health is one of the most important societal issues, that is often disregarded in the context of the relevant societal development prospects. Social innovation in the area of health care constitutes the righteous response to the problems faced by the modern society that lives and works more and more intensively, while equally intensively exploiting its resources (including health). Active commitment to counteract the adverse impact of social problems may boost innovation that will have practicable economic application, concurrently arising from a social need.

Implementation of social innovation may bring about advantageous deliverables that will fill in the market gap, which at the same time mitigates the adverse social impact (e.g. exclusion from social life). Fortunately, examples of such implementations in the Polish economic reality are not unique. This is evidenced by the effective use of the EU funds in the 2014–2020 financial perspective and the number of implementations of innovative solutions.

Every consecutive year, the social awareness of the need to care for the ecosystem in which a single individual lives is growing. Health is a constituent of this ecosystem that provides for health care also in terms of the podiatric medicine. Today's society is an increasingly conscious and demanding consumer. It also indirectly participates in the process of boosting social innovation – especially in the area of health care.

Footwear comfort – the comfort of the footwear user is difficult to define and is certainly a subjective feeling of each user. Based on studies conducted on users, this comfort is certainly influenced by the microclimate in the footwear depending on the properties of the materials used for manufacturing the footwear, the correct longitudinal and transverse size of the footwear, cushioning – often dependent on the properties of the sole material. Additional functions of the footwear, for instance, include antimicrobial properties that inhibit the growth of bacteria and fungi, thanks to which they improve the comfort of the user but also increase the mechanical resistance of the materials from which footwear is made, and eliminate unpleasant odour. Merging design and functionality of footwear materials in order to give them antimicrobial properties may be carried out by means of various methods, including spraying, bathing, sol-gel method, application

of microcapsules. An important innovative property of footwear is the auxetic property that makes the footwear fit the foot better and grow with the foot, which is particularly important for children's feet that grow rapidly. Auxetic materials for footwear are still in the realm of research and have enormous potential.

Based on the results indicated above, it is plausible to conclude that tannery shavings prove a great application potential for their closed-loop reuse as additives especially in the areas of construction, composite, plastics and packaging industries, as well as agriculture.

The proposed methods of processing tannery waste by means of pre-screening and pressure-free granulation, using readily available mineral additives and, among other things, an aqueous water glass solution for bed wetting, are relatively simple, waste-free, and their application costs remain economically reasonable. The granulation of the shavings makes it possible to produce agglomerates of suitable shape, size (from 0–1 mm to >14 mm fraction) and properties. An additional advantage of this solution is the possibility of using also other types of industrial waste, including waste gypsum arising from the flue gas cleaning process at the Belchatow Power Plant. In summary, it can be plausibly stated that the disc granulation process of tannery shavings provides for a solution successfully addressing the problem of the related processing and makes it possible to obtain a durable, mechanically stable, easily transportable and storable semi-finished product. The agglomerates obtained, using the indicated granulation method, due to the identity of the mineral additives used, such as gypsum, dolomite, lime or chalk meals, are dedicated to manufacturers of leather-like and composite materials. The granules and seed pellets produced from tannery waste may be used in agritechnology as biostimulants, including soil improvers and fertiliser additives.[1, 2]

The obtained results and conclusions in the identification of selected properties of tannery shavings, optimisation of unit processes for the purpose of the related processing and verification of new solutions based on those types of solid waste have confirmed the hypothesis. The application of unit processes for the purpose of reusing and processing leather waste makes it possible to develop new products that are environmentally friendly, compostable and non-toxic to the ecosystem with a wide range of applications (especially in plastics processing, construction and road building, as well as agriculture). In addition, given the organic quantities

1 M. Skwarek, M. Wala, J. Kołodziejek, K. Sieczyńska, M. Lasoń-Rydel, K. Ławińska, A. Obraniak, (2021), *Seed coating with biowaste materials and biocides—environment-friendly biostimulation or threat?*, "Agronomy", vol. 11.

2 M. Skwarek, J. Nawrocka, M. Lasoń-Rydel, K. Ławińska, (2020), *Diversity of plant biostimulants in plant growth promotion and stress protection in crop and fibrous plants*, "Fibres & Textiles in Eastern Europe", vol. 28, pp. 34–41.

of natural raw materials, efforts to recover individual valuable components from solid waste should be intensively developed, while optimising costs.

Therefore, the issues addressed in the monograph concern social, economic and environmental aspects, which is why this publication is addressed primarily to scientists, students, and practitioners dealing with innovation and knowledge-based economy. The monograph adopts a practical approach to social innovation, which may be an inspiration for the further research in the areas that the monograph could not include in detail.

References

Abdouss M., Mousavi A., Shoushtari A., Haji A., Moshref B., (2012), *Fabrication of chelating diethylenetriaminated PAN micro- and nano-fibres for heavy metal removal.* "Chemical Industry &Chemical Engineering Quarterly", vol. 18, pp. 27–34.

Adebajo M., Frost R., Kloprogge J., Carmody O., (2003), *Porous Materials for oil spill cleanup: A revive of synthesis and absorbing properties*, "Journal of Porous Materials", vol. 10, pp. 159–170.

Aerts P., Ker R.F., De Clercq D., Ilsley D.W., Alexander R.M., (1995), *The mechanical properties of the human heel pad: a paradox resolved*, "Journal of Biomechanics", vol. 28, no. 11, pp. 1299–1308.

Aftab M.N., Hameed A., Haq I., Run C., (2006), *Biodegradation of Leather Waste by Enzymatic Treatment*, "The Chinese Journal of Process Engineering", vol. 6, no. 3, pp. 462–465.

Agustini C.B., Spier F., da Costa M., Gutterres M., (2018), *Biogas production for anaerobic co-digestion of tannery solid wastes under presence and absence of the tanning agent*, "Resources, Conservation and Recycling", vol. 130, pp. 51–59.

Ahmad I., Kan C.W., (2017), *Visible-Light-Driven, Dye-Sensitized TiO_2 Photo-Catalyst for Self-Cleaning Cotton Fabrics,* "Coatings", vol. 7, no 11, p. 192.

Ahmad I., Kan C-W., Yao Z., (2019), *Photoactive cotton fabric for UV protection and self-cleaning,* "RSC Advances", vol. 9, pp. 18106–18114.

Alderson A., Rasburn J., Ameer-Beg S., Mullarkey P.G., Perrie W., Evans K.E., (2000), *An auxetic filter: a tuneable filter displaying enhanced size selectivity or defouling properties*, "Industrial & Engineering Chemistry Research", vol. 39, no. 3, pp. 654–665.

Alderson K.L., Pickles A.P., Neale P.J., Evans K.E., (1994), *Auxetic polyethylene: the effect of a negative Poisson's ratio on hardness*, "Acta Metallurgica et Materialia", vol. 42, pp. 2261–2266.

Alderson K.L., Webber R.S., Mohammed U.F., Murphy E., Evans K.E., (1997), *An experimental study of ultrasonic attenuation in microporous polyethylene*, "Applied Acoustics", vol. 50, pp. 23–33.

All-European Industry Federation, (2012), Social and Environmental Report of the European Leather Industry, COTANCE.

Altangerel Z., Purev-Ochir B., Ganzorig A., Tsagaantsooj T., Lkhamsuren G., Choisuren A., Chimed G., (2020), *Superhydrophobic modification and characterization of cashmere fiber surfaces by wet coating techniques of silica nanoparticles*, "Surfaces and Interfaces", vol. 19, 100533.

Amdouni S., Trabelsi A.B.H., Elasmi A.M., Chagtmi R., Haddad K., Jamaaoui F., Khedhira H., Chérif, C., (2021), *Tannery fleshing wastes conversion into high value-added biofuels and biochars using pyrolysis process*, "Fuel", vol. 294, 120423.

Anjum S.A., Wang L., Farooq M., Xue L., Ali S., (2011), *Fulvic acid application improves the maize performance under well- watered and drought conditions,* "Journal of Agronomy and Crop Science", vol. 197, pp. 409–417.

Ara K., Hama M., Akiba S., Koike K., Okisaka K., Hagura T., Kamiya T., Tomita F., (2006), *Foot Odour Due to Microbial Metabolism and its Control*, "Canadian Journal of Microbiology", vol. 52, no. 4, pp. 357–364.

Arcibar-Orozco J.A., Barajas-Elias B.S., Caballero-Briones F., Nielsen L., Rangel-Mendez J.R., (2019), *Hybrid carbon nanochromium composites prepared from chrome-tanned leather shavings for dye adsorption*, "Water Air and Soil Pollution", vol. 230, no. 142.

Ariaeenejad S., Kavousi K., Mamaghani A.S.A., Ghasemitabesh R., Hosseini Salekdeh G., (2022), *Simultaneous hydrolysis of various protein-rich industrial wastes by a naturally evolved protease from tannery wastewater microbiota*, "Science of The Total Environment", vol. 815, 152796.

Assadpour E., Jafari S.M., (2019), *Advances in spray-drying encapsulation of food bioactive ingredients: from microcapsules to nanocapsules*, "Annual Review of Food Science and Technology", vol. 10, pp. 103–131.

ASTM F1292-04, *Standard Specification for Impact Attenuation of Surfacing Materials within the Use Zone of Playground Equipment*, 2004.

ASTM F1614-06, *Shock Attenuation Properties of Materials Systems for Athletic Footwear*, American Society for Testing and Materials, 2006.

Avram G., Hysa E., (2022), *Education, Knowledge and Data in the Context of the Sharing Economy*, "The Sharing Economy in Europe", Cham: Palgrave Macmillan, pp. 181–206.

Ayala-Zavala J.F., Soto-Valdez H., González-León A. et al., (2008), *Microencapsulation of cinnamon leaf (Cinnamomum zeylanicum) and garlic (Allium sativum) oils in b-cyclodextrin*, "Journal of Inclusion Phenomena and Macrocyclic Chemistry", vol. 60, pp. 359–368.

Bacciarelli A., Kołodziejczyk M., Rybicki E., (2008), *Wpływ nanocząstek srebra na funkcjonowanie organizmu człowieka*, Materiały seminaryjne z XXIX Seminarium Polskich Kolorystów.

Bakshi P.S., Selvakumar D., Kadirvelu K., (2020), *Chitosan as an environment friendly biomaterial – a review on recent modifications and applications*, "International Journal of Biological Macromolecules", vol. 150, pp. 1072–1083.

Bannet, E., (2007), *Quixotes, Imitations and Transatlantic Genres. Eighteenth Century Studies*, The Johns Hopkins University Press, Baltimowe, pp. 553–569.

Bansode S., Banarjee S., Gaikwad D., Jadhav S., Thorat R., (2010), *Microencapsulation: A review*, "International Journal of Pharmaceutical Sciences Review and Research", vol. 1, no. 2, p. 43.

Bayramoðlu E.E., Gülümser G., Karaboz I., (2008), *The Investigation of Antibacterial Activities of Some Essential Oils in Wet Blue Leather*, "International Journal of Natural and Engineering Sciences", vol. 2, no. 1, pp. 33–36.

Bayryamov S.G., (2020), *Microencapsulation of natural oils by a coacervation technique using gelatin as shell material*, "Journal of Chemical Technology and Metallurgy", vol. 55, no. 6, pp. 1985–1989.

Bessadok B., Masri M., Brück T., Sadok S., (2017), *Characterization of the Crude Alkaline Extracellular Protease of Yarrowia lipolytica YlTun15*, "Journal of FisheriesSciences.com", vol. 11, no. 4, pp. 19–24.

Best Available Techniques (BAT) Reference Document for Leather Tanning Joint Research Center Institute for Prospective Technological Studies Sustainable Production and Consumption Unit European IPPC Bureau 2013.

Bezerra F.M., Carmona O.G., Carmona C.G., Lis M.J., de Moraes F.F., (2016), *Controlled release of microencapsulated citronella essential oil on cotton and polyester matrices*, "Cellulose", vol. 23, no. 2, pp. 1459–1470.

Bhullar S.K., Lala N.L., Ramkrishna S., (2015), *Smart biomaterials – a review*, "Reviews on Advanced Materials Science", vol. 40, pp. 303–314.

Błuszkowski Ł., Midler D., (2007), *Wywiad jako metoda badawcza*, [in:] K. Kuciński (ed.), *Doktoranci o metodologii nauk ekonomicznych*, Szkoła Główna Handlowa, Warszawa, p. 211.

Bogey R., *Gait analysis*, updated 23.02.2023, Gait Analysis: Fundamentals, Methods Of Analysis, Normal Gait (medscape.com)

Boh B., Knez E., (2006), *Microencapsulation of essential oils and phase change materials for applications in textiles products*, "Indian Journal of Fibre and Textile Research", vol. 31, no. 1, pp. 72–82.

Boh Podgornik B., Starešiníc M., (2016), *Microencapsulation Technology and Applications in Added-Value Functional Textiles*, "Physical Sciences Reviews", vol. 1, no. 1, pp. 20150003.

Borkowska M., Gelleta-Mac I., (2009), *Wady postawy i stóp u dzieci*, Wydawnictwo PZWL, Warszawa.

Bufalo G., Florio C., Cinelli G., Lopez F., Cuomo F., Ambrosone L., (2018), *Principles of minimal wrecking and maximum separation of solid waste to innovate tanning industries and reduce their environmental impact: The case of paperboard manufacture*, "Journal of Cleaner Production", vol. 174, pp. 324–332.

Bukowski A., Rudnicki S., Strycharz J., (2012), *Społeczny wymiar innowacji*, "Zarządzanie Publiczne" No 2(20), Uniwersytet Ekonomiczny w Krakowie, Kraków, pp. 14–15.

Carneiro VH., Meireles J., Puga H., (2013), *Auxetic materials – a review*, "Mater Sci – Poland", vol. 31, pp. 561–571.

Central Statistical Office 2020, *Statistical Yearbook of Industry 2019*.

Chanana A., Kataria M.K., Sharma M., Bilandi A., (2013), *Microencapsulation: Advantages in applications*, "International Research Journal of Pharmacy", vol. 4, no. 2, pp. 1–5.

Chan-Juan Z., Dan T., Ji-Huan H., (2018), *What factors affect lotus effect?*, "Thermal Science", vol. 22, pp. 1737–1743.

Chauhan P., Kumar A., Bhushan B., (2019), *Self-cleaning, stain-resistant and anti-bacterial superhydrophobic cotton fabric prepared by simple immersion technique*, "Journal of Colloid and Interface Science", vol. 535, pp. 66–74.

Chekkal I., Bianchi M., Remillat C., Becot F.X., Jaouen L., Scarpa F., (2010), V*ibro-acoustic properties of auxetic open cell foam: model and experimental results*, "Acta Acustica United Acustica", vol. 96, pp. 266–274.

Cheng Q., Yan L., (2005), *Nonwoven substrate finishing with essence microcapsules*, "AATCC Review", vol. 8, pp. 46–48.

Chi K-J., Schmitt D., (2005), *Mechanical energy and effective foot mass during impact loading of walking and running*, "Journal of Biomechanics ", vol. 38, no. 7, pp. 1387–1395.

Chirilă C., Crudu M., Deselnicu V., (2014), *Comparative Study regarding Resistance of Wet-White and Wet-Blue Leather to the Growth of Fungi*, "Leather and Footwear Journal", vol. 14, no. 2, pp. 107–120.

Chirilă C., Deselnicu V., Berechet M.D., (2017), *Footwear Protection against Fungi Using Thyme Essential Oil*, "Leather and Footwear Journal", vol. 17, no. 3, pp. 173–178.

Cho H., Seo D., Kim D.N., (2019), *Mechanics of Auxetic Materials*, [in:] Ch. Hsueh et al. (eds), *Handbook of Mechanics of Materials*, Springer, Singapore.

Choi J.B., Lakes R.S., (1996), *Fracture toughness of re-entrant foam materials with a negative Poisson's ratio: experiment and analysis*, "International Journal of Fracture", vol. 80, pp. 73–83.

Ciborowski R., (2012), *Modele rozwoju innowacyjnego*, [in:] *Ekonomika i zarządzanie innowacjami w warunkach zrównoważonego rozwoju*, edited by Andrzej H. Jasiński and Robert Ciborowski, Białystok, pp. 49–50.

Colla G., Hoagland L., Ruzzi M., Cardarelli M., Bonini P., Canaguier R., Rouphael Y., (2017), *Biostimulant action of protein hydrolysates: unraveling their effects on plant physiology and microbiome*, "Frontiers in Plant Science", vol. 8, p. 2202.

Cross T.M., Hoffer K.W., Jones D.P., Kirschner P.B., Langvin E., Meschter J.C., US-9402439-B2, *Auxetic structures and footwear with soles having auxetic structures*.

Cuadros R., Solà A., Ollé I., Otero L., Bacardit A., (2016), *Reducing the use of volatile organic compoundsin the leather industry*, "Journal of the Society of Leather Technologists and Chemists Journal", vol. 100, pp. 1–7.

Cuin T.A., Shabala S., (2007), *Amino acids regulate salinity-induced potassium efflux in barley root epidermis*, "Planta", vol. 225, pp. 753–761.

Dąbrowska G., Zdziechowska E., (2015), *The role of rhizobacteria in the stimulation of the growth and development processes and protection of plants against environmental factors*, "Progress in Plant Protection", vol. 55, no. 4, pp. 498–506.

Day E., Hahn M., (2020), *Optimal footwear longitudinal bending stiffness to improve running economy is speed dependent*, "Footwear Science", vol. 12, no. 1, pp. 3–13.

De Castro Dutra F., Emrich M., Magela da Costa G., Dias A., (2016), *Influence of drying temperature and atmosphere on the mechanical strength of iron-ore agglomerates and sodium silicates for application in sintering processes*, "The Canadian Journal of Chemical Engineering", vol. 94, pp. 75–80.

Dega W., Milanowska K., (1993), *Rehabilitacja medyczna*, Warszawa.

Deselnicu D.C., Vasilescu A.M., Purcarea A.A., Militaru G., (2014), *Sustainable Consumption and Production in the Footwear Sector*, "Leather and Footwear Journal", vol. 14, no. 3, pp. 159–180.

Devi N., Sarmah M., Khatun B., Maji T., (2017), *Encapsulation of active ingredients in polysaccharide-protein complex coacervates,* "Advances in colloid and interface science", vol. 239, pp. 136–145.

Diaa M., Hassabo A.G., (2022), *Self-Cleaning Properties of Cellulosic Fabrics (A Review)*, "Biointerface Research in Applied Chemistry", vol. 12, pp. 1847–1855.

Ding C., Zhang M., Dai L., Qi Y., Shi R., Yang J., (2017), *Fabrication and characterization of regenerated leather using chrome shavings raw material*, "The Journal of the American Leather Chemists Association", vol. 112, pp. 145–152.

Document for the Best Available Technology: Leather tanning, Joint Research Center Institute for Prospective Technological Studies, Sustainable Production and Consumption Unit European IPPC Bureau 2013.

Domański W., Surgiewicz J., (2001), *Chemical hazards in the tanning industry*, "WORK SAFETY science and practice", vol. 4, pp. 6–9.

Domínguez A., Deive F. J., Angeles Sanromán M., Longo M. A., (2010). Biodegradation and utilization of waste cooking oil by *Yarrowia lipolytica* CECT 1240. European Journal of Lipid Science and Technology, 112(11), pp. 1200–1208.

Domoradzki M., Korpal W., (2005), *Dobór materiałów do otoczkowania nasion rzodkiewki roztworem dekstryny*, "Inżynieria Rolnicza", vol. 11, no. 71, pp. 69–74.

Donoghue J.P., Alderson K.L., Evans K.E., (2009), *The fracture toughness of composite laminates with a negative Poisson's ratio*, "Physica Status Solidi B.", vol. 246, pp. 2011–2017.

Drucker P., (1992), *Innowacja i przedsiębiorczość. Praktyka i zasady*, PWE, Warsaw, p. 153.

Duda I., (2005), *Comfort and safety issues in footwear*, "Scientific Journals of the Cracow University of Economics", vol. 685, Kraków, pp. 5–18.

Durá J.V., García A.C., Solaz J., (2002), *Testing shock absorbing materials: the application of viscoelastic linear model*, "Sports Engineering", vol. 5, no. 1, pp. 9–14.

Dz.U. Nr 147, poz. 1033, 2007: Act of 10 July 2007 on fertilizers and fertilization.

Dz.Urz. WE, 24.11.2009: Regulation (EC) No. 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414 EEC.

Dzik T., Hryniewicz M., Janewicz A., Kosturkiewicz B., (2017), *Agglomeration of solid fuels in a roll press*, "Przemysł Chemiczny", vol. 96, no. 6, pp. 1852–1855.

Dziuba R. (2014), *Rola innowacyjności i konkurencyjności w rozwoju regionu Bałkanów Zachodnich na przykładzie Czarnogóry*, „Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania" 37/2, Wydawnictwo Uniwersytetu Szczecińskiego, Szczecin 2014, p. 225.

Edwards-Schachter M., Wallace M.L., (2017). *Shaken, but not stirred: Sixty years of defining social innovation*, "Technological Forecasting and Social Change", 119(4), pp. 64–79.

Emmerichs N., Wingender J., Flemming H-C., Mayer C., (2004), *Interaction between alginates and manganese cations: identification of preferred cation binding sites*, "International Journal of Biological Macromolecules", vol. 34, pp. 73–79.

EN 1177, *Impact Attenuating Playground Surfacing – Determination of Critical Fall Height* (2008).

EN 14808, *Surfaces for Sports Areas – Determination of Shock Absorption* (2005).

EN ISO 20344, *Personal Protective Equipment – Test Methods for Footwear* (2004).

European Commission, *Guide to Social Innovation 2013*, pp. 6–7, 72; 30–36.

Evans K.E., Alderson A., (2000), *Auxetic materials: functional materials and structures from lateral thinking*, "Advanced Materials", vol. 12, pp. 617–628.

Evans K.E., Caddock B.D., (1989), *Microporous materials with negative Poisson's ratios II, Mechanisms and interpretation*, "Journal of Physics D: Applied Physics", vol. 2, pp. 1877–1883.

Famielec S., (2014), Doctoral dissertation *Tanning waste burning process In the tunnel furnace as their method Disposal*, Politechnika Krakowska, Kraków.

FAO (2013), *World Statistical Compendium for Raw Hides and Skins, Leather and Leather Footwear 1993–2012*.

Fauzi M.A.R.D. et al., (2021), *Preparation, Properties and Potential of Carrageenan-Based Hard Capsules for Replacing Gelatine: A Review,* "Polymers", vol. 13, no. 16, p. 2666.

Foorginezhad S., Zerafat M.M., (2018*), Fabrication of stable fluorine-free superhydrophobic fabrics for anti-adhesion and self-cleaning properties*, "Applied Surface Science", vol. 464, pp. 458–471.

Framis C.P., (2018), *Assessment of tannery solid waste management, A case of Sheba Leather Industry in Wukro (Ethiopia) – report*, Wydawnictwo ETESEIB, pp. 2–92.

Furmanek W., (2017), *Innovations as the Category of Contemporaneity*, "Labor et Educatio", no. 5, Kraków, p.17, 19.

The Future We Want, RIO+20, United Nations Conference on Sustainable Development, Rio de Janeiro, Brazil, June 20–22, 2011.

Gawroński, D., (2021), *Reducing the effects of drought in crops by using humic acids and biohumus*, "Agricultural advisory issues", vol. 2, no. 104, pp. 48–59.

Ge Z., Hu H., Liu S., (2016), *A novel plied yarn structure with negative Poisson's ratio*, "The Journal of the Textile Institute", vol. 107, no. 5, pp. 578–588.

Gefen A., Megido-Ravid M., Itzchak Y., (2001*), In vivo biomechanical behavior of the human heel pad during the stance phase of gait*, "Journal of Biomechanics ", vol. 34, no. 12, pp. 1661–1665.

Gendaszewska D., Lasoń-Rydel M., Ławińska K., Grzesiak E., Pipiak P., (2021), *Characteristics of collagen preparations from leather wastes by the high pressure liquid chromatography method*, "Fibres & Textiles in Eastern Europe", vol. 29, pp. 75–79.

Gendaszewska D., Wieczorek D., (2022), *Solid tanning waste as secondary raw materials*, "Environmental protection – new solutions and perspectives for the future", TYGIEL Scientific Publishing House, Lublin, pp. 18–36.

Gibson L.J., (1981), *The elastic and plastic behaviour of cellular materials*, Churchill College, University of Cambridge, UK.

Gomułka S., (1998), *Teoria innowacji i wzrostu gospodarczego*, CASE, Warszawa, p. 17.

Goonetilleke R.S., (1999), *Footwear cushioning: relating objective and subjective measurements*, "Human Factors", vol. 41, no. 2, pp. 241–256.

Grima J.N., Caruana-Gauci R., Dudek M.R., Wojciechowski K.W., Gatt R., (2013), *Smart metamaterials with tunable auxetic and other properties*, "Smart Materials and Structures", vol. 22, 084016.

Grima J.N., Chetcuti E., Manicaro E., Attard D., Camilleri M., Gatt R., Evans K.E., (2011), *On the auxetic properties of generic rotating rigid triangles*, Proceedings of the Royal Society of London A, vol. 468, pp. 810–830.

Grima J.N., Evans K.E., (2000), *Auxetic behavior from rotating squares*, "Journal of Materials Science Letters", vol. 19, pp. 1563–1565.

Grima J.N., Farrugia P.S., Gatt R., Attard D., (2008), *On the auxetic properties of rotating rhombi and parallelograms: a preliminary investigation*, "Physica Status Solidi B.", vol. 245, pp. 521–529.

Grima J.N., Gatt R., Alderson A., Evans K.E., (2005), *On the auxetic properties of rotating rectangles with different connectivity*, "Journal of the Physical Society of Japan", vol. 74, pp. 2866–2867.

Grima J.N., Gatt R., Farrugia P.S., (2008), *On the properties of auxetic meta-tetrachiral structures*, "Physica Status Solidi B.", vol. 245, pp. 511–520.

Ha C.S., Plesha M.E., Lakes R.S., (2016), *Chiral three-dimensional lattices with tunable Poisson's ratio*, "Smart Materials and Structures", vol. 25, 054005.

Han C.H., Min B.G., (2020), *Superhydrophobic and Antibacterial Properties of Cotton Fabrics Coated with Copper Nanoparticles through Sonochemical Process*, "Fibers Polymers", vol. 21, pp. 785–791.

Hara P., (2019), *The importance of biostimulators in potato cultivation*, "Polish potato", vol. 2, pp. 18–24.

Hasan M.S., Nosonovsky M., (2020), *Lotus Effect and Friction: Does Nonsticky Mean Slippery?*, "Biomimetics", vol. 5, p. 28.

He C., Liu P., Griffin A.C., (1998), *Toward negative Poisson ratio polymers through molecular design*, "Macromolecules", vol. 31, pp. 3145–3147.

Hernández-Martínez R., Sancho-Solano A., Loera-Corral O., Rojo-Domínguez A., Regalado-González C., Huerta-Ochoa S., Prado-Barragán L.A., (2011), *Purification and characterization of a thermostable alkaline protease produced by Yarrowia lipolytica*, "Revista mexicana de ingeniería química", vol. 10, no. 2, pp. 333–341.

Hilliou L., (2021), *Structure-Elastic Properties Relationships in Gelling Carrageenans*, "Polymers", vol. 13, no. 23, p. 4120.

Howell B., Prendergast P., Hansen L., (1994), *Examination of acoustic behavior of negative Poisson's ratio materials*, "Applied Acoustics", vol. 43, pp. 141–148.

Hu M., Wu Z., Sun L., Guo S., Li H., Liao J., Wang B., (2019), *Improving pervaporation performance of PDMS membranes by interpenetrating polymer network for recovery of bio-butanol*, "Separation and Purification Technology", vol. 228, no. 1, 115690.

Huang X., Yu F., Peng Q., Huang Y., (2018), *Superb adsorption capacity of biochar derived from leather shavings for Congo red*, "RSC Advances", vol. 8, pp. 29781–29788.

Huczek M., Smolarek M., (2018), *Innowacje społeczne w procesie zarządzania organizacjami*, „Zeszyty Naukowe Wyższej Szkoły Humanitas. Zarządzanie", Sosnowiec, p. 10.

Hurst B., Branthwaite H., Greenhalgh A. et al., (2017), *Medical-grade footwear: the impact of fit and comfort*, "Journal of Foot and Ankle Research", vol. 10, no. 2.

Imbalzano G., Tran P., Ngo T.D., Lee P.V., (2017), *Three-dimensional modelling of auxetic sandwich panels for localised impact resistance*, "Journal of Sandwich Structures & Materials", vol. 19, no. 3, pp. 291–316.

Innovation Leaders, European Innovation Scoreboard 2022.

Jabłońska M., Dziuba R., Hurak I., (2018), *Czynniki rozwoju przedsiębiorczości w Polsce Wschodniej*, „Wiadomości Statystyczne", GUS, Warszawa, p. 57.

Jindorfer J., Kröll J., Schwameder H., (2020), *Does enhanced footwear comfort affect oxygen consumption and running biomechanics?*, "European Journal of Sport Science", vol. 20, no. 4, pp. 468–476.

Johnston R., (1966), *Technical Progress and Innovation*, "Oxford Economic Papers", vol. 18, iss. 2, pp. 158–176.

Jorgensen U., Bojsenmoller F., (1986), *Joint forces in extension of the knee: Analysis of a mechanical model*, "Acta Orthopaedica Scandinavica", vol. 57, no. 1, pp. 41–46.

Jothi Sri S. et al., (2012), *Microencapsulation: A Review*, "International Journal of Pharma and Biosciences", vol. 3, no. 1, pp. 509–531.

Kates R.W. et al., (2005), *What is sustainable development? Goals, indicators, values, and practice*, "Environment: Science and Policy for Sustainable Development", vol. 47, no. 3, pp. 8–21.

Kędzierska Szczepaniak A., Szopik-Depczyńska K., Łazorko K., (2016), *Innowacje w organizacjach*, Texter, Warszawa, pp. 11, 16.

Kim J., Shin D., Yoo D.S., Ki K., (2017), *Regularly configured structures with polygonal prisms for three-dimensional auxetic behavior*, Proceedings of the Royal Society of London A, vol. 473, 20160926.

Konaković M., Crane K., Deng B., Bouaziz S., Piker D., Pauly M., (2016), *Beyond developable: computational design and fabrication with auxetic materials*, "ACM Transactions on Graphics (TOG)", vol. 35, pp. 79–89.

Koozekonan A.G., Esmaeilpour M.R.M., Kalantary S., Karimi A., Azam K., Moshiran V.A., Golbabaei F., (2020), *Fabrication and characterization of PAN/CNT, PAN/TiO_2, and PAN/CNT/TiO_2 nanofibers for UV protection properties*, "The Journal of The Textile Institute", vol. 112, pp. 946–954.

Kozak M.W. (2008). *Czynniki determinujące możliwości wykorzystania polityki strukturalnej na potrzeby rozwoju polskich regionów*, [in:]: K. Bondyra, M.S. Szczepański, P. Śliwa (red.), *WieloPolska Regionalna. Regionalizm w Polsce a polityka strukturalna Unii Europejskiej*, Poznań: Wydawnictwo Wyższej Szkoły Bankowej w Poznaniu, p. 33.

Kozioł K., (1992), *Modele procesu innowacyjnego w przedsiębiorstwie*, „Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania" No 6, 2008, p. 523, [in:] R. Rothwell, (1992), *Successful Industrial Innovation: Critical Factors for the 1990's,* "R and D Management", no 22.

Kraśnicka T., (2013), *Innowacyjność przedsiębiorstw – uwarunkowania organizacyjne*, Studia Ekonomiczne nr 136, Wydawnictwo Uniwersytetu Ekonomicznego w Katowicach, Katowice, p.168.

Kreml A., (2014), *Innowacyjność w sferze bezpieczeństwa i higieny pracy jako czynnik rozwoju biznesu*, "Państwo i Społeczeństwo Państwo i Społeczeństwo", vol. 14, no. 3, Kraków, pp. 87.

Krifa M., Prichard C., (2020), *Nanotechnology in textile and apparel research – an overview of technologies and processes*, "The Journal of The Textile Institute", vol. 111, pp. 1–16.

Kusz D., Bienek T., Cholewiński J., Cieliński Ł., Czeladzka-Krerowicz K., Dudko S., Nowak M., Wojciechowski P., (2009), *Kompendium ortopedii*, Warszawa.

Kwaśnicki W., (2013), *Innowacje społeczne – nowy paradygmat czy kolejny etap w rozwoju kreatywności człowieka?*, [in:] W. Kwaśnicki (ed.), *Innowacyjność a samoorganizacja społeczna*, Uniwersytet Wrocławski, Wrocław, p. 9.

Kwaśnicki W., (2014), *Jak wspierać rozwój innowacji społecznych?*, [in:] A. Olejniczuk-Merta (ed.), *Innowacje społeczne od idei do upowszechniania efektu*, Instytut Badań Rynku, Konsumpcji i Koniunktur, Warszawa, p. 29.

Lakes R.S., (1987), *Foam structures with a negative Poisson's ratio*, "Science", vol. 235, pp. 1038–1041.

Lakes R.S., (2007), *Cellular solids with tunable positive or negative thermal expansion of unbounded magnitude*, "Applied Physics Letters", vol. 90, 221905.

Lakes R.S., (2017), *Negative Poisson's Ratio Materials: Auxetic Solids*, "Annual Review of Materials Research", vol. 47, pp. 63–81.

Lakes R.S., Witt R., (2000), *Making and characterizing negative Poisson's ratio materials*, "International Journal of Metallurgical Engineering Education", vol. 30, no. 1, pp. 50–58.

Lange O., (1961), *Uwaga o innowacjach*, [in:]: *Pisma ekonomiczne i społeczne 1930–1960*, PWN, Warszawa, p. 160.

Langmaier F., (1990), *Hygiena a komfort obutenohy*, "Kozarstvi", vol. 12, pp. 345–349.

Langmaier F., Mladek M., (1973), *Studie mikroklimatu obuvi*, "Kozarstvi", vol. 4, pp. 96–101.

Langmaier F., Mokrejs P., Kolomaznik K., Mladek M., (2008), *Plasticizing collagen hydrolysate with glycerol and low-molecular weight poly(ethylene glycols)*, "Thermochimica Acta", vol. 469, pp. 52–58.

Larsen U.D., Signund O., Bouwsta S., (1997), *Design and fabrication of compliant micromechanisms and structures with negative Poisson's ratio*, "Journal of Micro-electromechanical Systems", vol. 6, pp. 99–106.

Lawinska K., Modrzewski R., (2017), *Analysis of sieve holes blocking in a vibrating screen and a rotary and drum screen*, "Physicochemical Problems of Mineral Processing", vol. 53, no. 2, pp. 812–828.

Lawinska K., Modrzewski R., Serweta W., (2018), *The phenomenon of screen blocking for mixtures of varying blocking grain content*, "Gospodarka Surowcami Mineralnymi – Mineral Resources Management", vol. 34, pp. 83–96.

Lawinska K., Modrzewski R., Wodzinski P., (2015), *Comparison of the potential of using drum and vibrating screens for segregating mineral and municipal waste*, "Rocznik Ochrona Środowiska", vol. 17, no. 2, pp. 1365–1388.

Lawinska K., Modrzewski R., Wodzinski P., (2016), *Mathematical and empirical description of screen blocking*, "Granular Matter", vol. 18, no. 13.

Lempriere B.M., (1968), *Poisson's ratio in orthotropic materials*, "AIAA J.", vol. 6, no. 11, p. 2226.

Li D., Dong L., Lakes R.S., (2016), *A unit cell structure with tunable Poisson's ratio from positive to negative*, "Materials Letters", vol. 164, pp. 456–459.

Li D., Maa J., Dong L., Lakes R.S., (2016), *A bi-material structure with Poisson's ratio tunable from positive to negative via temperature control*, "Materials Letters", vol. 181, pp. 285–288.

Lin L., Regenstein J.M., Lv S. et al., (2017), *An overview of gelatin derived from aquatic animals: properties and modification*, "Trends in Food Science & Technology", vol. 68, pp. 102–112.

Liu K., Jiang L., (2012), *Bio-Inspired Self-Cleaning Surfaces*, "Annual Review of Materials Research", vol. 42, pp. 231–263.

Liu Q., (2006), *Literature review: materials with negative Poisson's ratios and potential applications to aerospace and defence*, Defence Science and Technology Organisation, Victoria.

López-Pérez L., Zarubina V., Melián-Cabrera I., (2021), *The Brunauer-Emmett-Teller model on alumino-silicate mesoporous materials. How far is it from the true surface area?*, "Microporous and Mesoporous Materials", vol. 319, 111065.

Łaczkowska M., Gendaszewska D., Grzesiak E., Lasoń-Rydel M., (2016), *Review of collagen extraction methods from leather waste*, "Technology and Quality of Products", vol. 61, pp. 74–79.

Ławińska K., (2021), *Production of agglomerates, composite materials, and seed coatings from tannery waste as new methods for its managemen*, "Materials", vol. 14, no. 21, p. 6695.

Ławińska K., Gendaszewska D., Grzesiak E., Jagiełło J., Obraniak A., (2017), *Use of tanning waste in seed production*, "Przemysł Chemiczny", vol. 96/11, pp. 2344–2347.

Ławińska K., Gendaszewska D., Grzesiak E., Lasoń-Rydel M., Obraniak A., (2017), *Coating legume seeds with collagen hydrolysates from tannery waste*, "Chemical Industry", vol. 96, no. 9, pp. 1877–1880.

Ławińska K., Gendaszewska D., Grzesiak E., Lasoń-Rydel M., Obraniak A., (2017), *Coating of leguminosarum seeds with collagen hydrolyzates from tanning waste*, "Przemysł Chemiczny", vol. 96/9, pp. 1877–1880.

Ławińska K., Lasoń-Rydel M., Gendaszewska D., Grzesiak E., Sieczyńska K., Gaidau C., Epure D.G., Obraniak A., (2019), *Coating of seeds with collagen hydrolysates from leather waste*, "Fibres & Textiles in Eastern Europe", vol. 27, no. 4(136), pp. 59–64.

Ławińska K., Modrzewski R., Obraniak A., (2020), *Comparison of granulation methods for tannery shavings*, "Fibres & Textiles in Eastern Europe", vol. 28, no. 5(143), pp. 119–123.

Ławińska K., Modrzewski R., Serweta W., (2019), *Tannery shavings and mineral additives as a basis of new composite materials*, "Fibres & Textiles in Eastern Europe", vol. 27, no. 5(137), pp. 89–93.

Ławińska K., Obraniak A., Modrzewski R., (2019), *Granulation process of waste tanning shavings*, "Fibres & Textiles in Eastern Europe", vol. 27, no. 2(134), pp. 107–110.

Ławińska K., Serweta W., Modrzewski R., (2018), *Qualitative evaluation of the possible application of collagen fibres: Composite materials with mineral fillers as insoles for healthy footwear*, "Fibres & Textiles in Eastern Europe", vol. 26, no. 5(131), pp. 81–85.

Ławińska K., Serweta W., Modrzewski R., (2019), *Studies on water absorptivity and desorptivity of tannery shavings-based composites with mineral additives*, "Przemysł Chemiczny", vol. 98/1, pp. 106–109.

Ławińska K., Szufa S., Modrzewski R., Obraniak A., Wężyk T., Rostocki A., Olejnik T.P., (2020), *Obtaining granules from waste tannery shavings and mineral additives by wet pulp granulation*, "Molecules", vol. 25, no. 22, p. 5419.

Ławińska K., Szufa S., Obraniak A., Olejnik T., Siuda R., Kwiatek J., Ogrodowczyk D., (2020), *Disc granulation process of carbonation lime mud as a method of post-production waste management*, "Energies", vol. 13, 3419.

Mahdavi S.A., Jafari S.M., Assadpoor E. et al., (2016), *Microencapsulation optimization of natural anthocyanins with maltodextrin, gum Arabic and gelatin*, "International Journal of Biological Macromolecules", vol. 85, pp. 379–385.

Maiti S.K., Ashby M.F., Gibson L.J., (1984), *Fracture toughness of brittle cellular solids,* "Scripta Metallurgica", vol. 18, pp. 213–217.

Malinowski A., Lewicki T., Śniegowski Z., (1975), *Antropometryczne pomiary stóp i możliwości ich zastosowania w przemyśle ortopedycznych*, „Przegląd techniki ortopedycznej i rehabilitacyjnej", vol. 3.

Mallavarapu G.R., Ramesh S., Chandrasekhara R.S., Rao B.R.P., Kaul P.N., Bhattacharya A.K., (1995), *Investigation of the essential oil of cinnamon leaf growth at Bangalore and Hyderabad*, "Flavour and Fragrance Journal", vol. 10, pp. 239–242.

Mark A.G., Palagi S., Qiu T., Fischer P., (2016), *Auxetic metamaterial simplifies soft robot design*, "2016 IEEE International Conference on Robotics and Automation (ICRA)", pp. 4951–4956.

Markowicz A., (2019), *Innowacje społeczne jako determinanty rozwoju społeczności lokalnych*, "Ekonomia Społeczna. Innowacje społeczne", vol. 1, Uniwersytet Ekonomiczny w Krakowie, Kraków, pp. 32–40.

Masilamani D., Madhan B., Shanmugam G., Palanivel S., Narayan B., (2016), *Extraction of collagen from raw trimming wastes of tannery: a waste to wealth approach*, "Journal of Cleaner Production", vol. 113, pp. 338–344.

Masłowska-Lipowicz I., Słubik A. (2022), *Novel method of obtaining textile fabrics with self-cleaning and antimicrobial properties*, "The Journal of the Textile Institute". https://www.tandfonline.com/doi/abs/10.1080/00405000.2022.2131954 (accessed: 09.03.2023).

Masłowska-Lipowicz I., Wyrębska Ł., Szałek B., Olszewski P., Gajewski R., (2020), *Materiały auksetyczne – struktury, potencjalne zastosowanie*, „Technologia i Jakość Wyrobów", vol. 65, pp. 116–128.

Masternak-Janus A., Rybaczewska-Błażejowska M., (2013), *Analiza efektywność innowacyjnej przedsiębiorstw przemysłowych w Polsce z wykorzystaniem metody DEA*, "Ekonomia i Zarządzanie", no. 4**,** Oficyna Wydawnicza Politechniki Białostockiej, Bialystok, p. 494.

Masters I.G., Evans K.E., (1996), *Models for the elastic deformation of honeycombs*, "Composite Structures", vol. 35, pp. 403–422.

Matysiak K., Kaczmarek S., Kierzek R., (2012), *Effect of Ecklonia maxima (Kelpak SL) marine algae extract on winter oilseed rape plants*, "OILSEED CROPS", vol. 33, pp.43–49.

Matysiak K., Kaczmarek S., Leszczyska D., (2012), *Influence Of Liquid Seaweed Extract of Ecklonia Maxima On Winter Wheat Cv Tonacja*, "Journal of Research and Applications in Agricultural Engineering", vol. 57, no. 4, pp. 44–47.

Matysiak K., Kierzek R., Siatkowski I., Kowalska J., Krawczyk R., Miziniak W., (2020), *Effect of Exogenous Application of Amino Acids L-Arginine and Glycine on Maize under Temperature Stress*, "Agronomy", vol. 10, no. 6, p. 769.

Michon C., Vigouroux F., Boulenguer P., Cuvelier G., Launay B., (2000), *Gelatin/iota carrageenan interactions in non-gelling conditions*, "Food hydrocolloids", vol. 14, no. 3, pp. 203–208.

Miller W., Hook P.B., Smith C.W., Wang X., Evans K.E., (2009), *The manufacture and characterisation of a novel, low modulus, negative Poisson's ratio composite*, "Composites Science and Technology", vol. 69, pp. 651–655.

Mohamed O.A., Kassem N.F., (2010), *Utilization of waste leather shavings as filler in paper making*, "Journal of Applied Polymer Science", vol. 118, pp. 1713–1719.

Muller D., Paluszekiw A., (2017), *Towards better solutions. Good practices in the footwear industry* – Report prepared as part of the international campaign Buy Responsibly Shoes. Publisher: Buy Responsibly Foundation, Cracow/Warsaw, https://www.ekonsument.pl/materialy/publ_660_strone_lepszych_praktyk_strony.pdf (accessed: 07.08.2023).

Nadi A., Boukhriss A., Bentis A., Jabrane E., Gmouh S., (2018), *Evolution in the Surface Modification of Textiles: A Review*, "Textile Progress", vol. 50, pp. 67–108.

Nazari A., (2019), *Superior Self-cleaning and Antimicrobial Properties on Cotton Fabrics Using Nano Titanium Dioxide along with Green Walnut Shell Dye*, "Fibers Polymers", vol. 20, pp. 2503–2509.

Nelson G., (2002), *Application of Microencapsulation in Textiles*, "International Journal of Pharmaceutics", vol. 242, pp. 55–62.

Niculescu O., Leca M., Moldovan Z., Deselnicu D.C., (2015), *Obtaining and Characterizing of a Product with Antifungal Properties Based on Essential Oils and Natural Waxes*

for Finishing Natural Leathers, "Revista de Chimie – Bucharest", vol. 66, no. 11, pp. 1733–1736.

Nigg B.M., Stefanyshyn D., Cole G., Stergiou P., Miller J., (2003), *The effect of material characteristics of shoe soles on muscle activation and energy aspects during running*, "Journal of Biomechanics", vol. 36, no. 4, p.569.

Novak N., Vesenjak M., Ren Z., (2016), *Auxetic cellular materials – a review*, "Strojniški Vestnik – Journal of Mechanical Engineering", vol. 62, pp. 485–493.

Obraniak A., Gluba T., Ławińska K., Derbiszewski B., (2018), *Minimisation of environmental efects related with storing fly ash from combustion of hard coal*, "Environment Protection Engineering", vol. 44, pp. 177–189.

Obraniak A., Lawinska K., (2017), *Spectrophotometric analysis of disintegration mechanisms (abrasion and crushing) of agglomerates during the disc granulation of dolomite*, "Granular Matter", vol. 20, p. 7.

OECD, Eurostat 2008.

OECD, *Podręcznik Frascati 2015*, Główny Urząd Statystyczny, Warszawa 2015, pp. 47, 48, 56.

OECD, (2005), *Oslo Manual, Principles of collecting and interpreting innovation data. Third Edition*, European Commission, pp. 50–53.

Olejniczuk-Merta A., (2013), *Innowacje społeczne*, „Konsumpcja i Rozwój", nr 1/2013, Warszawa, pp. 23–26.

Olszewski P. K., Kwiecień J., (2017), *Slow fashion in the footwear industry – consumer and entrepreneur perception in the light of sustainable development policy*, "Product Technology and Quality", vol. 62, pp. 39–52.

Painter R., US-6685746-B1, *Impregnation of leather with micro-encapsulated material.*

Pakdel E., Zhao H., Wang J. et al., (2021), *Superhydrophobic and photocatalytic self-cleaning cotton fabric using flower-like N-doped TiO_2/PDMS coating*, "Cellulose", vol. 28, pp. 8807–8820.

Parisi M., Nanni A., Colonna M., (2021), *Recycling of Chrome-Tanned Leather and Its Utilization as Polymeric Materials and in Polymer-Based Composites: A Review*, "Polymers (Basel)", vol. 13, pp. 2–23.

Park D., Lee J., Romo A., (2015), *Poisson's Ratio Material Distributions*, [in:] Y. Ikeda, C.M. Herr, D. Holzer, S. Kaijima, M.J. Kim, A. Schnabel (eds), *In Emerging Experience in Past, Present and Future of Digital Architecture, Proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia CAADRIA 2015*, Hong Kong, pp. 725–744.

Parker J., (1974), *The Economics of Innovation*, London.

Pati A., Chaudhary R., Subramani S., (2014), *A review on management of chrome-tanned leather shavings: a holistic paradigm to combat the environmental issues*, "Environmental Science and Pollution Research", vol. 21, pp. 11266–11282.

Pérez-Limiñana M.Á., Payá-Nohales F.J., Arán-Ais F., Orgilés-Barceló C., (2013), *Effect of the shell-forming polymer ratio on the encapsulation of tea tree oil by complex coacervation as a natural biocide*, "Journal of Microencapsulation", vol.31, no. 2, pp. 176–83.

Pietrelli L., Ferrom S., Reverberi A.P., Vocciante M., (2020), *Removal and recovery of heavy metals from tannery sludge subjected to plasma pyro-gasification process*, "Journal of Cleaner Production", vol. 273, p. 23166.

Pillai P., Archana G., (2012), *A novel process for biodegradation and effective utilization of chrome shavings, a solid waste generated in tanneries, using chromium resistant Bacillus subtilis P13*, "Process Biochemistry", vol. 47, pp. 2116–2122.

Pinheiro N.S.C., Perez-Lopez O.W., Gutterres M., (2020), *Solid leather wastes as adsorbents for cationic and anionic dye removal*, "Environmental Technology", vol. 43, no. 9, pp. 1285–1293.

Pipiak P., Skwarek M., (2020), *The use of amino acid fertilizers in agriculture*, "Technology and Quality of Products", vol. 65, pp. 144–157.

Pisano R., Arsiccio A., Capozzi L.C. et al., (2019), *Achieving continuous manufacturing in lyophilization: technologies and approaches*, "European Journal of Pharmaceutics and Biopharmaceutics", vol. 142, pp. 265–279.

PN-EN 14119:2005, *Badania tekstyliów. Ocena działania mikrogrzybów. Metoda B1 oraz metoda B2*.

PN-EN ISO 20645:2006, *Płaskie wyroby włókiennicze. Wyznaczanie aktywności antybakteryjnej. Metoda dyfuzji na płytce z agarem*.

Podgornik B.B., Šandríc S., Kert M., (2021), *Microencapsulation for Functional Textile Coatings with Emphasis on Biodegradability—A Systematic Review*, "Coatings", vol. 11, no. 11, p. 1371.

Pol E., Ville S., Pol, S. Ville, (2009). *Socialinnovation: Buzz word or enduring term?*, "The Journal of Socio-Economics", Vol 38(6), pp. 878–885.

Pomykalski A., (2001), *Zarządzanie innowacjami*, PWN, Warszawa, p.56.

Pooryousef M., Alizadeh K., (2014), *Effect of foliar application of free amino acids on alfalfa performance under rainfed conditions*, "Research on Crops", vol. 15, pp. 254–258.

Popplow, M., (1998), *Protection and Promotion: Privileges for Inventions and Books for Machines in the Early Modern Period. History of Technology*, No 20, Bloomsbury, Londyn, pp. 103–124;

Portellaa E.H., Romanzinib D., Angrizanib C.C., Amicob S.C., Zatteraa A.J., (2016*), Influence of Stacking Sequence on the Mechanical and Dynamic Mechanical Properties of Cotton/Glass Fiber Reinforced Polyester Composites*, "Material Research", vol. 19, no 3, pp. 542–547.

Portich P., Footwear Industry, ILO [MOP], 29 March 2011, http://iloencyclopaedia.org/part-xiv-42166/leather-fur-and-footwear/143-88-leather-fur-and-footwear/footwear-industry (accessed: 07.08.2023).

Prakash B., Kujur A., Yadav A. et al., (2018), *Nanoencapsulation: an efficient technology to boost the antimicrobial potential of plant essential oils in food system*, "Food Control", vol. 89, pp. 1–11.

Prall D., Lakes R.S., (1997), *Properties of a chiral honeycomb with a Poisson's ratio of –1*, "International Journal of Mechanical Sciences", vol. 39, pp. 305–314.

Praszkier R., Nowak A., (2012), *Przedsiębiorczość społeczna. Teoria i praktyka*, Oficyna a Wolters Kluwer business, Warszawa, pp. 60–75.

Przybysławska M., Winnicka K., (2012), *Technologie otrzymywania mikrokapsułek*, „Farmacja Polska", vol. 68, no. 4, pp. 283–289.

Radwan I.A., Abed A.H., Abeer M.R., Ibrahim R.A., Abdallah A.S., (2014), *Effect of Thyme, Clove and Cinnamon Essential Oils on Candida albicans and Moulds Isolated*

from Different Sources, "American Journal of Animal and Veterinary Sciences", vol. 9, no. 4, pp. 303–314.

Rakoczy B., (2015), *The procedural dimension of the principle of sustainable development*, "Białostockie Studia Prawnicze", vol. 18, pp. 35–44.

Ramamurthy G., Ramalingam B., Katheem M.F., Sastry T.P., Inbasekaran S., Thanveer V., Jayaramachandran S., Das S.K., Mandal A.B., (2015), *Total elimination of polluting chrome shavings, chrome, and dye exhaust liquors of tannery by a method using keratin hydrolysate*, "ACS Sustainable Chemistry & Engineering", vol. 3, pp. 1348–1358.

Rani S., Goel A., (2021), *Microencapsulation technology in textiles: A review study*, "The Pharma Innovation Journal", vol. 10, no. 5, pp. 660–663.

Raufflet E. (2009), *Mobilizing business for post-secondary education*: CIDA University, South Africa, "Journal of Business Ethics", Vol. 89, pp. 191–202;

Ravindran B., Wong J.W.C., Selvam A., Thirunavukarasu K., Sekaran G., (2016), *Microbial biodegradation of proteinaceous tannery solid waste and production of a novel value added product – Metalloprotease*, "Bioresource Technology", vol. 217, pp. 150–156.

Rigueto C.V.T., Nazari M.T., De Souza C.F., Cadore J.S., Brião V.B., Piccin J.S., (2020), *Alternative techniques for caffeine removal from wastewater: an overview of opportunities and challenges*, "Journal of Water Process Engineering", vol. 35, pp. 1–12.

Rocznik Statystyczny Przemysłu. Statistical Yearbook of Industry – Poland, Warsaw 2020.

Rodrigues R.F., Leite S.R., Santos D.A., Barrozo M.A.S., (2017), *Drum granulation of single super phosphate fertilizer: Effect of process variables and optimization*, "Powder Technology", vol. 321, pp. 251–258.

Rostocki A., Ławińska K., Modrzewski R., Siegień G., Hejft R., Obraniak A., (2022), *Methods for treatment of animal and plant-based biomass waste*, "Fibres & Textiles in Eastern Europe", vol. 30, no. 4, pp. 32–42.

Rostocki A., Unyay H., Ławińska K., Obraniak A., (2023), *Granulates based on bio and industrial waste and biochar in a sustainable economy*, "Energies", vol. 16, p. 56.

Rudnicka A., Kostrzewska M., (2020), Sewn with class. The clothing industry in the face of social and environmental challenges, University of Lodz Publishing House, Lodz [Available at: https://wydawnictwo.uni.lodz.pl/wpcontent/uploads/2020/07/Rudnicka_UszyteZklasa_ONLINE-.pdf (accessed: 07.08.2023)].

Rutkowska A., (2016), *Biostimulators in modern plant cultivation*, "ISSUE", vol. 48, pp. 65–80.

Sadak M.S.H., Abdelhamid M.T., Schmidhalter U., (2015), *Effect of foliar application of aminoacids on plant yield and some physiological parameters in bean plants irrigated with seawater*, "Acta Biologica Colombiana", vol. 20, pp. 141–152.

Salwa A.R. Hammad, Osama A.M. Ali, (2014), *Physiological and biochemical studies on drought tolerance of wheat plants by application of amino acids and yeast extract*, "Annals of Agricultural Sciences", vol. 59, no. 1, pp. 133–145.

Sánchez-Navarro M.M., Pérez-Limiñana M.Á., Arán-Ais F., Orgilés-Barceló C., (2015), *Scent properties by natural fragrance microencapsulation for footwear applications*, "Polymer International", vol. 64, no. 10, pp. 1458–1464.

Sanjay M.S., Sudarsanam D., Raj G.A., Baskar K., (2020), *Isolation and identification of chromium reducing bacteria from tannery effluent*, "Journal of King Saud University – Science", vol. 32, no. 1, pp. 265–271.

Scarpa F., Ciffo L.G., Yates J.R., (2003), *Dynamic properties of high structural integrity auxetic open cell foam*, "Smart Materials and Structures", vol. 13, p. 49.

Schmidt E., (2020), *Production of essential oils*, [in:] K. Hüsnü Can Başer, G. Buchbauer (eds), *Handbook of Essential Oils*, CRC Press, Boca Raton, p. 36.

Semenova M., (2017), *Protein-polysaccharide associative interactions in the design of tailor made colloidal particles*, "Current Opinion in Colloid and Interface Science", vol. 28, pp. 15–21.

Serweta W., Olejniczak Z., Matusiak M., (2019), *Improve of Footwear Comfort Sensation with Material Packages and Knitted Fabrics*, "FIBRES & TEXTILES in Eastern Europe", vol.27, no. 3(135), pp. 85–90.

Serweta W., Wójcik J., Matusiak M., Ławińska K., Szałek B., (2020), *Research on the Possibilities of Polymer Textile Applications as Footwear Packages to Improve Health Properties*, "Fibres & Textiles in Eastern Europe", vol. 4, no. 142, pp. 89–94.

Shadrivov I.V., Lapine M., Kivshar Y.S. (eds), (2015), *Nonlinear, Tunable and Active Metamaterials, Nonlinear, Tunable and Active Metamaterials*, Springer International Publishing, Switzerland.

Shan S., Kang S.H., Zhao Z., Fang L., Bertoldi K., (2015), *Design of planar isotropic negative Poisson's ratio structures*, "Extreme Mechanics Letters", vol. 4, pp. 96–102.

Shanthi C. Babu, Banerjee P., Babu N.K., Rajakumar G., (2013), *Recovery and characterization of protein hydrolysate from chrome shavings by microbial degradation*, "Journal of the American Leather Chemists Association", vol. 108, pp. 231–239.

Shao Y., Zhao J., Fan Y., Wan Z., Lu L., Zhang Z., Ming W., Ren L., (2020), *Shape memory superhydrophobic surface with switchable transition between "Lotus Effect" to "Rose Petal Effect"*, "Chemical Engineering Journal", vol. 382, 122989.

Sharkawy A., Fernandes I.P., Barreiro M.F., Rodrigues A.E., Shoeib T., (2017), *Aroma-Loaded Microcapsules with Antibacterial Activity for Eco-Friendly Textile Application: Synthesis, Characterization, Release, and Green Grafting*, "Industrial & Engineering Chemistry Research", vol. 56, no. 19, pp. 5516–5526.

Sharma R., Goel A., (2018), *Development of insect repellent finish by a simple coacervation microencapsulation technique*, "International Journal of Clothing Science and Technology", vol. 30, no. 2, pp. 152–158.

Silva R.M., Rodrigues J.L., Pinto V.V., Ferreira M.J., Russo R., Pereira C.M., (2009), *Evaluation of shock absorption properties of rubber materials regarding footwear applications*, "Polymer Testing", vol. 28, no. 6, pp. 642–647.

Sing C.E., (2017), *Development of the modern theory of polymeric complex coacervation*, "Advances in Colloid and Interface Science", vol. 239, pp. 2–16.

Singh A.K., Raj A., (2020), *Emerging and eco-friendly approaches for waste management*, "Environmental Sciences Europe", vol. 32, p.107.

Singh N., Sheikha J., (2020), *Microencapsulation and its application in production of functional textiles*, "Indian Journal of Fibre & Textile Research", vol. 45, pp. 495–509.

Skonieczny J., *Innowacja Społeczna*, „Zeszyty Naukowe Uniwersytetu Ekonomicznego w Poznaniu", nr (246), Poznań 2022, p. 99.

Skubiak B., (2016), *Innowacje społeczne w teorii i praktyce*, „Barometr Regionalny", tom 14, nr 1, Wyższa Szkoła Zarządzania i Administracji w Zamościu, Zamość 2016, p. 29–30.

Skwarek M., Nawrocka J., Lasoń-Rydel M., Ławińska K., (2020), *Diversity of plant biostimulants in plant growth promotion and stress protection in crop and fibrous plants*, "Fibres & Textiles in Eastern Europe", vol. 28, pp. 34–41.

Skwarek M., Wala M., Kołodziejek J., Sieczyńska K., Lasoń-Rydel M., Ławińska K., Obraniak A., (2021), *Seed coating with biowaste materials and biocides—environment-friendly biostimulation or threat?*, "Agronomy", vol. 11, p. 1034.

Starešiníc M., Šumiga B., Boh B., (2011), *Microencapsulation for Textile Applications and Use of SEM Image Analysis for Visualisation of Microcapsules*, "Tekstilec", vol. 54, pp. 80–103.

Statistics of the footwear industry for 2019, source: annual collection of the Department of the Analytical Center of the Tax Administration Chamber in Warsaw approved by the Central Statistical Office, Poland, 2019, pp. 1–13.

Steviæ T., Beriæ T., Šavikin K., Sokoviæ M., Goðevac D., Dimkiæ I., Stankoviæ S., (2014), *Antifungal Activity of Selected Essential Oils against Fungi Isolated from Medicinal Plant*, "Industrial Crops and Products", vol. 55, pp. 116–122.

Stojmanovski Mercieca L.A., Formosa C., Grima J.N., Chockalingam N., Gatt R., Gatt A., (2017), *On the Use of Auxetics in Footwear: Investigating the Effect of Padding and Padding Material on Forefoot Pressure in High Heels*, "Physica Status Solidi B", vol. 254, no. 12, 1700528.

Strong Innovators, European Innovation Scoreboard 2022.

Tailby S. (2003), *Falling mass shock absorption test*, "SATRA Bulletin", October, p. 17.

Theocaris P.S., Stavroulakis G.E., Panagiotopoulos P.D., (1997), *Negative Poisson's ratios in composites with star-shaped inclusions: a numerical homogenization approach*, "Archive of Applied Mechanics", vol. 67, pp. 274–286.

Thi V.H.T., Lee B.K., (2017), *Development of multifunctional self-cleaning and UV blocking cotton fabric with modification of photoactive ZnO coating via microwave method*, "Journal of Photochemistry and Photobiology A: Chemistry", vol. 338, pp. 13–22.

Timilsena Y.P., Akanbi T.O., Khalid N. et al., (2019), *Complex coacervation: principles, mechanisms and applications in microencapsulation*, "International Journal of Biological Macromolecules", vol. 121, pp. 1276–1286.

Tonnesen H.H., Karlsen J., (2002), *Alginate in drug delivery system,* "Drug Development and Industrial Pharmacy", vol. 28, no. 6, pp. 621–630.

Tu J., Bolla S., et al. (2005), *Alginate microparticles prepared by spray-coagulation method: preparation, drug loading and release characterization*, "International Journal of Pharmaceutics", vol. 303, no. 1–2, pp. 171–181.

Tudu B.K., Sinhamahapatra A., Kumar**,** A., (2020), *Surface Modification of Cotton Fabric Using TiO_2 Nanoparticles for Self-Cleaning, Oil-Water Separation, Antistain, Anti-Water Absorption and Antibacterial Properties*, "ACS Omega", vol. 5, pp. 7850–7860.

Tulshyan A., Dedhia E., (2021), *An overview of microencapsulation technology in the application of aroma and antibacterial finishes*, "International Journal of Home Science", vol. 7, no. 1, pp. 34–39.

Türkoğlu G.C., Sariişik A.M., Erkan G., Kayalar H., Kontart O., Öztuna S., (2017), *Determination of antioxidant capacity of capsule loaded textiles*, "Indian Journal of Fibre & Textile Research", vol. 42, pp. 189–195.

Tutaj J., (2019), *Innowacje – próba pomiaru*, [in:] Z. Malar, J. Tutaj (eds), *Innowacje a dobrostan społeczeństwa, gospodarki i przedsiębiorstw:próba pomiaru*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław, p. 12.

Underhill R.S., (2014), *Defense applications of Auxetic materials*, "Advanced Materials", vol. 1, pp. 7–13.
Valdes A., Ramos M., (2018), *Recent Trends in Microencapsulation for Smart and Active Innovative Textile Products*, "Current Organic Chemistry", vol. 22, no. 12, pp. 1237–1248.
Verdejo R., Mills N.J., (2004), *Simulating the effects of long distance running on shoe midsole foam*, "Polymer Testing", vol. 23, no. 4, pp. 567–574.
Vidaurre-Arbizu M., Pérez-Bou S., Zuazua-Ros A., Martín-Gómez C., (2021), *From the leather industry to building sector: Exploration of potential applications of discarded solid wastes*, "Journal of Cleaner Production", vol. 291, 125960.
Voigt W., (1928), *Lehrbuch der Kristallphysik*, B. G. Teubner-Verlag, Leipzig, Berlin.
Wacławski Z., *Rola innowacji społecznych w rozwoju regionu województwa lubelskiego – przykłady dobrych praktyk*, "Nierówności Społeczne a Wzrost Gospodarczy", No 50 (2/2017), Uniwersytet Rzeszowski, Rzeszów, pp. 463–368.
Walocha J., Skawina A., Gorczyca J., (2006), *Anatomia prawidłowa człowieka. Miednica. Podręcznik dla studentów i lekarzy. Wydanie II poprawione*, Wydawnictwo Uniwersytetu Jagiellońskiego, Kraków, pp. 13–19.
Wan J., Xu L.H., Pan H. et al., (2021), *Green water-based fabrication of SiO_2-TiO_2 aerogels with superhydrophobic and photocatalytic properties and their application on cotton fabric*, "Journal of Porous Materials", vol. 28, pp. 1501–1510.
Wang X.T., Wang B., Li X.W., Ma L., (2017), *Mechanical properties of 3D re-entrant auxetic cellular structures*, "International Journal of Mechanical Sciences", vol. 131, pp. 396–407.
Wang Z., Hu H., (2014), *Auxetic materials and their potential applications in textiles*, "Textile Research Journal", vol. 84, pp. 1600–1611.
Wang Z.P., Poh L.H., Dirrenberger J., Zhu Y., Forest S., (2017), *Isogeometric shape optimization of smoothed petal auxetic structures via computational periodic homogenization*, "Computer Methods in Applied Mechanics and Engineering", vol. 323, pp. 250–271.
Weijers R.E., Kessels A.G., Kemerink G.J., (2005), *The damping properties of the venous plexus of the heel region of the foot during simulated heelstrike*, "Journal of Biomechanics", vol. 38, no. 12, pp. 2423–2430.
Whittle M.W., (1999), *Generation and attenuation of transient impulsive forces beneath the foot: a review*, "Gait Posture", vol. 10, no. 3, p. 264.
Wieczorek D., Lasoń-Rydel M., Gendaszewska D., (2021), *The influence of the presence of tanning shavings on the growth of yeast from the Dipodascaceae family*, "Technology and Quality of Products", vol. 66, pp. 170–184.
Wiktorska-Święcka A., Klimowicz M., Moroń D., (2015), *Zarządzanie innowacjami społecznymi*, Difin, Warszawa, p. 11.
Wojciechowski K.W., (1987), *Constant thermodynamic tension Monte Carlo studies of elastic properties of a two-dimensional system of hard cyclic hexamers*, "Molecular Physics", vol. 61, p. 1247.
Wojdyła A.T., Sobolewski J., (2016), *The possibility of using agents containing amino acids in the protection of beans against black rot*, "Scientific Journals Institute of Horticulture", vol. 24, pp. 131–140.
Wolański N., (2005), *Rozwój biologiczny człowieka*, Wydawnictwo PWN, Warszawa, p. 125.
Wronka-Pośpiech M., (2015), *Innowacje społeczne w procesie zarządzania organizacjami*, "Zeszyty Naukowe Uniwersytetu Ekonomicznego w Katowicach", Katowice, p. 11.

Wspólna odpowiedzialność. Rola innowacji, edited by N. Ćwik, Forum Odpowiedzialnego Biznesu, 2013, pp. 115–130.

Wu Z., Fang K., Chen W., Zhao Y., Xu Y., Zhang C., (2021), *Durable superhydrophobic and photocatalytic cotton modified by PDMS with TiO_2 supported bamboo charcoal nanocomposites*, "Industrial Crops and Product", vol.171, 113896.

Yang L., Harrysson O., West H., Cormier D., (2015), *Mechanical properties of 3D re-entrant honeycomb auxetic structures realized via additive manufacturing*, "International Journal of Solids and Structures", vol. 69, pp. 475–490.

Yang M., Liu W., Jiang C. et al., (2019), *Robust fabrication of superhydrophobic and photocatalytic self-cleaning cotton textile based on TiO_2 and fluoroalkylsilane*, "Journal of Materials Science", vol. 54, pp. 2079–2092.

Yick K., Yu A., Li P., (2019), *Insights into footwear preferences and insole design to improve thermal environment of footwear*, "International Journal of Fashion Design, Technology and Education", vol. 12, no. 3, pp. 325–334.

Yılmaz B., Karavana H.A., (2020), *Application of Chitosan-Encapsulated Orange Oil onto Footwear Insock Leathers*, "Johnson Matthey Technology Review", vol. 64, no. 4, p. 443.

Zainescu G., (2018), *Polymer Compositions from Leather Fibers (Leather Shavings) for Mortar in Constructions*, In Proceedings of the 18th SGEM International Multidisciplinary Scientific GeoConference SGEM2018, Energy and Clean Technologies Stef92 Technology, Albena, Bulgaria, 2–8 July 2018, pp. 79–86.

Zajda K., (2014), *Uwarunkowania innowacji społecznych w społecznościach wiejskich i metody ich stymulowania*, [in:] E. Psyk-Piotrowska (ed.), *Nowe mechanizmy rozwoju obszarów wiejskich*, Uniwersytet Łódzki, Łódź, p. 145.

Zalewska A., Średzińska K., Kułak W., (2021), *Postawa ciała a siła mięśniowa u dzieci w wieku szkolnym*, Uniwersytet Medyczny w Białymstoku, Białystok, p.19.

Zastępowski M., (2017), *Model procesu innowacyjnego Polskich małych i średnich Przedsiębiorstw*, „Organizacja i Kierowanie", nr 2, SGH, Warszawa, p. 372.

Zhang J., Wang F., Yalamarty S.S.K., Filipczak N., Jin Y., Li X., (2022), *Nano Silver-Induced Toxicity and Associated Mechanisms*, "International Journal of Nanomedicine", vol. 26, no. 17, pp. 1851–1864.

Zhang J., Yan Z., Liu X., Zhang Y., Zou H., Le Y., Chen J.-F., (2020), *Conductive skeleton-heterostructure composites based on chrome shavings for enhanced electromagnetic interference shielding*, "ACS Applied Materials & Interfaces", vol. 12, pp. 53076–53087.

Zhu C., Shi J., Xu S. et al., (2017), *Design and characterization of self-cleaning cotton fabrics exploiting zinc oxide nanoparticle-triggered photocatalytic degradation*, "Cellulose", vol. 24, pp. 2657–2667.

Żero S., (2018), *Różnice w interpretacji pojęć innowacji oraz imitacji*, [in:] E. Gruszewska, A. Matel, E. Kuzionko-Ochrymiuk (eds), *Współczesne problemy ekonomiczne w badaniach młodych naukowców*. T. 2, Zarządzanie organizacją, finanse i inwestycje, Polskie Towarzystwo Ekonomiczne, Białystok, p. 41.

http://www.life-shoebat.eu/pl/ (accessed: 07.02.2023).

http://www.socialinnovator.info/process-social-innovation (accessed: 12.02.2023).

http://www.wildsingapore.com/wildfacts/plants/seaweed/phaeophyta/phaeophyta.html (accessed: 07.08.2023).

https://badam.poznan.pl/2018/ii_nasza-przestrzen/08_bezpieczenstwo/programy-w-zakresie-zwiekszenia-bezpieczenstwa-mieszkancow-poznania/ (accessed: 02.04.2023).
https://ec.europa.eu/research-and-innovation/en/statistics/ performance-indicators/european-innovation-scoreboard/eis# (accessed: 06.01.2023).
https://ekonsument.pl/s56_co_robimy.html (accessed: 07.08.2023).
https://en.wikipedia.org/wiki/Rhizobacteria (accessed: 07.08.2023).
https://eskulap.olsztyn.pl/leczona-choroba/wrodzona-stopa-przywiedziona/ (accessed: 12.12.2023).
https://fizjo-gabinet.pl/stopa-konsko-szpotawa-fizjoterapia/ (accessed: 12.12.2023).
https://histmag.org/Ekologia-spoleczenstwo-gospodarka-koncepcja-zrownowazonego-rozwoju.-952 (accessed: 07.08.2023).
https://izrs.eu/aktualnosci/prawnik-przyszlosci---lider-zrownowazonego-rozwoju (accessed: 07.08.2023).
https://obamawhitehouse.archives.gov/administration/eop/sicp/about (accessed: 18.03.2023).
https://obamawhitehouse.archives.gov/administration/eop/sicp/initiatives/social-innovation-fund (accessed: 18.03.2023).
https://poland.representation.ec.europa.eu/strategies-and-priorytety/key-dzialania-eu-for-polskie/polityka-spojnosci_pl (accessed: 09.03.2023).
https://s3platform.jrc.ec.europa.eu/documents/20182/84453/Guide_to_Social_Innovation.pdf (accessed: 12.02.2023).
https://stat.gov.pl/files/gfx/portalinformacyjny/pl/defaultaktualnosci/5496/18/1/1/podrecznik_oslo_2018_internet.pdf (accessed: 02.04.2023).
https://www.fundusze Europejskie.gov.pl/media/109449/umowa_partnerstwa_broszura_210x210_nowa_3-small.pdf (accessed: 09.03.2023).
https://www.globalinnovationindex.org/analysis-economy (accessed: 07.01.2023).
https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.bryk.pl%2F wypracowania%2Fpozostale%2Frehabilitacja%2F18677-wady-wrodzone-w-obrebie-kkd. html&psig=AOvVaw2Xf4oLqogGLEck5vXaxC_R&ust=1681543402919000&source=images&cd=vf e&ved=0CA4QjRxqFwoTCKjXzvfqqP4CFQAAAAAdAAAAABAK (accessed: 12.12.2023).
https://www.nowoczesnagospodarka.gov.pl/media/111296/FENG_zatwiertowani_przed_KE.pdf (accessed: 09.03.2023).
https://www.parp.gov.pl/csr (accessed: 07.08.2023).
https://www.parp.gov.pl/storage/publications/pdf/sektor-moda_raport_24-06-2020.pdf (accessed: 07.08.2023).
https://www.poir.gov.pl/media/113708/harmonogram_naboru_świadcz_FENG_11012023.pdf (accessed: 18.03.2023).
https://www.poir.gov.pl/strony/about-the-program/fe-dla-nowoczesnaj-gospodarki/aktualnosci/schedule-naborow-realizatorch-w-ramach-programu-fundusze-european-dla-nowoczesnaj-gospodarki- na-2023-r/ (accessed: 18.03.2023).
https://www.pracujwlogistyce.pl/raporty/21-raporty/7372-polskie-firmy-produkuja-46-5-mln-par-butow-rocznie-a-wartosc-tego-rynku-wynosi-3-3-mld-euro (accessed: 07.08.2023).

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The prepared scientific monograph entitled *The importance of social innovations in the knowledge-based economy in the context of footwear sector solutions* is an attempt to further exemplify social innovations by identifying real links between social need and a specific good, service, method and process, in the context of solutions used in the footwear industry. Poland is one of the leading European footwear manufacturers, ranking 7th in terms of production volume in the EU, with a market share of 2.5%. In addition, strong competition is observed in the industry, which is conducive to the emergence of new innovations. The work contains theoretical and practical references to innovations in the industry, such as examples of modifications of footwear materials that have been used in business practice, and their measurable effect is to improve the comfort of using footwear. The authors refer to the environmental aspects of innovation, indicating the directions of utilization of production residues of the footwear and tanning industry, including composites, granules, and biostimulants for plants. The subject matter taken up in the monograph is an important contribution to the development of further scientific research covering the footwear industry and its importance in developing social innovations in Poland and the world. Based on the obtained research results and statistical data analysis, we attempted to outline the prospects for the development of social innovations in the footwear industry until 2050. The book can be an interesting study for practitioners and theoreticians, particularly for scientists representing disciplines such as economics and finance, management sciences, materials engineering, or entrepreneurs looking for opportunities to finance innovation in various areas.

The book is also available as an e-book

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