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MERGING FOOTWEAR DESIGN AND FUNCTIONALITY

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Abstract:

Functionality and appearance are key aspects of good footwear. Developments in recent science and technology offer a wider scope of innovations, contributing to diversity and higher complexity of the production concept of footwear. Contemporary industrial footwear market offers a practically limitless number of new design and fashion solutions, often of quite similar appearance, but with significant differences in quality level, both regarding manufacture, raw material content, durability, and in some special functional finishes. The materials for footwear manufacture are functionalized for functional protective purposes, such as antimicrobial, waterproofing, fire resistant, wear and tear resistant, and recently for some therapeutical purposes. Novelties in material functionalization for the materials built in the footwear are most often promoted and presented on tags and labels and are used as advertisement issues, while some functionalities have become a logo for some brands.

Keywords:

footwear design, leather functionalization, antimicrobial agents, footwear manufacture

1. Introduction

Two basic aspects characterize footwear form the beginning of its history from the point of view a functional usable article – comfort and appearance. Both of them are defined by the materials, tools, machines, and devices used in the manufacture, manufacturing processes themselves, as well as by the form and shape of the footwear, whose historical development can be monitored and analyzed globally and individually. Developments in science and technology offer a much higher number of innovations in all the above aspects, which contribute significantly to the diversity and higher complexity of the production concept of footwear.

Design has, as an art discipline, grown from the needs of serial or mass industrial production, which establishes a new relationship between the form and function of the items manufactured. This situation has been a focus of numerous discussions and has not been solved successfully up to the present days. One of the outstanding theoreticians of functional design, Thomas Maldonaldo, defined design as a creative activity consisting of determining precise properties of the item to be produced industrially. Precise properties include not only the outer visible characteristics but also the structural links which give a coherent unity to the product, either simple or complex [1]. This definition is rather general and shows design as a global discipline which requires, in order to offer finished products, taking care of numerous parameters, and keep equilibrium among diversified determinants, such as technical tools used in the manufacture, contemporary esthetic criteria and their negation, used value of the product, customer preferentials, ergonomic, economic, and other factors.

Footwear functionality can also be evaluated from the point of view of purpose or type, material used in its manufacture, or the manner of manufacture itself. Apart from basic materials, numerous other materials are used in footwear manufacture, for uppers and bottom stock as well as for the inner parts of the footwear. A growing number of new technologies and procedures have emerged in recent decades in this area, including innovative smart functionalities, which have resulted in a new concept of active footwear [2]. A broad selection of various footwear models has been offered to the customers, and the choice of materials, functional segments, and additional finishes, such as antimicrobial and water repellent, play an important role in final selection and purchase [3].

Processes of achieving functionalization for special purposes are usually performed in two ways: by treating materials in various manufacturing phases or by coating ready-made materials or footwear. Numerous technologies of functional finish have been developed, depending on the raw material used or the material that is supposed to acquire target properties. Footwear industry also distinguishes these finishes by the part of the footwear, and the material is intended for the following: uppers, bottom stock, or parts to be built into the article.

Leather has been recognized and esteemed as one of the oldest natural materials, still surviving in this industrial era, in both footwear manufacturing and many other branches of industrial manufacture. Contemporary leather industry has taken huge steps in chemical treatments and is quite demanding regarding research and innovations. The process of leather treatment is related to and dependent upon numerous areas of science, from chemistry, physics, mathematics, and environmental protection to ethics. The process of leather treatment involves a continuous interaction of various disciplines, trying at the same time to keep pace with turbulent market conditions, environmental protection, safety regulations, needs, and requirements of customers/buyers and keeping in mind numerous other aspects which represent a growing challenge to new generations of chemists and technologists [3].

Contemporary industrialized society poses a growing number of requirements to science and production. In leather manufacturing, these requirements go into two different directions: new quality of finished leather or meeting increasingly stringent requirements of environmental protection.

The aim of this article is to present the latest achievements in the methodology, materials, and techniques of footwear finishing and their significant impact on the design of multifunctional footwear which needs to combine and fulfill criteria for improved quality and usability with superior design.

2. Experimental

2.1. Materials

Usable quality of leather depends on the type of raw skin or hide used, its strength, and degree of finishing as well as on the quality of the technological process used. Finished leather quality is expressed as a sum of all of its properties that ensure hide applicability in manufacture, stability in storage, and definite life of the materials under the conditions of use. Footwear manufacturers often check the quality of their eco-products according to the given criteria of eco-labs, even when they do not use the labels officially. This practice develops and raises quality standards and safety of their product brands.

The most often used raw materials in the manufacture of footwear nappa for uppers are calf, kip, or cow hide, as their processing offers full, soft, elastic, and pliable leathers of full and corrected grain for various types of intermediate and finishing treatments. Chrome and combined tannages have recently been often substituted by vegetable one, particularly for the footwear declared as chrome free. The type of tannage significantly impacts the properties of finished leather as well. Collagen fibers tanned with vegetable tannage are thicker and fuller, and the leather structure is denser and more closed than when tanned with mineral (chrome tannage). It is the result of tanning matter structure and the bonds they create between the collagen fibers and within them, as seen by the contents of tanning matter bonded. Fibrous composition is characteristic for all finished leathers, and their physical–mechanical properties depend upon this composition. When leather is exposed to tensile loads, fibers are often separated, due to elongation mostly, while leather generally offers significant resistance to elongation.

Key characteristics of leather microstructure are as follows: regularity of fiber interlacing, the angle of interlacing, interlacing density, fiber bending, separation degree, and fiber thickness. In addition to leather microstructure, monitoring some physical and chemical properties that could impact the mechanical properties of leather, such as humidity, fat, and leachable matter, is of key importance when evaluating the mechanical properties of leather. Sample should be mandatorily conditioned prior to mechanical testing, as the amount of moisture in leather is closely related to its end-use properties.

2.2. Methods

Mechanical properties of finished leather are also important in defining its end-use properties. Breaking strength and elongation are important mechanical properties that determine the resistance of leather to tensile loads. They are measured according to the technical standard HRN EN SO 336:2012. This standard specifies the method of determining tension strength, elongation at specified load, and the rate of stretching, as well as the elongation of leather at break, and can be used for all types of leather [4].

Breaking force was measured on samples of footwear nappa, tanned in different ways and with different types of leather grain finish, for the purpose of monitoring material quality and giving recommendations as to which type of tannage to be used. The measurements were performed on a Tensolab 3000 dynamometer, produced by Mesdan, with the stretching rate of 100 ± 20 mm/min and with the range of forces in accordance with the testing sample.

Table 1. Breaking strength and breaking elongation results for vegetable-tanned footwear nappa with semianiline retannage and chrome-tanned footwear nappa with aniline retannage

Sample		Thickness, d (mm)	Breaking force, F (N)	Breaking elongation, e (%)	Breaking strength, Tn (MPa)
		Average values			
1.	Cowhide footwear nappa, vegetable	1.60	171.65	91.00	10.80
2.	Cowhide footwear nappa, vegetable tanned, semianiline retanned	1.59	231.94	87.60	14.70
3.	Cowhide footwear nappa, chrome tanned, aniline retanned	1.37	360.72	70.50	26.30
4.	Cowhide footwear nappa, chrome tanned, aniline retanned	1.50	361.99	65.50	24.00

3. Results and discussion

3.1. Mechanical properties

Breaking force and breaking elongation, together with leather thickness, necessary to calculate breaking strength, are summarized in Table 1. Testing samples included vegetable-tanned footwear nappa with semianiline retanning and chrome-tanned footwear nappa with aniline retannage. Each test included measurements of six testing samples, cut in the direction of the central axis and in the direction perpendicular to the central axis. Working conditions for testing were as follows: temperature of 23°C and relative air humidity of 50%.

The results obtained indicate that both vegetable- and chrome-tanned footwear leathers were of high end-use quality. The average values of the breaking force *F* and breaking strength Tn for chrome-tanned leather were, as expected, higher than the same values for vegetable-tanned samples.

Leather quality is additionally influenced by microstructure elements, differing according to the topological position on the skin, which results in variations of mechanical properties. Crupon (C) is a central part of the hide, situated at both sides of cow's spinal column. It is characterized by uniform thickness and the densest interlacing of almost vertically positioned collagen fibers, which makes it the part of the hide with the highest quality of microstructure. Bellies (side parts of the hide) are generally of nonuniform thickness, while collagen fibers are attenuated and positioned almost horizontally in space, which results in inferior mechanical properties.

The resistance of footwear nappa on tensile loads, in accordance with the standard method, was done on the samples of cow footwear nappa with combined tannage (chrome and vegetable) finished with polyurethane (PU) finish on the grain. Testing samples were taken from the belly and back parts of the hide, so as to establish the impact of the sampling area onto the mechanical properties of leather. Table 2 summarizes the average values obtained in testing six samples, for breaking force and breaking elongation, as well as for leather depth necessary to calculate breaking strength. Testing samples were cut in the direction of central axis (↑) and in the direction perpendicular to it (←). Working conditions for testing were as follows: temperature of 200°C and relative air humidity of 65%.

Table 2. Results of strength and breaking elongation for the crupon part of the footwear nappa sample (combined tannage, PU finish on the grain) and the belly part of the footwear nappa sample (combined tannage, PU finish on the grain)

Sample	d (mm)	F (N)	e (%)	Tn (MPa)
	Average values			
↑ C (Crupon)	1.05	256.74	45.72	24.45
← C (Crupon)	1.05	173.38	81.48	16.51
↑ B (Belly)	1.15	201.43	74.76	17.51
←B (Belly)	1.15	185.35	54.36	16.12

The average values of elongation percentage in the direction of testing sample man axis for the crupon part are lower than for the belly part, which is explained by the hide microstructure, or spatial position and density of the collagen fiber interlacing. As opposed to elongation, breaking force and breaking strength of the crupon part in the direction of the man axis are higher than those of the belly part. The results obtained confirm the dependence of mechanical properties of leather resistance to breaking force, stretching and breaking strength on the type of tannage used, and microstructure characteristics of the crupon and belly part of the hide. Naturally, the impact of the type of raw hide, its quality, and the selection of the processing technology should not be neglected as well. Footwear sector has been trying to improve at the moment all the factors that impact comfort and durability of the products, which requires using newly developed materials of new functionalities.

There is a prevailing public opinion that the usage of artificial materials in footwear manufacture contributes to the feeling of discomfort, as these materials are not able to sustain optimal microclimate within the footwear. Therefore, footwear designers and technologists have to find structural and technological solutions to eliminate the negative impact of the materials on the microclimatic conditions within the footwear, meaning also ensuring healthy conditions for the feet.

Thermophysiological properties of both the footwear manufactured and the materials used for the footwear are important functional properties of the footwear. However, the present state of the art in this area of research leaves enough space and opportunity for further investigation. One of the recent investigations revealed that even though particular footwear upper was box calf, the shoe lining and insole were of synthetic textile fabric and synthetic polymer, which resulted in shoe discomfort and initiated further investigation to solve the problem [5]. It was also established that poor water vapor permeability and poor water absorption of the synthetic soles used in the manufacture of protective footwear directly impacted the quality of the products.

To improve the thermal comfort of the footwear, nonwoven textile materials, foams, and leather that are most used for footwear have been treated with microcapsules and nano-finishes, so as to be able to keep the feet temperature constant for a longer period of time. The investigations related to the mechanism of structural and dimensional changes of leather surface under the impact of various weather conditions are also important. They can offer a considerable contribution to the development of new materials for the treatment of footwear leather [6, 7].

Footwear, as opposed to clothing, is generally not washed, meaning that its care and maintenance are minimal. However, there are some top-quality products that ask for the leather or footwear to be washable. New generation of materials has been manufactured for finished leather with pronounced washability, the most important among them being acrylic polymer-based materials. New generation of soft polymeric agents is based on hydrophobic and hydrophilic elements. Hydrophobic ones offer softness, while hydrophilic ones initiate emulsification in water and efficiently bond the agent to the surface of the leather. Properly designed technological procedure results in a leather that is light, soft, of full handle, resistant to washing, dry-cleaning, intense light, heat, humidity, of good dyeing properties throughout the cross-section, with intensive hue, offering at the same time good resistance to stretching, tearing, and increased waterproofness effect. Leather washability is tested following the standards EN SO 1502:2004 – resistance of coloration to machine washing and EN SO 1503:2004 – resistance of coloration to mild washing [8, 9]. Washing agent is also an important factor in the process of leather washing. Various recipes of environmentally friendly liquid washing agents in low and high concentration, applied to washing nubuck and nappa washable leathers, yielded a range of different results. The best results for both leather samples were those obtained with a recipe of anionic and nonionic surfactants, improved with a lanoline component. The impact of washing agents with various contents of surfactants and additives was also tested when drying in the open and in a drying machine, comparing spectral values of washed and unwashed samples. Footwear are in general subjected to extreme end-use conditions, while closed space inside them and the lack of ventilation create a good basis for the growth of microorganisms. These microorganisms are in principle responsible for unpleasant smell and can also be a health hazard, especially when chronic diseases are present, such as diabetes [10]. All of these clearly indicate a need for antimicrobial finish of footwear.

3.2. Antimicrobial functionalization

The purpose of antimicrobial treatment is to improve material protective and sanitary properties, protecting the wearer from detrimental impact of the environment, actions of microorganisms included. There are three categories of microorganisms: bacteria, fungi, and algae. Cellulosic fibers are more sensitive to the activity of fungi than protein ones, which are, on their part, more susceptible to the impact of bacteria. Microorganisms play an important part in treatment and processing textile materials and leather, since they, through their life activities, impact favorable or detrimentally onto the production process and the properties of finished materials alike. Natural materials are sensitive to the activities of microorganisms, especially under the conditions of adequate (higher) humidity and heat. As opposed to natural fibers, synthetic ones are, due to their high hydrophobicity, more resistant to the impact of microorganisms [11]. Bacteria are the most important microorganisms in leather making. Bacteria are common on skin and leather alike; they can develop bad odors, which is especially the common case in the area of the feet.

Microorganisms on natural leather can cause rot and putrefaction, fermentation, or generate pigments, glitter, and various stains. Higher concentration of microorganisms on textiles look like dirt causes bad odor, discoloration, reduced strength, all of which, generally and in higher or lower extent reduces product use value. The other aspect of possible impact of microorganisms includes causing irritations, allergies, and contamination of the wearer or the people who manipulate contaminated textiles or leather [12]. This is why materials are treated antimicrobially, with the aim to control and prevent the development and reproduction of microorganisms. In this way, contagious diseases are prevented, and the incidence of allergic reactions and respiratory problems is reduced. At the same time, material degradation in the form of discoloration, dirty smears, and unpleasant smells is also prevented [13].

3.2.1. Antimicrobial agents used to treat materials in footwear industry

The conditions of use are quite demanding on footwear as it is in permanent contact with the foot for a prolonged time and functions in an environment with poor ventilation. Such conditions favor the development of microorganisms and bad odors from the feet and can result in the degradation of some parts of the footwear (lining, insoles). A scientific approach to functionalization of the leather to be used in footwear manufacture is of key importance in the research field of changes on footwear and feet under the conditions favorable for the development of microflora. Antimicrobial protection treatment for leather is done in the course of final operations through retanning processes and treatment of tanned leather grain. Important investigations have also been done with the usage of antimicrobial chitosan-based polymer. Chitosan is a hydrophilic polysaccharide obtained from the chitin shells of some insects and crabs. It is efficient for both gram-positive and gram-negative bacteria as well as for fungi. It should be noted that antimicrobial coating for leather should be economically and environmentally acceptable [14].

The development of antimicrobial coatings for leather components of footwear favors chitosan-based products, as it possesses the ability to build a film on the leather, having in mind peculiarities of particular tanning procedures and various methods of finishing leather grain [14]. Investigation of antimicrobial potential on the surfaces has also been done using photoactive products, such as benzophene and rose bengal, and the results have been proved to be excellent as antibacterial impact is concerned [15]. The investigations mentioned also include characterization and antimicrobial properties of leather coatings based on colloidal nano-silver as well as the assessment of antimicrobial effect on the footwear leathers treated with nanocomposites [16, 17]. Of considerable importance are also the investigations that favor synergistic effects of various antimicrobial products as an efficient way of solving the problem of antimicrobial protection [18].

The review of the investigation conducted by the Spanish institute INESCOP, dealing with antimicrobial agents for footwear, and the properties of various microcapsules with controlled release are described [18]. The investigation concerned with mechanical and waterproofing properties of the films from gelatinous casein modified with microbial transglutaminase (MTG). Furthermore, the assessment of the properties of the compounds of modified films and PU components in leather finishing coatings and the impact of MTG on improved mechanical properties of the leather treated (tensile strength and elongation at break) were also investigated [19].

The complexity of the problem of antimicrobial protection in footwear initiated the need to investigate the antimicrobial properties of lining and insole footwear leathers tanned in different ways, so as to compare the results obtained and to develop the field further. These investigations resulted in the international standard EN ISO 16187:2013 footwear and footwear parts – methods of testing to evaluate antimicrobial effects [20]. The standard lists the quantitative methods for testing antibacterial effects of the footwear and its component parts and is used for all types of footwear and their component parts [21].

3.2.2. Procedures of applying antimicrobial agents

The procedure of microencapsulation has a considerable potential in introducing new, smart functionalities, with no impact on material appearance, in a wide range of applications, especially for controlled release and improvement in the resistance to outer factors [22]. In the case of footwear industry, microencapsulation is still a technique to be developed. However, it could contribute to higher level of innovations in the field of treating various materials used in footwear manufacture. This could be, for example, achieved by incorporating various products with therapeutical and/or antimicrobial properties, such as essential oils, which could provide constant care for the feet, as well as a new approach to traditional footwear [18]. In addition, oils are generally used for their antimicrobial, antifungal, moisturizing, regenerative, and aromatic properties in the care of feet [2].

Microcapsules are easy to apply to textiles in the form of a solution, dispersion, or emulsion, by impregnating, coating, or spraying. All of these procedures require a binder, which can be acrylic, PU, silicon, starch, or something else. Its task is to bind or fix the microcapsules onto the material so that they remain fixed during wearing or washing/care. Microcapsules can be easily applied to cotton, silk, synthetic, and other fibers, and provided the envelope material is properly selected, they are not harmful for the wearer. The other method is to implant microcapsules into the fibers. It has some advantages: microcapsule implantation is permanent, fibers retain their properties, fibers are multifunctional, and agents can be added in the processes of spinning, weaving, or dyeing [23].

Numerous attempts have been made to apply scents directly onto fibers, textiles, and leather. The most frequent disadvantage has been the disappearance of the scent already after the first washing cycle or after a short period of use. Microencapsulation offered a more durable presence of the scent. Microcapsules can contain various essential oils, such as lavender, rosemary, pine, and others. Textiles with the application of such scents are used in aromatherapy to ease some minor problems, such as insomnia and headache, or to eliminate unpleasant odors [23].

The combination of microcapsules and coatings in footwear industry, performed during the processes of raw hide treatment, on treated leather or on footwear parts already cut, offers the possibility of introducing innovative properties, which most often cannot be achieved employing other existing technologies. Contemporary trend of using natural polymers as an alternative to synthetic ones is one of the reasons for conducting numerous investigations of microcapsules with natural and/or biodegradable capsules [2].

Numerous researchers have been involved in developing innovative antimicrobial agents, based on advanced technologies, such as microencapsulation and nanotechnologies. Recent investigations have been aimed at microencapsulating various natural compounds with proved antimicrobial properties, so as to obtain antimicrobial coatings with different properties of release control. Microencapsulation is for this purpose done in two ways – by “in situ” polymerization and by complex coacervation processes, which offers the possibility of using various envelopes/shells of different polymeric materials, both synthetic and semi-synthetic polymers, such as melamine–formaldehyde and gelatine. Natural essential oils of tea tree, lemon, clove, chamomile, and neem oil have been used in antimicrobial treatment by microencapsulation [18]. Synthetic microcapsules are most often used for the materials which are incorporated into the inner parts of the footwear. Special attention should be paid to the part of the footwear where microcapsules are implanted, so as to prevent destroying the footwear too early [2].

3.3. Merging the requirements for footwear design, functionalization, and environmental protection

In designing haute couture footwear, the accent is usually on new and different shapes of footwear, new shapes of soles and heels, new cuts, material combinations and variations, trimmings, and decorations (Figure 1), while functional treatments of the material involved are in most cases taken for granted, as high fashion prefers the usage of high-quality materials that follow most recent technological developments. Such models are made in small and limited quantities, involve

Figure 1. Examples of haute couture footwear: a) Holmes of Norwich 1958, b) John Fluevog 1992, c) Fnsk 2009, and d) Nicholas Kirkwood 2010 [24]

numerous hand operations, which in effect result in extremely high price of the product.

Footwear design in higher- and middle-price class follows the trend and tendencies of haute couture. However, most of the above segments are more moderate and often simpler, due to industrial way of producing them. These products often include top design and high-quality footwear, made of natural leather exclusively, certified materials, and high-quality manufacture as well as numerous special treatments, finishes, and innovations in industrial footwear production. Sometimes, some of these functional treatments are recognizable in the market and constitute even a logo or trade mark of the brand. This group includes many of more or less well-known footwear manufacturers and renowned global brands.

The success of the Italian footwear producer Geox on global market is based on excellent product design and a number of functional innovations, the most revolutionary and well known among them being the patent-protected system for ventilation with waterproof rubber sole (*Geoxbreathes*®), often advertised as "breathing shoes" (Figure 2). The long-term development concept and systematic investigations of innovative ideas and notions, many of which concern new materials, production processes, equipment, and machines, have resulted in the protected Geox technology, with over 60 different patents register in Italy and globally [20, 25].

Vapor-permeable footwear with waterproof (Figure 3c) is the new generation of innovative and patent-protected waterproof technology, protecting from rain, mud, and snow and simultaneously increasing permeability by natural thermoregulation. The notion of vapor-permeable footwear with waterproof and vapor-permeable sole includes the bonded assembly of uppers and sole, containing a segment made of waterproof material and a layer permeable to water vapor, or waterproof and vapor-permeable membranes, which cover the area toward the inner part of the footwear. The footwear contains at least one waterproof and vapor-permeable protective barrier, situated at the inner part of the shoe on the membrane, covering it at least partially. Protective barrier and the membrane are sealed in a watertight manner onto the body of the sole at least at one sealing zone [27]. The technology has been applied to a wide range of products and covers a broad spectrum of styles and solutions for formal, *casual*, and active purposes.

Meeting increasingly stringent requirements of environmental protection in leather-making industry includes advocating products made of leather with lower environmental impact. It is thus necessary to monitor the impact of products and manufacturing on the depletion of natural resources as well as on the emissions into water, air, and ground. For example, the manufacture of washable leather, despite chrome tanning applied, has been made more environmentally acceptable by considerable reduction in the amount of chrome in finished leather, waste water, and residual waste. This can be done by measures taken within the technological process and using technologies that introduce new and environment-friendly materials, together with recycling tanning solutions. Maximum level of bath exhaustion in retanning, dyeing, and fatliquoring also contributes to lower pollution by interventions within the technological process.

Numerous footwear manufacturers follow contemporary development trends and meet requirements in all the segments of footwear industry, which makes them competitive on the global and European markets. The footwear is made of certified materials only, produced in the environment-friendly manner, with no harmful matter or compounds, while the manufacturing processes use only water-based glues. Such companies also possess the certificate ISO 14001, for the system of managing environmental protection.

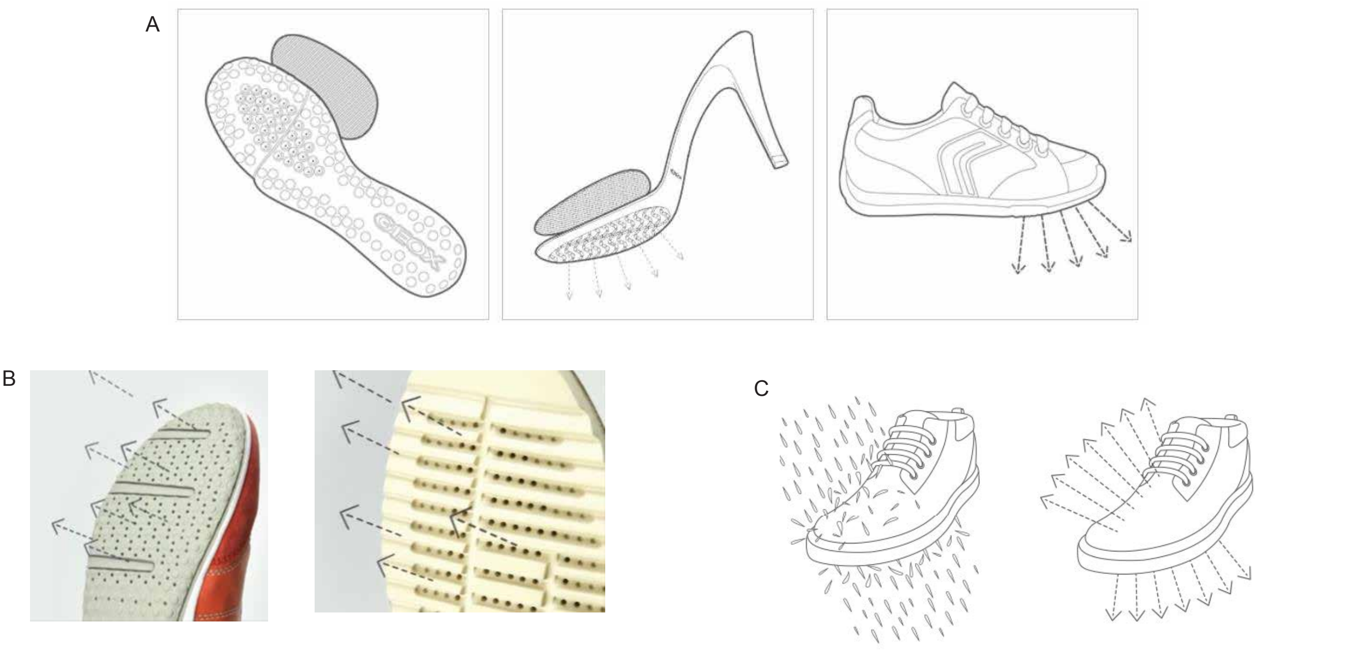

Figure 2. a) Illustration of *Geoxbreathes*® efekta; b) and c) advertising samples of Geox footwear with their functionalities specially presented [26]

There is a trend among footwear manufacturers to address eco-labels on their products directly to end users, who is then in the position to actively participate in environmental protection and advocating sustainable manufacture and consumption by selecting such a product. Eco-labels are voluntary instruments of protecting the environment showing a contribution of a product to one or more aspects of environmental protection. Branding eco-designed footwear is increasingly the present manner of improving competitiveness, as it offers a broader contribution to the society in general by introducing the concept of sustainable development into the traditional sector of textiles/leather/footwear, and its popularization in the market and the development of innovative solutions.

According to the EC decision 2016/1349 on establishing environmental measures for granting the EU environmental label for footwear, products that contribute to the environmental dimension of sustainable development throughout their whole life cycle are promoted, products that are durable and in which hazardous materials are present in very limited amounts. Footwear durability is an important aspect in reducing waste from the industry, while the Measure-7 Parameters that increase the durability in the abovementioned decision, is an important measure to establish whether a product is environmentally friendly or not [28].

3.4. Novelties in the field of functional eco-materials and technologies

Scientists and multidisciplinary designers have created a conceptual prototype Amoeba *tennis shoes* (Figure 3) in the laboratory of Shamees Aden in London. The aim is to investigate the future of new materials obtained from protocells. *Protocells* are chemical cocktails mixed from basic inanimate molecules under laboratory conditions and combined to create matter that exhibits some of the characteristics of living cells, e.g., the ability to metabolize food, to move, and to propagate. These investigations have initiated a series of discussions on social and ethical implications of these new technologies for the future of design [29].

A new method of designing leather products employs basic postulates of the infrared design theory. The design of leather face/grain for the manufacture of shoes, purses, and belts is approached with predetermined double design. One design is visible through the eyes of the viewer in the daylight, and the other in near-infrared spectrum. The application of this duality on leather involves familiarity and control of specific properties of various types of leather materials. In this way, leather products can be branded, designed, individualized, and protected in a completely new way [31, 31].

Apart from defining complete individuality, or uniqueness, of leather products, the duality method developed raises the level of brand protection for these products to new heights. The combination of para-visible and invisible offers completely new marketing possibilities for each leather product [32].

The application of the research described and IRD technology on leather and leather products is shown in Figure 4.

Additive technologies, with the three-dimensional (3D) printing included, have become increasingly popular in various branches not only of industry, but also in fine arts, culture in general and elsewhere. There is almost no area of everyday life where additive technologies are not present. Positive examples of 3D printing and design of garment and footwear parts include the manufacture of wearable fashion prototypes using low-budget 3D printers [33], production of anatomic inserts for footwear which involve functionalization of anatomic materials, and building-in inner structure into the base of the insert, which all influences absorption properties of the footwear in case of an impact [34], manufacture of footwear using 3D CAD models and 3D printing [35], or extravagant examples of footwear, hybrid fusion of traditional footwear, and 3D print technology [36].

Industrial designers at the Massachusetts Institute of Technology, Christophe Guberan, and Carlo Clopath, developed by the end of 2015, in collaboration with computer scientist Skylar Tibbits, also at the MIT, a project of 3D printed recreational footwear, which changed the shape reacting to the impulses from the wearer (Figure 5) [36]. After printing a precise two-dimensional (2D) sample from the material of various layer thicknesses and properties onto a stretched piece of textile, the shape of the footwear can be independently reshaped into preprogrammed forms. This program is exclusively innovative and scientifically valid also by the fact that no robotics or sensors are used in it,

A

B

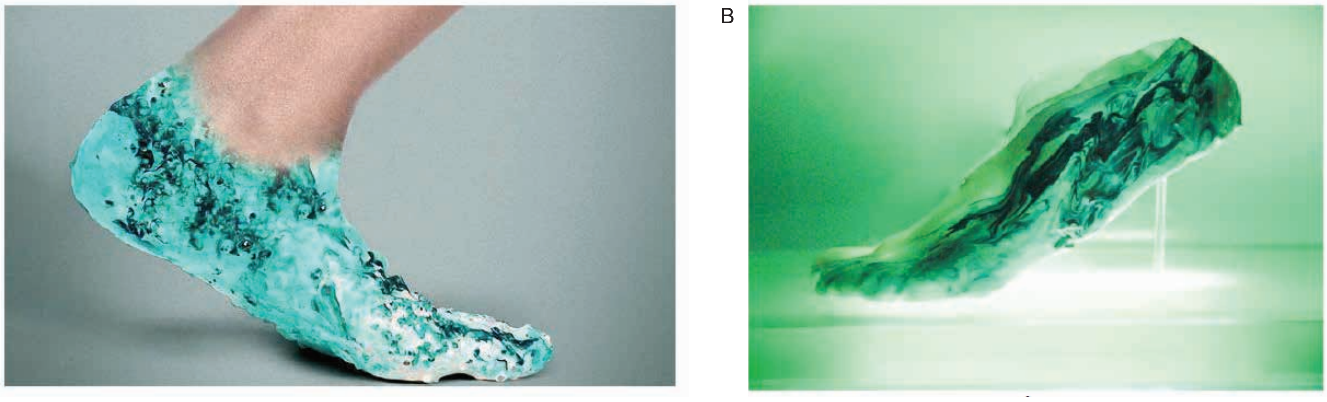

Figure 3. a, b) Shamees Aden Amoeba prototype of tennis shoes [30]

Figure 4. Application of infrared design method on footwear design: a) low boots made of goat nappa leather designed by a mosaic, visible by the viewer at daylight; b) the same boots in near-infrared spectrum [32]

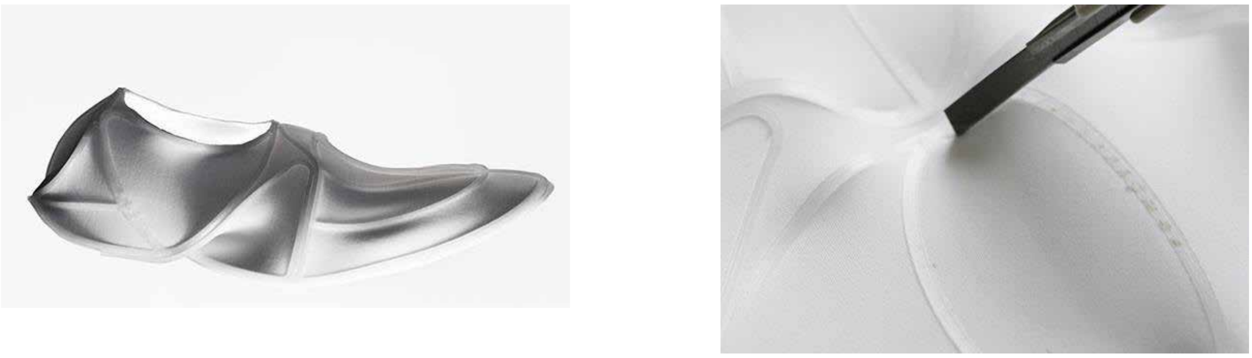

Figure 5. MIT designers: 3D print wearer-reactive footwear [36] 3D, three-dimensional

which proves that the so-called advanced technologies are not necessary components for interactive footwear.

4. CONCLUSIONS

Contemporary footwear industry has developed and progressed considerably in chemical technology, but also in the other accompanying technologies, and has become highly demanding regarding investigations and innovations. The market puts high criteria of multifunctional products of top design, higher quality, and better end-use properties. Numerous new technologies have been developed for functional treatments, depending upon the raw material used, or the material that is supposed to get some new properties. There is, at the moment, high interest in producing environmentally friendly functionalization materials, and the last decade has seen a number of natural antimicrobial products, such as sucitral, nerol, citronellol, linalool, geraniol, limonene, oregano, thyme, and others. Antimicrobial treatment by microencapsulation in footwear industry is a technique under development. However, it could contribute to the high level of innovation of various treatments and has a considerable impact in introducing new and smart functionalities, with no impact on the appearance of the material. Besides physicochemical methods of raw hide treatment, mechanical operations are also important, as they offer achieving targeted properties and acceptable outer appearance of natural leather. Haute couture footwear design is usually aimed at new footwear shapes, new forms and shapes of soles and heels, new cuts, combinations and variations of the materials used, haberdashery items, and accessories, while functional treatments of the material are taken for granted. The footwear design for the articles in higher- and medium-price class follows the trends and tendencies of haute couture, with everything a little bit more modest and simple, which usually presumes top design and high quality of the footwear, generally of natural leather exclusively, with other materials of certified quality, high quality of manufacture, including at the same time numerous special treatments, finishes, and innovations in industrial footwear production.

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