Thermoregulating and Hydrating Microcapsules: Contributions of Textile Technology in the Design of Wearable Products for Wheelchair Dependents

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Abstract. In this essay we present a number of functionalization methods for textiles through the use of microcapsules. For this purpose, the text explores the contributions of textile technology and reports on ways to obtain the functionalization of active components in textiles, as well as the possibilities of using encapsulation in everyday life. We also discuss the ways in which the microcapsules can be applied to fabrics and examine the durability of the properties with the everyday use. For a better understanding of the durability question, it is presented a research developed by the Minho University in 2011, which exposes the losses and damages of the microcapsules caused by daily maintenance. Though the possibilities of functionalization using this technique are manifold, in this essay we focus on the disabled body, specifically vis-à-vis wheelchair dependents who actively participate in the labor market, on account of the consequences that arise from remaining in the same position for hours. Thus, we present thermoregulating microcapsules that control the temperature of the skin, and moisturizing microcapsules that maintain the skin appropriately moisturized, with an aim to prevent pressure ulcers caused by excessive heat and friction. Through the use of microcapsules applied to the structure of textiles, we aim to provide greater comfort to the body of the wheelchair dependent, enabling the maintenance of adequate skin temperature and moisture levels, and thus preventing lesions caused by the lack of body movement.

Keywords: Product design · Textile technology · Thermoregulating and moisturizing microcapsules · Wheelchair dependents · Pressure ulcers

1 Introduction

Textile technology extends throughout different fields of activity, such as engineering, medicine and design, and provides a significant contribution for the performance of daily activities, seeing that the distinct procedures have potentiated the various uses and specificities of the products. The textile surface alters its characteristics after one or a

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few functionalizations are applied onto the fabric. According to Sánchez [1], the procedures for producing smart textiles center on microencapsulation, electronic and nanotechnology-based technologies. Each process adds qualities to the textiles and expands the possibilities for the user. This essay focuses on the use of microcapsules, and how this process can bring functional benefits to clothing and positively impact on the daily activities of physically disabled people, specifically vis-à-vis wheel-chair dependents.

"The word "disabled", when applied to people who suffer physical, sensorial or mental limitations, is the opposite in meaning to "able", and this very conception explains the difficulty of adapting built space, from housing to work environments, to the needs of the users with particular limitations and difficulties. Thus, many disabled people become incapable of performing everyday tasks, from the maintenance of their personal hygiene to their ability to work and engage in leisure activities, a situation that can result in the social exclusion of these people" [2].

The group of wheelchair dependents taken as a basis for this research relates particularly to those who actively participate in the labor market, seeing as we aim to analyze particular situations in which the disabled individual must remain in the same position for hours, resulting in the formation of skin lesions, also known as pressure ulcers. In this way, the focus of the present essay lies in the use of textile technology for optimizing the level of comfort of the wheelchair user's body. For this purpose, we must highlight the challenges faced by these individuals in performing their daily activities, and subsequently underscore the ways in which technology can exploit the potential of the design of textile surfaces, and consequently reinvent the functionalities of clothing.

"Between the people with physical disabilities and non-disabled people, there are evident differences in the living states. […] people with limb disabilities have special needs for the aesthetic and functional structures of clothing, distinct from non-disabled people, and consequently their garments have specific design requirements" [3].

It is important to emphasize that the principles of exclusion of disabled persons from life in society inevitably influenced all peoples who were exposed to Greek culture, including Western society. For these peoples, physical beauty was often associated to character, which in turn rendered disabled individuals into objects of pity, who were the result of divine punishment, or else became a source of amusement for the majority of citizens, regarded by society as "normal" [4].

These individuals need special care to protect their skin from injuries caused by poor mobility, seeing that when the body remains in the same position for hours, it tends to heat up and sweat, forming lesions that can quickly be aggravated, compromising the individual's health. Hence, daily care is needed to provide comfort and well-being to the individual, including skin hydration, and which also meets their physiological needs.

The use of microcapsules can both enhance the qualities of textile surfaces. The applications produce long-lasting fragrances embedded in the textiles, or add insect repelling, sun protective and moisturizing functionalities. Moreover, it is possible to alter the color of the textile material according to the light intensity, and even regulate the user's skin temperature in relation to the outside environment, allowing the body to cool down when the physical surroundings are excessively hot, or warming up the body when the environment is very cold, which is made possible by way of thermoregulating capsules. These possibilities unlock the potential of a fabric and its function, enhance the quality of the material, and also improve the user's protection.

In what refers to body comfort based on physiological needs, it is also worth highlighting the use of microcapsules in clothing to facilitate a healthy rate of body transpiration, preventing or reducing the formation of body odor, and reducing discomfort caused by the accumulation of sweat and moisture in clothing.

These benefits can be applied to different textile materials, such as fabrics made of 100% cotton or even synthetic fibers, and thus the textile structure must be tested, as each type of fabric presents specifications and variations related to the level of absorption and to the deterioration or degradation of the functional components.

Seeing that the research study in question aims to contribute to the level of comfort and skin protection of disabled people, the microcapsules should, ideally, be applied to 100% cotton fabric, on account of its textile qualities: comfort, softness, durability and low cost, besides the material's great capacity for absorbing sweat [5].

There are numerous ways to achieve the functionalization of textiles through the use of microcapsules, and this technology is being tested and applied in different manners on a daily basis. Among the different segments that apply microcapsules, we can highlight its use in carbon paper, liquid crystal, adhesives, cosmetic products, insecticides, medical drugs and other medical uses, in food and in the textile industry [6–8].

In addition to bringing thermal and skin comfort to wheelchair users, it is also important to address the durability of these microcapsules, seeing as often the data relating to this factor are not explicit and confound the user with regard to the lifespan of the active components in the fabric.

For this purpose, this essay dwells on research developed by Cruz et al. [9], at Universidade do Minho, in Portugal, where durability tests are performed on the microcapsules, also demonstrating their behavior after being washed in domestic washing machines. Based on this study, we can observe the amount of microcapsules lost in every wash, which opens up new possibilities for the reapplication of the product, with a view to greater durability of the fabric with the active components.

The text emphasizes the importance of textile technology in the everyday life of the wheelchair dependent, and evidences the contribution and improvement of the use of encapsulation for moisturizing the skin during the performance of professional activities. It is also worth highlighting the need for improvement of the durability of the active components in the fabric, with an aim to increasing the number of washes without losing the article's required properties.

2 The Everyday Needs of Wheelchair Dependents Who Actively Participate in the Labor Market

The contributions afforded by microcapsules applied to textile articles are countless, as they enhance the functionality of the garment, fulfilling pre-established needs like the durability of the active components incorporated to the textile surface. The microcapsules break open according to the use of the clothing, and as a result of stimuli such as heat and light irradiation. Such properties reveal themselves as extremely useful for people with physical impairments, in light of the challenge of maintaining their skin appropriately moisturized.

There are also microcapsules that do not break open, but rather maintain the active components inside the shell, and alter their actual forms to provide comfort to the user in different situations, as for example thermoregulating capsules that regulate skin temperature. However, after successive washes, these microcapsules are eliminated from the fabric, and consequently must be reapplied, if necessary.

This type of thermoregulating microcapsule is extremely important when it comes to wheelchair users' clothing, particularly in garments worn from the waist down, seeing that these are often areas of the body with little or no sensibility in the case of wheelchair dependents. The active thermoregulator material controls the skin temperature, which provides both thermal comfort and the prevention of pressure ulcers caused by excess heat.

The application of active thermoregulating components in microcapsules eliminates the need for daily reapplication of the product, respecting the difficulties and limitations faced by people with physical disabilities, and thus facilitates the use of the actual wearable product.

Data obtained from the National Health Survey, conducted by the Brazilian Institute of Geography and Statistics - IBGE (2015), among a Brazilian population of 200.6 million people, reveal that 6.2% of people had at least one of the four impairments: intellectual, physical, hearing and visual. In Brazil, 0.8% or 1.6 million people live with intellectual disabilities, while 1.3%, or 2.6 million cope with physical disabilities. Hearing impairments, in turn, represents 1.1%, or 2.2 million people and visual impairments represents 3.6% or 7.2 million people [2].

This scenario demonstrates the relevance of this research in identifying, to start with, the contributions provided by textile technology for the everyday lives of these users, and also in discussing the possibilities of improvement in the development of products aimed at people with physical disabilities, with a view to ensuring their comfort, well-being, health and autonomy for performing their daily activities. The creation of products directed at disabled users requires an in-depth understanding of their needs and the difficulties faced on a daily basis. In Brazil, for example, there are no laws to differentiate the number of working hours of a wheelchair dependent and those of a person without a disability, where the number of hours generally varies from 6 to 10 consecutive hours. The 6-h working days includes a 15-min break, and the 10-h working day includes a 2-h interval for lunch or dinner.

In order to fulfill this number of hours of work, the wheelchair user must remain in the same position for long hours. The body heats up and transpires, besides having to cope with friction caused by small movements of the body against the chair. These characteristics induce the formation of skin lesions, also known as pressure ulcers.

To prevent these ulcers, the wheelchair dependent needs to change positions often, moisturize their skin a number of times a day, or even control their body temperature. These are some of the difficulties faced by the wheelchair user at the workplace, which evidences the relevance of textile technology-based solutions.

Among the different types of disabilities, people with physical impairments suffer more from pressure ulcers. The main cause for the formation of these lesions is the inadequate supply of blood and nutrients in a particular part of the body, due to external pressure exerted by an object against bony or cartilaginous prominences. Humidity and friction further aggravate the condition, as the sores appear in parts of the body that support its weight. For this reason, wheelchair dependents are more susceptible to developing pressure ulcers in the ischial region, which supports the weight of the body when a person is in a sitting position [10].

The first stage of development of pressure ulcers consists in a mild skin alteration, normally indicated by the appearance of a red spot on fair skin and a bluish or purple one on darker-colored skin. As the change is not abrupt, it frequently passes unnoticed, but there are other properties that indicate that they are pressure sores: the temperature of the skin being either hotter or colder; the skin's consistency or texture, which can be either firmer and thicker or lighter and softer; and for those with more sensitive skin, there can be physical pain or itching [11].

The second stage involves a decrease of the skin thickness (epidermis and/or dermis). The ulcer presents itself as a blister or small wound on the skin, though still superficial. The third stage is characterized by a significant loss of skin thickness with damage or necrosis of the subcutaneous tissue, almost reaching the underlying fascia. In the fourth stage, the tissue is extensively destroyed, presenting necrosis and even muscular and bone lesions, with or without loss of the whole thickness of the skin. In case the ulcer is not identified from the outset, it can evolve rapidly to the next stages, wherein the later stages are more difficult to treat.

The image below shows the depth of pressure ulcers in each of the four stages (Fig. 1):

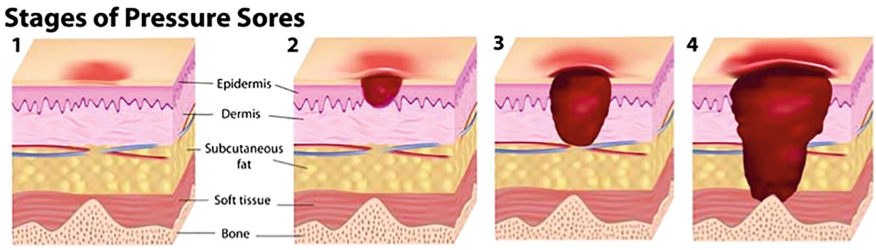

Fig. 1. Stages of pressure ulcer development (Source: https://mangarhealth.com/uk/news/new-mangar-health-websites-launched/)

In other words, with the use of these microcapsules, the microclimate between the seat surface and the user's body reaches an equilibrium state and ceases the production of sweat resulting from excessive heat, also preventing localized damage to the skin.

This functionalization provides greater thermal comfort for wheelchair dependents. At present, microcapsules are integrated into acrylic fibers and polyurethane foam, and used in various textile-related applications, such as ski garments, gloves, socks, nightwear, shoes, protection equipment, medical textile products, among others [11].

Another form of combating pressure ulcers is skin moisturizing, which minimizes lesions caused by friction between the skin and the wheelchair.

From this, we can infer that the concomitant application of microencapsulation of moisturizers and thermoregulation components can significantly prevent skin lesions in wheelchair users.

3 Possibilities for the Use of Microcapsules

Since the 1970s, author Papanek [12] has made appeals for designers to stop working within a culture of consumerism and superficiality, and start developing research projects that cater to the needs of all kinds of people, regardless of their social and economic circumstances.

In this sense, the range of different applications of textile technology point to important directions for future research in design. In the case of microcapsules, or active finishes, as they are known in the textile industry, offer many possibilities: scented lingerie, odor-absorbing kitchen aprons, pajamas that glow in the dark, t-shirts with antimicrobial compounds or ultraviolet protection, among other active finishes [13].

Microencapsulation consists in a technology of microparticles in the form of protective shells, whose casing material can be polymeric ceramic or gelatin, which enclose active ingredients. The active components can be solid, liquid or gaseous. This technology is mainly used for protection purposes and for controlled release of substances (that is, the product in the core can be gradually released as the product is being used).

The use of microcapsules as aimed at positively contributing to an individual's health, well-being and comfort, and also to their perception of the product when in contact with their body. The possibilities of functionalizations are manifold, and include: protecting the encapsulated product's instability, when dealing with a material that is sensitive to the outside environment; improving the encapsulated substance's capacity (namely, improve solubility, dispersion ability and fluidity); improving the lifespan of the encapsulated components, in such as way as to prevent degradation-based reactions (dehydration, oxidation); controlling the release time of the encapsulated substance; enabling the convenient and safe manipulation of encapsulated toxic materials; masking odors and tastes; immobilizing enzymes and microorganisms; controlling drug release and the manipulation of encapsulated liquids and solids; releasing the encapsulated components in a predictable manner; and ensuring thermal comfort [8].

Microcapsules are micron-sized capsules (>1 μm), generally ranging in diameter from 1 μm to 1000 μm. Particles smaller than 1 μm are called nanoparticles, and when larger than 1000 μm are called microgranules or microcapsules [14].

Microcapsules can have a spherical or irregular shape, and are composed of two parts: the core and the shell. The inner part is the core, which can be an active ingredient or contain one, and can be permanent or temporary. The outer shell, in its turn, protects the core. The image below represents the structure of a microcapsule, its outer shell and the active components contained in the core [15].

Microencapsulation has been know in the United States since 1968, when it was applied to a self-copying paper without the use of carbon for use in multiple-page commercial forms. Later on, in 1980, researches studies advanced, leading to the development of perfume-containing microcapsules. Regarded as the true form "olfactory communication," they were extensively explored in the advertising of perfumes, soaps, fabric softeners and detergents. In its turn, microencapsulation applied to textiles dates from early 1990 [1] (Fig. 2).

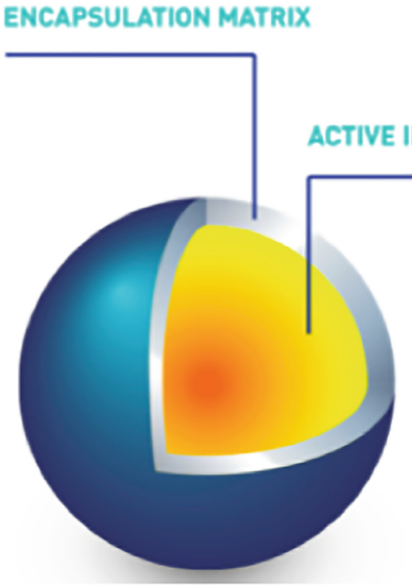

Fig. 2. Structure of a microcapsule (Source: https://capsularis.com/microencapsulation/?lang=en)

Even though they so small that they cannot be seen by the naked eye, microcapsules are able to cover a relatively large application area, and allow a relatively uniform and adequate liberation of the active components. By examining the contributions and possibilities of microencapsulation listed up to this point, we can conclude that the main objective of microencapsulation is to guarantee that the encapsulated material reaches the area of action without being adversely affected by the outside environment.

The encapsulated active components can be released by the rupture of the membrane; by slow and progressive dissolution of the polymer of the membrane; by friction; or biodegradation [1]; temperature-related degradation; pH-related acidity and alkalinity; solubility of the release medium, that is, rupture can occur through mechanical pressure or by friction [16]. It is important to highlight that the release mechanism of each type of microcapsule depends on the composition of the capsule shell material and its thickness. The shell protects the active components in the core, and influences the way in which the microcapsules will be broken. However, the ultimate purpose and benefits derived from their use are determined by the active components.

Microcapsules that do not break are developed with more resistant shells, with a view to embed themselves in the fabric for longer, thus achieving certain types of functionalization in ways where the active component does not leave the microcapsule. As an example, thermoregulating agents remain embedded the fabric, keeping the body warm when it loses body heat, or providing a cooling effect as the body heats up.

Microcapsules are used in the textile industry with the purpose of making people's daily lives easier and/or provide body comfort to individuals, in such a way as to respect their physical and physiological needs.

According to Cheng et al. [17], many researches have centered on the materials, the identification methods and the release of the active agents. However, those that focus of the performance of the active properties are often overlooked. In other words, studies to evaluate the application, durability and the finishes of fabrics with effectively embedded microcapsules.

This negligence results in microcapsules with "low encapsulation capacity and lack of mechanical stability". In other words, initially the product may eventually achieve a satisfactory degree of impregnation of the encapsulated substance, but the dynamics of its liberation becomes compromised due to the absence of mechanical stability, which adversely affects its performance and the delivery of its objectives [8]. This in turn impacts directly on the product's durability, as it arrives in the market with programmed obsolescence. However, the duration time of the substance's functionality is not explicit to the user.

Some manufacturers frequently make the information about the product and its functionalities available on the labels of the items of clothing, or present it through advertisement, as is the case with swimwear with sun protection. Nonetheless, they rarely clarify that this functionality is temporary, that is, its durability is linked to the number of washes. As these functionalities are achieved through the application of microcapsules, part of them are lost as the items of clothing are washed, and over time the remaining microcapsules tend to lose its properties and features.

From this perspective, the next section a durability test for thermoregulating microcapsules, applied to plain knit fabric (also known as jersey knit). By collecting microscopic samples, we aim to evidence the behavior of the microcapsules as a wearable product is used.

4 Durability of the Thermoregulating Effect Applied to the Fabric

The investigation and experiments conducted at the Textile Science and Technology Center at the Universidade do Minho, in Portugal, by Cruz et al. [9], together with Irmãos Araújo Ltd. [Araújo Brother's Ltd.], also from Portugal, include tests for durability and longevity of the thermoregulating microcapsules applied to jersey knit fabric. These microcapsules cater to the need of providing greater comfort to the user, based on their ability to absorb, store or release of heat energy depending on environmental and metabolic conditions.

This research is relevant for our investigation as the content addresses the durability of thermoregulating microcapsules, a feature of encapsulation that can greatly benefit wheelchair users. As referred to previously, the use of thermoregulation material contributes to the comfort of users in various different situations, especially to the body of people with physical disabilities that lead to poor mobility, such as wheelchair dependents. The wheelchair user often does not realize that a moderate degree of discomfort can lead to and even aggravate pressure ulcers.

Phase Change Materials (PCM) microcapsules are typically coated with a polymer membrane, generally polyurethane foam, containing paraffin liquid as a core component with phase change properties that are sensitive to small differences in temperature [9].

The durability test proposed by Cruz et al. [9] utilizes a 100% cotton jersey knit fabric, dyed with a reactive dye with medium reactivity and sustainability. After the dyeing process, the knit fabric is finalized with a thermoregulating finishing composed of PCM microcapsules. The finish is applied by impregnation in the process of bath exhaustion in industrial washing machines.

The impregnation method started being used in 1999, and is currently employed in the application of products like fragrances, vitamins, moisturizing crème and even insect repellant to textiles. Nelson [18] and Rodrigues et al. [19] use the dyeing processes for the impregnation of microcapsules in the fabric. According to Salem [20], normally the dyeing is carried out in an aqueous bath in either continuous or exhaustion processes.

In the case of continuous dyeing process, the impregnation bath remains stationary while the textile substrate is fed continuously through the padding bath. Next, the fabric is mechanically compressed and fixed by dry heat or vapor, or by prolonged repose. In the exhaustion process, in turn, the dye is displaced from the bath to the fiber, through direct and continuous contact obtained from the movement of one of them, or both [20].

Once the fabric is ready, the durability test is carried out. Twenty washes are performed at a temperature of 40º, and a drying cycle of approximately one hour, using domestic detergent. After every five washes, the durability of the finishing is evaluated using a high-resolution scanning electron microscope, equipped with field emission and integrated X-ray microanalysis system. For this purpose, 1 cm^2 samples are used [15].

Within this context, the distribution and behavior of the PCM microcapsules are evaluated according to the number of washes. The microscopic images below show the textile fibers at a magnification of 1000x, whereby it is possible to verify that after the fifth wash a significant reduction in the amount of microcapsules occurs [9].

After the 10^{th} and the 15^{th} wash, this amount is reduced even further, although no deformities were observed in the microcapsules (Fig. 3).

After the 20^{th} wash, the microcapsules become scarce and present deformities. As the microcapsules become damaged, small eruptions on their surface appear. These damages or cracks in the shell walls result in a loss of the capacity for thermoregulation of the particles, since the inner liquid escapes encapsulation [9].

This level of damage can be verified and evaluated when viewed at a magnification of 15 000X. The Fig. 4 below summarizes the process of loss of textile's functionalization, as a result of successive washes.

In other words, with the loss of microcapsules after a number of washes, the thermoregulation potential of the textile is reduced.

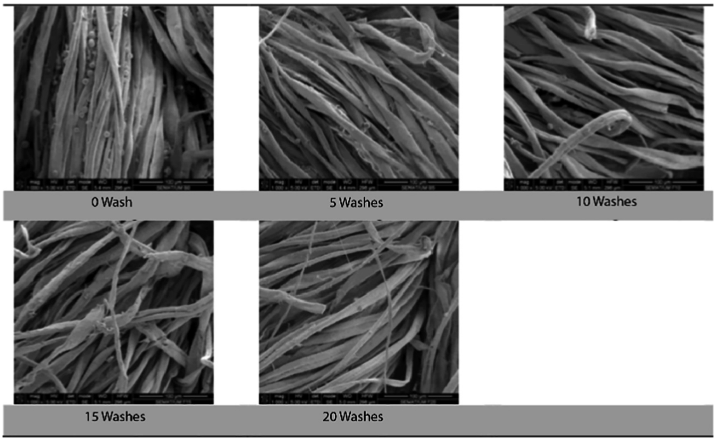

Fig. 3. Microscopic image at a magnification of 1000X. (Source: CRUZ et al. 2011)

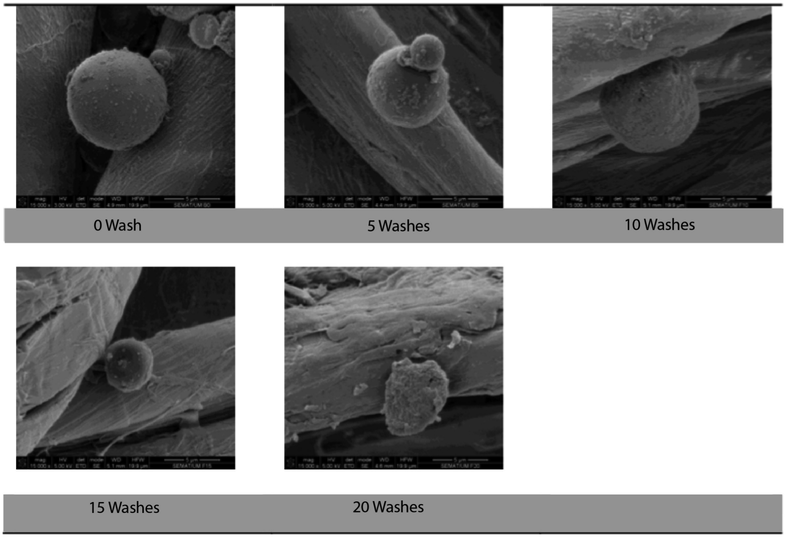

Fig. 4. Microscopic image at a magnification of 15 000X. (Source: CRUZ et al. 2011)

5 Main Discussions and Conclusions of the Study

Based on the data obtained, we have elected three main points for discussion: (1) environmental sustainability; (2) the financial sustainability of the wheelchair user; (3) the extension of longevity of textile surface functionalization. These aspects drive the advancement of the present study, with a view to investigate the contributions of the process of encapsulation of moisturizing and thermoregulating substances, capable of protecting the cutaneous tissue of wheelchair users.

Based on the tests performed by Cruz et al. [9], it is possible to infer that the successive home washes eliminate a large part of the thermoregulating and moisturizing microcapsules that constitute the functionalization of the textile, besides deforming the structure of the remaining microcapsules. This affects the original features of the product, compromising its efficiency, and also drastically reduces its lifespan. As a consequence, within a short period of time the product will be disposed of and the user will have to acquire a new one. In other words, in the case of users with reduced mobility, namely wheelchair dependents, who are the target audience of this study, the durability of the product does not cater to their daily needs for thermoregulation and skin moisturization for an indefinite period. Thus, we become conscious of two significant impacts: (1) on environmental sustainability and (2) on the financial sustainability of the wheelchair dependent, both ascribable to the rapid disposal of the product. As regards the first impact, it is worth emphasizing the constant and lasting negative effects of the textile industry on the environmental and social well-being of the planet. In addition to the serious problems caused by the acceleration of production and disposal of products, we must also account for the high levels of water consumption and for the massive contamination of the atmosphere due to the emission of carbon dioxide [21].

Concerning the second point, when the product loses its properties, its use is not feasible for the wheelchair dependent, since this exposes them to the development of new pressure ulcers. Faced with the impossibility of neglecting the protection of their skin, the user must resort to discarding the product and acquire a new one, thus corroborating to the unsustainable cycle described above.

In both cases, the role of Design/Designer entails a concern for ensuring a sustainable life cycle to the product, directed at extending its lifespan, increasing the possibilities of its reuse, and consequently, minimizing its chances of disposal. And herein lies the responsibility of the present research: identifying, proposing and developing procedures aimed at the extension of longevity of textile functionalization processes, specifically those relating to thermoregulation and moisturizing. In this sense, the possibilities of reapplication of the functionality by the wheelchair user themselves must be investigated. That is, a procedure that takes into account the motor difficulties of this public, and thus, enables the domestic reapplication of the microcapsules with the active components, in a manner that is practical and efficient for the user.

Thus the future developments of the research study point to experiments aimed at enhancing the resistance of shell walls of microcapsules, with a view to preserving their active properties in the textile structure for a longer period of time [22]. Also, assessing the viability of reapplication of these microcapsules by way of spray technology. In addition to these experiments, we must also investigate the use of cotton fibers, which are more adequate for sensitive skin, as the fibers minimize both the natural dehydration of the skin, and the friction between the textile surface and the cutaneous tissue [23].

Finally, from this perspective we must seek ways to collaborate with the sustainable cycle of product design, through processes focused on intelligent use and the consequent extension of a product’s lifespan, the reduction of costs for users, and ultimately minimizing the negative impact on the environment; all of which must be achieved concomitantly to the comfort of wheelchair dependents in their everyday activities.

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