Inclusive Design and Textile Technology in the Everyday Lives of Wheelchair Dependent

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Abstract. This paper discusses the benefits of textile technology to inclusive design, focusing on aspects that prioritize comfort and health for wheelchair dependent individuals. To this end, the focus of this paper is the ergonomics of products designed for the disabled, as well as their conception. It investigates the development of a form of technological processing based on applying microcapsules to textile materials, in addition to exploring its many functionalities and the possibilities for widening its scope of application, particularly relating to the contact of the fabric with the skin. The process reported here deals with people with mobility difficulties, specifically wheelchair dependents, having as its goal the prevention of pressure ulcers. To exemplify these possibilities, the research work carried out by designer Elisa Marangon Beretta is presented, wherein microcapsules of eicosane are applied onto polyurethane foam, used in wheelchair seats, with the purpose of contributing to the comfort and well-being of wheelchair dependents. New possibilities of textile processing are further explored, relating to the use of microencapsulation for offering greater comfort, preventing pressure ulcers and providing better adaptation approaches to increase the ability of physically disabled people to participate in everyday life, and hence improve their general health.

Keywords: Inclusive design · Textile technology · Microencapsulation Wheelchair dependent

1 Introduction

Since the 19th century, with the advent of studies of pathologies in medicine and the social sciences, disabilities became an object of study. Pathology is understood as the field that studies anatomical or physiological deviations that constitute or characterize a given disease. Initially deficiencies were classified according to their pathological features, divided into the following categories: mental, physical and sensory-perceptual, which in turn enabled diagnosis and determined a course of treatment in the medical field. This way, the disable person was seen as an individual that had some form of incapacity or suffered a disadvantage relating to their body [1].

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

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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. It is important to remember that the fundamental principles of exclusion of disabled people from social life were shaped by the influence of the Greek culture, and as a result were ultimately adopted by the peoples of Western society exposed to it. For these people, physical beauty is frequently associated with character, whereas the disabled are frequently seen as subjects to be pitied, who suffer the consequences of a God-sent punishment, or as a form of entertainment for society's 'normal' and accepted citizens [2].

Generally speaking, people with motor deficiencies resent a variety of neurosensory conditions that affect them in terms of mobility, speech or general motor coordination, as result of nerve, neuromuscular and osteoarticular lesions, or even congenital or acquired malformation. Depending on the case, people with difficulty of locomotion can move themselves with the aid of prosthesis, wheelchair or other auxiliary appliances.

The need for an interface for the locomotion of disabled users and which can also aid them in carrying out everyday activities denotes that the products developed to this end must be based on ergonomic concepts. "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 principles of ergonomics prescribe that the product must be adapted to the user's body and not otherwise, seeing that if the product is inadequate the body must modify its posture in an effort to adapt to it, which in turn can lead to varying degrees of discomfort, aches and pains and major health problems. Consequently, it is advisable that the development of such products be based on three elements, responsible for satisfying certain needs of users, such as technical, ergonomic and aesthetic qualities [4].

The precision in human body measurements increases the chances of developing an ergonomic product with increased usability that provides a greater measure of comfort for the user. Measurements must meet anthropometric criteria, wherein a number of techniques are employed in obtaining accurate static and dynamic measurements of the human body. That is to say, they must include both simplified measurements taken of the human body standing up and measurements of detailed parts of the body when sitting, bending down, kneeling, crouching etc., and/or making different types of movements [4].

The body must be the starting point for any and all products developed, from clothing to tools to physical environments. Design projects must also take into account that bodies change over the course of a lifetime and are different according to each age group, and also differ according to race and climate. Finally, different types of disabilities also define specific body characteristics, as considered in this paper.

On this account, the development of products aimed at disabled people should seek to provide physical comfort and well-being and to promote better health, but is also important in improving everyday situations, facilitating personal autonomy in daily life.

In this context, this research examines textile technology and the processing of textiles with the use of microcapsules, focusing on skin protection for disabled individuals who are wheelchair users, thus avoiding the formation of skin injury that can become severely aggravated if untreated. In other words, the relevance of this investigation lies in the application of textile technology in the remit of inclusive design. In this particular case, it centers on contexts that deal with the physical adaptation of individuals with motor disabilities for appropriate everyday wheelchair use. Even though the benefits for wheelchair users are many, due to their wide variety of needs, this research looks specifically at the prevention of pressure ulcers, thus contributing to improving the quality of daily activities for wheelchair users.

This paper takes as a case study a research work on a microencapsulation technique developed in Rio Grande do Sul, Brazil, in 2015, aimed at decreasing the intensity and frequency of the pressure and shearing force between the disabled individual's body and the wheelchair. The research project, carried out by designer Elisa Marangon Beretta, was chosen for its use of technological processing of textiles based on microcapsules, with the aim of decreasing the formation of sores and abrasions on the skin of wheelchair users when in a static position for a considerable length of time.

The case study foregrounds one of the greatest scourges of wheelchair users is remaining in a single position for a long period of time. This situation is aggravated when the wheelchair dependent actively participates in the labor market, as they are often unable to take pauses to the adjust their posture or shift positions in the wheelchair, therefore preventing any single area of skin from being under constant pressure, further exacerbated due to heat from the wheelchair-seating. This condition can result in skin breakdown and even in sores called pressure ulcers. According to a definition provided by Rocha [5], these ulcers consist in "localized areas of ischemia and cellular necrosis that tend to occur due to prolonged compression of soft tissue between a bony prominence and a firm surface".

In this way, the contribution of this paper lies in its analysis of the application of phase change materials encapsulated in textile materials for body temperature control and prevention of pressure ulcers, caused by constant pressure of an area of the skin against the wheelchair due to everyday use of the chair, further worsened by an unfavorable ergonomic condition and lack of thermal comfort.

2 Technology Applied to the Textile Product

Researches aimed at the discovery, development and processing of new technological fabrics are conducted in laboratories that manipulate chemical substances, with applications of physics and investigating technological possibilities of materials and processes. This framework enables the creation of textiles for different uses, namely adaptive, curative, ecological, sportive and also designed for physically disabled people with the objective of improving their well-being and health [6].

Intelligent fabrics were introduced in the early 1990s, strongly influenced by military investigation and wearable technology in general. In this context, it is worth highlighting an interactive garment called the "wearable motherboard", a pioneering project with adaptive and responsive structures such as integrated sensors and communication ability. The piece aimed to rescue soldiers, monitoring their health status in real time [7].

Technology has offered contributions for the better adaptation of clothing to the body. A new type of smart clothing developed by researchers from the University of Bath's Centre for Biomimetics, England, coordinated by Professor Julian Vincent in 2004, employs microtechnology to present thermal comfort for the user. Using principles of biomimetics[1], the piece of clothing comprises a cooling function, thus controlling the ideal temperature of the user's body when the ambient temperature rises, and providing heat retention when the external temperature falls [8].

Ergonomic clothing design projects seek to fulfill an array of different purposes, such as fabrics that protect the body from weather interference or performance fabrics in sportswear that maximize athletic performance, and high-end moisture management fabrics that allow sweat to pass through from the inside out and evaporate, keeping the skin and clothing dry, but preventing rain droplets from penetrating from the outside. Fabric science is frequently incorporated into athlete uniforms, so as to maximize prevent sweat and the actual costume from adversely affecting their performance [9].

Smart textiles are based on researches into different disciplines such as: textile design, technology, chemistry, physics, material science, engineering, biochemistry, computer science and technology.

These textiles are possible due to the following three developments: the first relates to the introduction of new types of mechanically and electrically high-performing textile fibers and structures, specifically conductive materials. Secondly, the miniaturization of electronics that enables the integration of electronics into textile structures and into various products. The third one refers to the capability of making technology be used and worn while and also being interconnected with other devices, such as computers and mobile phones. "In addition, there are experimental textiles that do not arise from the influence of existing textiles, but from references obtained in different areas, such as the architecture, arts, contemporary culture, such as the nature itself. In an emerging era of biotechnology, nature is not only being copied by biological imitation (biomimetics), nor just being exploited in the development of bioactive materials, but mostly collaborating with the emergence of other 'natural' versions through textile engineering" [10].

The developments of products that apply intelligent textiles generally stem from a concern with providing users with elements of protection, wellness and optimization of comfort, as well as easy care, durability, and resistance to washing and wind. Developments are also taking place in researches and projects that seek to heighten and sharpen our senses, as is the case of the Co-Evolving Smart Textile project, by the Brazilian

[1] According to Bar-Cohen [17] and Allen [18], biomimetics consists in the development of novel technologies through the distillation of principles from the study of biological systems. Biomimetic technologies arise from a flow of ideas from the biological sciences into engineering, benefiting from the millions of years of design effort performed by natural selection in living systems.

researchers Rachel Zuanon and Geraldo Lima. In this research work, "(…) the textile acts as an interface, through which the individual interacts with the surrounding environment and stimulates its sensory device in different ways, in a dialogical relationship with numerous references capable of association and recognition by this body. In this mediation, co-evolving smart textile appears as a possibility to simultaneously promote and expand the scope of sensations to the human body and, thus, provide the differentiated management of body-environment communication [10].

The project conceived by designer Elisa Marangon Beretta employs textile technology to a technique of microencapsulation applied to the fabric used in wheelchair seating so as to create a low-friction interface, and avoid skin injury problems, a common problem for wheelchair users due to prolonged pressure and shear forces that contribute to the formation of pressure ulcers.

Recent 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, 6.2% of people over the age of 18 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 the greatest number, representing 3.6% or 7.2 million people, relates to people with visual disabilities. This panorama demonstrates the relevance of this study just to begin identifying the benefits already provided by textile technology for the everyday life of these people, and in turn, to propose new applications for this technology to benefit wheelchair dependents. Among these types of disabilities, the physical disability is that which causes most harm to skin health, because of patient's static position in a wheelchair or bed, which, as previously mentioned, can result in superficial sores or more severe injuries [11].

The major cause for the formation of pressure ulcers 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 [5–12].

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 [13].

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 ulcers in each stage [13] (Fig. 1).

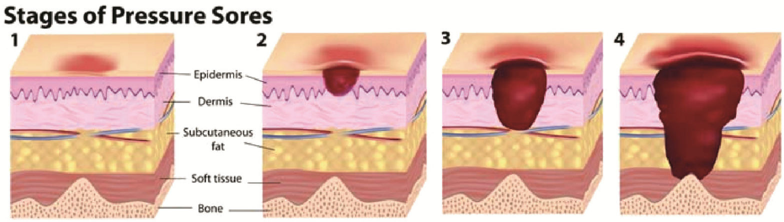

Fig. 1. Stages of pressure ulcer development (Source: https://mangarhealth.com/uk/news/new-mangar-health-websites-launched/)

The main of preventing the formation of pressure ulcers is to change positions every two hours, in the case of patients confined to a bed, in order to alleviate the skin pressure points in areas of greater risk. For people in wheelchairs who remain in a sitting position for a long time should shift their position with increased frequency, every ten to fifteen minutes. However, this is often unfeasible for wheelchair dependents who actively participate in the labor market, which underscores the importance of Beretta's research, in which textile technology is employed for the protection of the wheelchair user's skin.

3 Inclusive Design in the Daily Lives of Wheelchair Dependents

From the 1970s onwards, design began moving towards a more human-centered approach with Victor Papanek, industrial designer and design director of the California Institute of the Arts. Since that time, Papanek encouraged a more solidary attitude in the attempt of abandoning 'design for profit' in favor of human desires and needs. To this day, the designer continues appeal to designers to stop working within a culture of consumerism and in a superficial way, and to start developing research projects aimed at solving the problems of the society, and to cater to the need all kinds of people, regardless of their social and economic circumstances. In the 1980s and 1990s, an increase in the number of research work in the field of design centered on issues related to sustainability and consumer education can be observed. In that same period accessibility and social inclusion also become matters of interest for designers [14].

As of the 1970s, the first signs of inclusive design begin to appear, even though at present the number of research projects that associate design and technology to improve the life of disabled individuals is still limited. Many wheelchair dependents have joined the labor market, working the same number of hours as individuals without disabilities, which only enhances the importance of this study.

The principle reason that led a much greater number of disabled individuals to find employment is the existence of a Quotas Law, passed in 1991[2], which established that any company with more than hundred or more employees must fill between 2% to 5% of their positions with people with a disability. Currently, there already are 9.3 million disabled people working and who fit the criteria, in addition to 827 thousand vacant positions. However, the working hours of a wheelchair dependent is no different from that of a person without a disability, being an average of eight hours a day, Monday to Friday, and four hours on Saturdays, totaling forty-four hours of work per week.

Many wheelchair dependents are fully capable of working, and these activities play a crucial role in restoring and enhancing their self-esteem, promoting their independence and social inclusion. As they enter the labor market, these individuals begin to feel the need to visually identify themselves according to the normative guidelines of the company they work in, having to dress appropriately in formal attire, sportively or even wear uniforms. Besides, upon joining the workforce and having to remain seated in the same position for long hours, the chances of developing pressure ulcers increase. This scenario provides the main motivation for seeking solutions in the domain of textile technology capable of contributing to the well-being and health of disables persons in these conditions.

Therefore, the project developed by Elisa Marangon Beretta in 2015 significantly contributes to reducing the formation of pressure ulcers in disabled users due to long permanence in a sitting position without physical movement. The designer employs the technique of microencapsulation applied to the fabric and introduces a personalized wheelchair seating system finely adjusted to the individual user's anatomy. It is important to point out that this option improves the user's positioning, but could also negatively impact on thermal discomfort, as it increases the contact surface area. That being the case, the designer applies a textile substance using phase changing technology to the textile cover of the wheelchair seat, adjusted to the wheelchair user's skin temperature. This way, the appearance of pressure ulcers is avoided as temperature control is established in the areas of friction between the body and the wheelchair [15].

The PCMs are based on the absorption or liberation of heat when a change of physical state occurs - from solid to liquid, or liquid to gas, or vice-versa. Hence they can be defined in a simplified way as substances with the capacity of altering their physical state at a given temperature interval, absorbing or liberating heat energy from the surrounding environment. When the phase change is completed, the continued heating/cooling results in a gradual temperature increase/reduction, which in turn is defined by a thermo-regulating property known as sensible heat [16].

The casing material in the process of encapsulation can be polymeric, ceramic or gelatin. The encapsulation can also be classified as porous or non-porous, being that the porous gradually releases the material within the core while the non-porous acts as a protective layer to the phase change material. Furthermore, the microcapsules can be permanent or temporary. The temporary ones also gradually release the material in the core when the protective shell is broken. The permanent ones, on the other hand, are designed to protect the core as long as possible [15].

[2] Brazilian Law Nº 8.213, enacted on July 24, 1991.

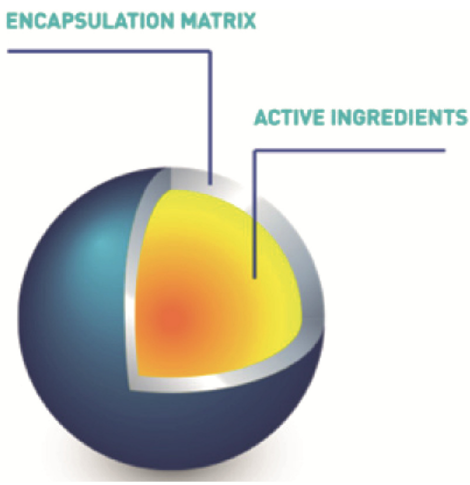

Fig. 2. Structure of a microcapsule (Source: http://capsularis.com/capsularis-expert-microencapsulation/?lang=en)

The image above represents the structure of a microcapsule (Fig. 2). The encapsulation matrix, referred to as the coating material, protects the material from external influences, while the active ingredients, also referred to as the core, holds the substance that characterizes the textile substrate's functionality.

The definition of the protective casing in the microencapsulation process occurs according to the specific characteristics of the material being encapsulated and its potential application, such as fibers and textile substrates, surface coatings, physiotherapy equipment, isolating panels, among others.

The image below shows each stage of the development of the personalized wheelchair seat. The study consists in obtaining the shape of the user's body through the use of molds made by health professionals using both plaster and vacuum mattresses and also through

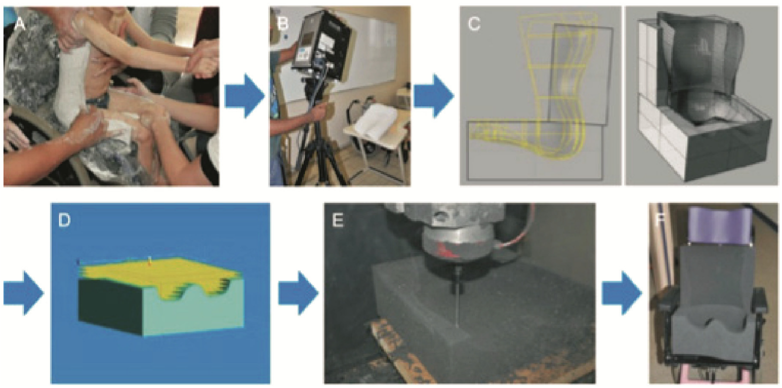

Fig. 3. Production process of personalized seats Source: (BERETTA, 2015)

direct scanning of the patient. The plaster molds (Fig. 3A) are scanned by a using a 3D scanner (Fig. 3B). The data collected is transposed to a CAD/CAM program (Fig. 3C) and processed so as to customize the form for manufacturing using CNC-controlled precision machine tools (Fig. 3D). The seat is directly manufactured in foam (Fig. 3E), which guarantees the precision of its forms. In Fig. 3F it is possible to visualize the structure of the personalized seat, fitted into the wheelchair. [15, 16] Next, the textile substrate containing microcapsules with PCM embedded into their core is applied onto this structure. These microcapsules act as a shell, which avoids PCM leakage in its liquid phase.

Once this stage of the process is finalized, the designer performs validation tests, verifying the latent heat energy emanating from the seat surface by conducting a thermography analysis. This requires that the user remains seated on the seat for 20 min. As soon as they rise from the seat the temperature of the surface is measured by thermography to obtain a mapping of the heat energy on the surface. In Fig. 4 it is possible to observe that the manually shaped seat leads to a concentration of heat energy in its central area, and consequently to the production of temperature peaks in the area of the buttocks and back upper and inner thighs of the user's legs in contact with the surface of the seat. Figure 4 (below) the optimum distribution of heat throughout the seat, resulting from the application of textile substrate with phase change thermal storage.

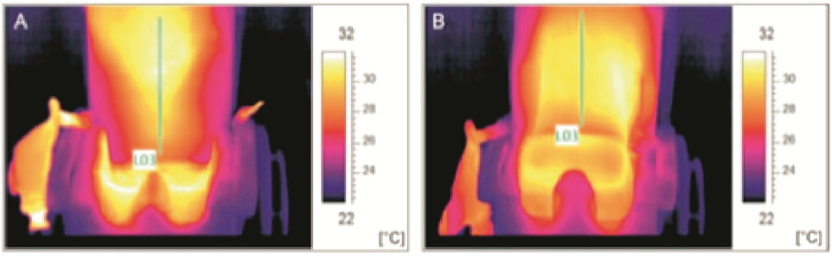

Fig. 4. Temperature measurement of the seat Source: (BERETTA, 2015)

Beretta's project demonstrates that the eicosane microcapsules can reduce the heating effect of the wheelchair seat on the wheelchair user's skin, namely by thermoregulation provided by foam and textile material. In other words, the microclimate between the seat surface area 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.

Over the last years, phase change materials have been used to manufacture thermoregulating textiles and provide greater thermal comfort for wheelchair dependents. At present, PCM 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 [15].

In other words, the development of new fabrics with the use of microencapsulation has been assisting many people with a range of different needs, particularly including: sun protective fabrics, insect-repellent textiles for users who are allergic to insect bites and/or use in high-risk insect-transmitted disease areas or periods. Microencapsulation is also used for applications such as controlled release of various types of fragrance, maintain the scent on items of clothing and/or user for longer periods of time. Such processing techniques can effect a potentialization of products and their functions, and also significantly extend the reach of inclusive design.

4 Results and Discussions

In Elisa Marangon Beretta's investigation and subsequent tests, this paper identifies the results of the application of textile technology, more specifically that of encapsulation articulated with certain materials and procedures such as the 3D modeling in conjunction with the manufacturing process on a CNC machine, used in the production of an inclusive design-oriented product. The fact is that these resources and processes demonstrate the intrinsic importance of both an interdisciplinary and a transdisciplinary approach to inclusive design. The major contributions to improving the everyday quality of life of disabled persons who depend on the use of a wheelchair provided by Beretta's research work can be summed up as follows:

4.1 Ergonomics, Comfort and Inclusion

Beretta's project emphasizes the way in which design can contribute to develop inclusive and ergonomic interfaces and, in the case of the disabled individual's body, highlights that it is necessary to research materials and processes that can provide and ensure the comfort of the user for an unlimited amount of time.

The previously listed project-based actions present the benefits of a personalized seat, once every disabled individual has a different body structure, with distinct variations relating to their impairment of movement. The fabrication of a mold of the user's body provides a better understanding of the specificities of each body, and supplies relevant and valuable information for the decisions related to the project. The mold is used as a basis for digital modeling, and the fabrication process is rendered directly using the foam material. This process is crucial to ensure precision and ergonomic correspondence between the seat and the wheelchair dependent's body. In other words, a product design that is oriented towards the physical needs of each individual user is a fundamental aspect in dealing with a project that centers on adapting and producing inclusive interfaces.

4.2 Textile Materials and Thermoregulation of the Human Body

Ergonomic comfort is not sufficient to ameliorate the effects of heating for the wheelchair user. However, by way of inclusive interfaces it is possible to identify the ideal distribution of the pressure of the user's body onto the seat during the use of the wheelchair.

The completion of the production process and the subsequent testing that ensued demonstrated a higher level of tactile comfort for the user, due to the seat's ability to mold itself to the contours of the user's body, minimizing the friction between the body and the seat, and hence preventing the appearance of pressure ulcers. In this regard, the domain of textile technology can be considered a fundamental field of research in the context of attaining thermal and ergonomic comfort for disabled users in their daily lives. Beretta's investigation emphasizes the use of Phase Change Materials (PCMs) with the aim of achieving thermoregulation. As shown by the designer, the PCM's capacity for absorbing and releasing heat point to a method of working that is consistent to the design of inclusive interfaces. This potential presents itself as directly proportional to the needs arising from each individual body/lesion, which in turn denotes a vast field of possibilities awaiting to be explored and put into use, ultimately offering considerable benefits for the health and well-being of disabled users.

4.3 Beyond the Prevention of Pressure Ulcers

A thorough understanding of the microencapsulation process opens up a vast field of application. In Beretta's case, the option for microencapsulation with an eicosane nucleus seeks to reduce the formation of pressure ulcers by ensuring a thermal balance between the wheelchair dependent's skin and the wheelchair seat. To this end, determining the fabric's qualities (less or more permeable, for example) has direct impact on the fabrication of the seat, whereby the permeability of the fabric to air is an essential factor in achieving thermal comfort, as is the textile's thickness, weight and density and the type of processing that should be applied. According to [15], attaining a balance between the breathability rate and the thermal transference in the production of a textile for this end is of crucial importance. In this way, in addition to proposing a project-oriented approach to the prevention of pressure ulcers, the microencapsulation studies developed by Beretta also point to fertile perspectives vis-à-vis an inclusive approach in product design.

5 Conclusions

This paper foregrounds textile technology an effective means to optimize the relation between the wheelchair dependent's body and the surrounding environment, based on designer Elisa Marangon Beretta's research work. The benefits derived from the project directly impacts the quality of everyday activities of the wheelchair user, as they promote the prevention of pressure ulcers by way of textile encapsulation, aimed at providing the user with thermal and ergonometric comfort.

This discussion foregrounds the significance and meaning of design with an inclusive approach, as although a number of research studies and actions aimed at improving the daily lives of wheelchair dependent individuals have already been performed, there still exists a substantial number of products, work conditions and physical environments that are partially or totally inadequate for the disabled individual and require further study, adaptions and solutions. That being said, the need for projects that include more through investigation pursued in conjunction with other fields of knowledge is paramount. Clearly a trans and interdisciplinary approach to research can offer a wider frame of reference for the exploration of materials and processes, which, added to analog and digital procedures, can provide a broader perspective for the consolidation of inclusive design.

With future development, the research aims to use make use of the results obtained by Baretta [15] and expand them in the development of an assistive interface directed at reducing the appearances of pressure ulcers in wheelchair dependents. In this way, the ultimate objective is to evaluate the potential for other substances (in addition to the use of eicosane) in microencapsulation applied to textile materials, thus enabling the production of even more consistent results for the aforementioned context.

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