UNIVERSITY OF BEIRA INTERIOR
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THE CONTRIBUTION OF FASHION DESIGN TO THE DEVELOPMENT OF ALTERNATIVE MEDICAL CLOTHING

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(2nd cycle of study)

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Dedication

I dedicate this thesis to the memory of my grandfather Noé Bernardes, who always sought to teach me good values in order to become a humble and honorable man.

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I would like to show my appreciation to the individuals that made this research possible:

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To all of you, my heartfelt regards!

“The art of medicine consists in amusing the patient while nature cures the disease.”

Voltaire

Abstract

The present research work envisage the development of paediatric, antimicrobial and sustainable clothing for use in hospital environment. This innovative piece of cloth was devised to offer thermoregulation, physiological comfort and psychological well being for children undergoing chemotherapy. Simultaneously, it is intended to contribute for the prevention of nosocomial infections, particularly, cross-contamination with Staphylococcus aureus.

To accomplish these goals we sought to create an aesthetically pleasing and appealing imaging combined with an ergonomic shape; well adapted to infants; with an easy facility of dressing / undressing; open and close; flexibility; freedom of movement; temperature and moisture management and, especially, antimicrobial protection.

For this purpose we built a single knit structure (jersey) with two different raw material compositions: 100% cotton and 100% hemp, which were put to test.

The aforementioned knits were submitted to an antimicrobial finishing treatment provided by three different agents: Agiene®, Bionyl® and Chitosan, each one individually applied by three different techniques: pad batch, print screen and spray/exhaustion.

Antimicrobial activity was analysed by ISO 20743:2007 standard wheather major thermo physical properties were studied with alambeta (considering the dry and the wet state). The physiological behaviour was characterised by the permetest apparatus.

Results have shown that the best optimized performance was attained by the sample 100% hemp with chitosan applied by pad batch. Taking into account this information and all the previous considerations, a prototype of the gown was produced.

Keywords

Design; engineering; medical textile; hemp; cotton; chemotehrapy treatment; paediatric; physiological comfort; thermoregulation; gown; Agiene®; Chitosan; Bionyl®.

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List of Acronyms

GRP	Gabinete de Relações Públicas
UBI	Universidade da Beira Interior
LEITAT	LEITAT Technological Center- Barcelona- Spain
HIV	Human Immunodeficiency Virus
CFU	Colony Forming Units
ABNIT	Brazilian Associaation of Nonwoven and Technical Textile Industries

CHAPTER 1

INTRODUCTION

1.1 Definitions and Terminology

In the last few years, nanotechnology has been used to obtain textile materials with high performance such as antimicrobial properties, or medical treatments of certain wounds such as ulcers, traumatic and post- operative wound, and even skin grafts. Their role is destroy or inhibit the growth of microorganism since they may cause serious health problems.In contact with a human body, bacteria find the perfect environment for their growth, because it provides (bacteria and fungi) moisture, humidity and nutrients.

In the first place a proper antimicrobial treatment does not cause irritation, toxicity or allergy to the user, it does not adversely affect the quality of the textile materials and it does not produce harmful substances to humans and the environment. Secondly, the finishing should be durable to laundering, dry cleaning and hot pressing. Thirdly, the finishing should not negatively affect the appearance or quality of the textile.

Most antimicrobial compounds are extracted from plants, being represented by polyacetylenes, polypeptides, essential oils, lectins, alkaloids, terpenoids, polyphenols and phenolics. Almost all antimicrobial agents already in the textile indurty, such as tricosan, polyhexamethylene biguanide, silver, quaternary ammonium compounds, are biocides (is a chemical substance or microorganism that can exert a controlling effect on any harmful organism by chemical or biological means). Tipically they alter or damage the cell wall, denature proteins, inhibit lipid synthesis or inhibit enzyme activity, all of which are essential for cell survival.

One further consideration is that antimicrobial finishing and dyeing of textile should not kill the resident flora of nonpathogenic bacteria on the wearer skin. The aforementioned flora consist of several bacteria genera, which are important to produce antibiotics to create an unfavorable environment for the growth of pathogenic bacteria. Antimicrobial agents on textile may only reduce the density of the skin resident flora but do not completely eliminate them.

Considering the global price rise of cotton, the research focuses on finding alternatives for cotton in antimicrobial medical textile, this fiber is naturally attacked by fungis and bacterias. The different types of textiles that has been carried ou include hemp and cotton. Three different antimicrobial products, Bionyl® (powder), Agiene® (nano silver particles), and Chitosan (natural antimicrobial found in the exoskeletons of crustaceans) were applied with

different application techniques as, power spray (application by electrostatic spray gun), liquid spray, screen print, pad batch and exhaustion.

The research findings were further optimized to increase the durability of antimicrobial properties and simultaneously aiming at eco-friendliness of the developed textiles.

1.2 General-Purpose

This research aims to develop a pediatric antimicrobial and sustainable clothing for use in the hospital environment, aiming to provide thermoregulation, clothing comfort to the patient and mainly to avoid cross-contamination of the bacteria *Staphylococcus aureus*. Also of great importance was the use of knits intead of nonwoven fabric as a new functional alternative for medical textiles.

1.3 Specific Goal

- Explore the concepts of functional textiles and antimicrobial activity.
- Investigate the properties of cotton and hemp fibers, considering the possibility of replacement of cotton by hemp fiber for medical clothing.
- Develop a functional and fashionable product for pediatric patients undergoing chemotherapy treatments.
- Prove the effectiveness of the investigated antimicrobial agents.
- Create opportunities and the scientific foundation for the development of medical clothing associating style and functionality.

1.4 Justification of the Work

In the recently past years an important breakthrough had happen, steadily, in functional textiles with this process we aim not only to develop new materials, but also new processes and specific functionality, combined with the concepts of fashion design, providing optimized solutions fo specific problems.

The interest for this research comes after the analysis and study of the behavior of pediatric patients undergoing chemotherapeutic treatment. They need to interact with the clothing to provide psychological confort, due to the fact of being in a very invasive health care. The fashion design is used as a fundamental tool for the development of interactive and functional clothing.

Due to is continuos price raise, it is recommended that we need a fiber that can replace cotton in the medical environment. A fiber that can be more sustainable and environmentally friendly and at the same time provide comfort to the user.

1.5 Applied Methodology

Firstly a theoretical study was conducted in order to comprehend define the market in which we were about to work.

In a second stage an exploratory research to characterize the problem and suggest a technological solution for pediatric patients undergoing chemotherapy treatment.

Finally, we made all the pratical and experimental work so as to produce and test, a prototype with all aforementioned desired properties.

CHAPTER 2

LITERATURE REVIEW AND STATE OF THE ART IN HOSPITAL CLOTHING

2.1 Contextualization of the problem

There is evidence that in hospital environment and health staff can contaminate patients with various types of bacteria, in this study, investigated a specific tipe of bacteria: *Staphylococcus aureus*.

The presence of oxygen (aerobic) or without oxygen (anaerobic) can develop the *Staphylococcus aureus* colonys. However, such bacteria have higher growth when there is oxygen.

When present in hospital textiles, they can odour generate, contaminate patients and even deteriorate. When present in the body of patients who usually have low immune system can cause diseases such as folliculitis, impetigo, endocarditis, osteomyelitis, and pneumonia, which, if aggravated, can lead to death.

Another factor that greatly influenced this research was the importance of the patients' feelings, how were submitted to treatment for a long period of time. In the case of pediatric chemotherapy patients, they have frequently a low immunological resistance, which can lead, when exposed to bacteria, in contamination and even decisively influence the treatment result.

2.2 Medical apparel

The hospital environment is comprihend by several distinct activities which may have direct or indirect contact with a variety of fungi, bacteria and various other microorganisms. Contamination can occur directly (contact with contaminated blood) or indirectly (through respiratory system).

Due to these factors, the hospital clothes should function as protection and, somehow, as disinfection. Depending upon the function performed in the hospital, the garment consists of: gloves, aprons, masks, goggles and boots.

In Quintana *et al*. (2007), it was found that "[...] children experience panic situations when placed in front of a person wearing white or with a nurse uniform" (p.414-423). While in Bocannera *et al*. (2004), found the positive color influences over the patient treatment, "[…] it

can help establish balance and contribute to the harmony of body, mind and emotions." (vol.6, nº 3.)

The clothing is a product that is directly related to the user/body. Interface communication between the body and those around them. Clothing should be extremely comfortable; if they are tight they can cause discomfort and directly interfere on the heat dissipation (Gambrell, 2002, p.457-464).

The development of uniforms for workers and patients in hospitals is a matter of great importance in order to protect and to assist in distinguishing the users' identification.

2.3 Functions of medical clothing

The medical garment must take care of the needs of patients at the time they are bedridden. In this case the patients need clothes which protect them against bacterias, potential environment contamination, provide breathability and body thermoregulation

As patients have a low immune system, they are more vulnerable to contracting diseases, so the hospital clothing should be thought of as an aid to the disease barrier.

In sum, medical clothing should have the following functions:

- Protect the patients skin of the exposure of bacteria;
- Allow the skin to breathe;
- Not allow the development and proliferation of bacteria present in the hospital environment or even in the textile;
- Being ergonomic, easily allowing opening and in case of an emergency the patient can be easily undressing so as due care can be performed.

2.4 Characteristics of medical apparel

Patients on chemotherapy treatments tend to be psychologically affected, especially children. They need something to make them feel more confident against this battle against their illness. They often feel more debilitated by having an outfit that make them feel like "real patients", due to the standardization of the medical clothing, placing them in a position of ill. Hospital clothes should help them feel more confident in themselves and comfortable with the treatment carried.

One of the concerns that we had is how we can help this patient, improving their self-esteem through the clothing and, at the same time, develop a garment which protects them against the avoiding or minimizing contamination. It may directly affect their treatment. From this

point, inspiration struck to manufacture a medical gown, its purpose is to interact with the patients, demystifying the image of medical clothing and confectionate a gown which will act as a barrier against these potential contaminations.

According to the following table, we can observe the some examples of antimicrobial textiles fields.

Table 1- Antimicrobial textile and their fields of application. (Source: Biofunctional Textile and the Skin, p.43)

Medicine	Sport and leisure	Outdoor	Technology	Domestic
Support stockings	Shoes	Jackets	Wall hangings	Curtains
Antidecubitus mattress	Socks	Tents	Roof coverings	Coverings
Incontinence liners	T-shirts	Uniforms	Facade linings	Cloths
Encasings	Cycle wear	Personal protective	Air filters	Bath mats
Bedding filling	Team kit	Astro turf	Automotive	Sanitizers
Pillows	Jogging suits	Sunshades	Geotextiles	Underwear
Implants		Awnings		Carpets

2.5 Maintenance and care in hospital clothing

The clothing care of paediatric patients is crucial because any waste materials such as faeces, urine or even detergent can irritate children's skin courting infections and even bacterial contamination. The clothes used for the treatment of patients should be washed and sterilized before the first use, this process aims to combat any dirt and remove the grime present in the garments.

Clothes should be machine washed, on a lighter program. It is recommended that adult and children’s clothing be washed separately, using the usual detergent without the addition of a softener. It is not advisable to use detergent or bleach that may affect the properties of the garment and cause irritation to the patients’ skin.

Clothes which have a closure system by Velcro, buttons, and even moorings, should be washed closed.

Regarding drying, it should be carried out naturally exposing the clothes outside in the sun, with the aim of reducing the waste. Drying using radiators and drying machines should be avoided, as this may directly affect the roughness of the clothing.

2.6 Hospital disinfection

Disinfection is aimed at removing microorganisms by the application of physical or chemical agents.

The gowns that the patients wear need to be washed in a way that not only the visible stains are washed but also to eliminate the greatest quantity of microorganisms possible.

Cross infection can occur when germ pathogens survive for a short or long period of time, due to the presence of organic matter such as urine, faeces, pus or even blood. It is proven that no existing wash cycle can eliminate effectively, bacteria sporulated (sporulation is the formation of spores made by bacteria due to the critical condition for survival, caused by the restriction of essential nutrients supplied for its vegetative state as : Carbon, sulfate, phosphate and nitrogen. In order for the process of sporulation to occur it is essential that the presence of mineral salts such as potassium, calcium and magnesium combined with the favourable conditions of pH, temperature and humidity).

For the best cleaning and sterilization process effectiveness it's essential the following processes:

Chloro-disinfection: This process is accomplished by chlorine compounds, but should be handled with special care because chlorine can damage the textile fiber. At temperatures above 35ºC, every 10ºC doubles the chemical wear of the clothing, so it is advised to carry out the treatment from 5 to 10 minutes at a maximum temperature of 35ºC and pH of at least 9.

Thermo-disinfection: disinfection process that combines time/temperature washing. There is a need to balance the temperature and time of exposure to maximize the destruction of microorganisms. The disinfection must be carried out with water at a temperature between 85^{o}C and 95^{o}C for 15 minutes. The temperature and time of exposure are critical factors for the disinfection efficiency. The woven or knit when subjected to this treatment may be damaged if the temperature and exposure time is exceeded.

After the washing treatment finishes its advisable the medical clothes undergo a process of calendaring or pressing.

2.7 The creative design process design of medical apparel

In the 12th century society, we realized that there was not any concern with children's clothing it was treated as adult clothing; children, depending on the social class, usually had to dress in a similar manner to their parents. Later, in the last century the child clothing wasn't considered as adult clothes on a smaller scale anymore, but an outfit designed especially for

them. Usually the children's clothing was designed in a simple outfit; it was practically a simple and broad gown, which had as main objective freedom of movement for children.

Jean Jacques Rousseau was a philosopher pedagogue, who in the mid-eighteenth century introduced a new proposal for children's clothing. He proposed the use of lighter fabrics and colours and defended the differentiation of adult and infant clothing. Rousseau was against fashion that denied freedom to the children clothing, as such he invented a more straightforward way to influence them. He influenced the design, pattern making and even the choice of textile. The historic, economic and social movements always influenced fashion directly.

In the early 20th century, we began to think in more detail about children's clothing. The development of new technologies, the research of new materials and functional textiles directly modified child's clothing.

For the development of children's clothing, it is always important to think about comfort, thermoregulation, modelling, and possible skin irritation that can be caused by a chemical treatment of textiles.

2.8 Characterization of the medical clothing market

The use of textile materials for medical purposes has been evolving over time. It has been almost 4000 years since the first record on this subject; the ancient Egyptians were the first civilizations to develop studies. At that time the Egyptians already noted a concern in the development of functional fabrics and yarns. Flax was developed to assist in the tissue and sutures. They, in order to prevent tissue deterioration used lime to preserve their flesh; examples can be seen in museums all across the world.

In Asia the development of medical textiles, starts with the Chinese, which also used flax for suturing. Later they developed cotton fabric to stop bleeding in case of haemorrhage or even for protecting open wounds. Ever since that time the textile has a social assistance facet.

With the emergence of new technologies after the Industrial Revolution, we got a major advance in the area. The use of synthetic fibres is increasing ever since. We have more recently started the incorporation of biodegradable fibres for the development of functional textiles.

In today's market the hospital textiles are built mostly out of fibres like cotton, silk, linen and viscose of regenerated ryon or synthetic fibres in the case of non natural polymers. There are several companies on the market today that provide great resources and invest in new technologies to develop medical textiles.

An U.S. company that internationally recognized is *Johnson & Johnson*, which was founded in 1886. It's one of the largest company's health care sectors in the world. The company is

presently in 57 countries worldwide and has over 200 affiliates. Its most popular product segment in health care is the *Band-Aid*®, used to protect small open wounds.

The North American DuPont™ also has more than two centuries on the medical segment. The company develops large research in the hospital textile segment. It has evolved to become a pioneer in non-woven fabrics in hospital environment. The investigations of the company are focused on new materials and technologies to develop garments that provide the highest freshness, aiming comfort and flexibility of the material. When applied *Softesse*®, a product developed by the company with antimicrobial properties, tissue or nonwoven is received as an effective barrier between the wound in the skin of the patient and the user's body, preventing accidents blood exposure. The product, Softesse, can be easily coated and laminated with various polymers. This product is designed for professionals and patients in protected environment in critical area.

Another product which is also important on the hospital environment, is being developed by The United States *Kimberly-Clark Corporation*, the product developed is a bandage, made with cotton fibre, and has antimicrobial properties, this network acts as a barrier body against exposure of bacteria.

The *Polymer Group USA* is a company that is present in 10 countries worldwide, possesses great ability to research nonwovens and new technologies for the development of healthcare fabrics. Their flagship product is the *MediSoft*®, clothes that are designed for medical purposes, it is a single use garment with a high level of comfort and protection against bacteria. The product is developed for the purpose of protecting surgical clothing and surgical drapes.

2.9 Conceptualization of the prototype

It is of great importance to children playing in the hospital because it will aware them of where they are, in such easier way it will also help them to realize more clearly the situation that they are living.

Through play, children can find themselves and rescue their deepest feelings. By their interaction with the games children, can unconsciously, build strategies and communications to confront their treatment and even create tools to resolve a particular conflict (Fortuna, 2007, p.37).

The construction of subjectivity may be affected due to physical suffering and psychic child during hospitalization. Their changed routine is modified because of the treatment. They turn away from school, friends, family and their toys which can generate feelings of pain, sorrow, anguish and anxiety. The fear of loneliness generated by separation from family during the treatment can produce dramatic situations, creating fantasies about the hospital environment (Cunha, 2007, p.71-73).

The banter in paediatric treatment is very important because it helps children to know and accept the environment around them, occupies better the time, moving away some of the fear of treatment, facilitating their socialization, decreasing anxiety (Almeida, 2007, p.149-167).

With the choice of a particular toy, a child can extend the knowledge of their body, which helps in a straightforward way to understand the disease and the treatment. It decreases the hostility of the procedures in the treatment that most of the time is very invasive and painful (Pedrosa *et al.*, 2007, p.99-106).

In Brazil, it was developed, in partnership with *AC Camargo Cancer Center*, *DC Comics* and *JWT Agency*, a project directed to children undergoing chemotherapy called "superformula". Taking as inspiration superheroes as Batman, Superman and Wonder Woman, was developed thematic capsules for chemotherapy, which aims to assist children to understand the disease and at the same time encourage them to continue with the treatment (Blog Gestão de Logística Hospitalar, 2013).

(a) **(b)**

Figure 1 – (a-b) Simples of chemotherapy bag. (a) Batman chemotherapy bag; (b) Severals Heroes chemotherapy bag. (Source: Blog de Logística Hospitalar)

The director of paediatric oncology at AC Camargo, Cecilia Lima da Costa, said:

"Patients are the real superheroes, whose power is to believe in the cure."

(Blog Gestão de Logística Hospitalar, 2013)

Through bibliographic research, we came to the conclusion that it is of great importance for the hospital to develop a gown ecologically viable, sustainable with high antimicrobial activity, which can be developed combining knowledge of Fashion Design and textile engineering.

The main purpose of the new technological solution is to protect the body against bacterial contamination, by being effective against possible infections and cross-contamination and, also

promoting thermoregulation, providing comfort to the patient. Another important concern for developing the hospital gown is the ergonomic fuction to facilitate the work of medical personnel on the chemotherapy patient medication, for this reason the openings will be in the middle of the arm and also in the thoracic region.

Children in chemotherapy treatments are affected in every way, from a weakened immune system to emotional level. Considering this situation and the need for psychological care, we propose to develop a gown that can also interact with these little patients, so that they feel a little safer in relation to the treatment and give to them a chance to forget a little bit this fight that they are living.

The interaction between the patient and the clothing is major factor, which will be developed within the theme “Batman”. Interactivity patient/clothing will be made through the possibility that the patient will have to increase or shorten the length of the gown body and also the sleeves. Another possibility will be the development of a cover, which will be antibacterial as well. We are looking to provide “comfort” and interactivity with the clothing. With these contribution we believe, that we can improve their self-esteem.

2.9.1 Product differentiation

It has been considered, for some time, that the cotton fibre is not optimal for using in hospital garments. The cotton fibre is not as sustainable as previously thought because it damages the soil on which was grown, there is a great need for the use of agrochemical to prevent the possible pests in planting, requires a large volume of water in its cultivation and, most relevant factor is that the cotton fibre is naturally attacked by fungi and bacteria.

The proposed product is a new alternative in the development of sustainable textiles for application in the hospital environment. We propose to replace the cotton fibre by hemp fibre, which is economically viable, sustainable and is not attacked by fungi and bacteria, as in the case of cotton. The knit developed can also be treated with different antimicrobial agents.

The gown seeks greater patient comfort and running as an antimicrobial barrier mechanism, which is easy to handle, if there is a special need for medical intervention and during an or even to provide medication,emergency it should support quick undressing of the patient, moreover it should have capability for thermoregulation and, especially, bioactive character.

2.9.2 Definition and analysis of the target group

In the fashion world, one of the decisive factors for the development of the collection is that the designer knows, clearly, the target group for which he/she creates. Through knowledge of the fundamentals of design and analysing target group needs, the creation process starts.

Our target group is male paediatric chemotherapy patients, with an age range from 2 to 10 years old, and are undergoing chemo treatments. This group requires assistance in the case of clothes, to help their bodies fight against potential bacterial infections, since they have a low immune system due to its intense and very invasive treatment.

Combining the knowledge and expertise of Fashion Design and Textile Engineering, we have developed a product for this target group, a sustainable, functional and interactive product extremely necessary for treatment success. We also aim to provide the patient with comfort and protection effectiveness.

2.9.3 Trend research

In the contemporary fashion world everything is rather ephemeral and transitional. What is created today tomorrow is already outdated, so our work does not follow fashion trends but technology - oriented applications on the medical textile field. The product can be considered anti-trend within the fashion, because what we propose is a timeless product, is not geared to the fashion world but, above all, for functional fabrics that mainly aims to help users in one way or another.

According to Das (2000), it is already known that textiles are no longer used just for the purpose of dressing the user, they are gradually gaining functionality, it makes the market add value to the product.

After a long time using the cotton fibre for hospital purposes, we began using rubber, but that was not very well accepted by professionals and specialists in this field, because it did not allow the body to breathe.

To improve the problem of thermoregulation the industrial segment decided to introduce synthetic yarns, working out non natural polymers together with natural fibres, in this case cotton. One example is a fabric blending polyester with cotton.

The latest technology on the development of medical textile, is intended to modify the textile surface, making it hydrophobic, it does not allow the fluid excess to reach the skin surface of the user, on the other hand, a great need for thermoregulation, increasing comfort is demanded. Due to constant research and technology investment on this market, a medical textile is growing between 10-15% annually over the past two decades" (Das, 2000).

In the late nineteenth century, medical clothing had only intended to protect surgeons' clothes against fluid or blood. There was a concern with antimicrobial activities disregarding comfort to the users. At the beginning of the twentieth century comes the first pieces sterilized (May-Plumlee, 2002, p. 02-03).

A little later begins to be developed fabrics made of muslin, because, at that time, professionals believed that this material could act as a body barrier, which was later contested.

In a second stage a layer of rubber was applied onto the textile surface, which significantly increased the weight of the garment, hindering the body ability to breathe.

McCullough (1993), in his study, says that researchers should develop medical textiles with high antimicrobial activity and also liquid-proof in order to reduce the risk of corporal exposure to various fluids (McCullough, 1993, 368-374).

DAS (2000) in his study, establishes a number of factors that are essential for the development of hospital textile .It should:

- Promote the safety of patients and medical personnel.
- Have efficacy in antimicrobial activity,
- Combining thermoregulation and comfort (Das, 2000).

2.9.4 Theme definition

For the development of a fashion collection it is always very important to define the theme, which usually tends to be thought relation or inspired in other sources such as social, economic or historical elements. The designer, in his creative process, has to seek a viable way to attend the need of the market in which he is inserted and also to develop an innovative product in the appropriated economic context.

The theme of the collection is fetched from the sum of the information obtained in the survey of trends designed for a specific target group.

The theme of our product developed is "Garmenthero" a kind of super hero apparel, which aims to protect the user of possible infections and in the same time interacting them with their own clothes. The *Batman* costume is the inspiration for the development of our functional and interactive paediatric medical clothing. It aims to provide these children on treatment, even for a short moment, a little more of happiness, by giving them unconsciously, a tool to fight against this difficult time that they are living.

In the prototype it will be printed digitally the batman icon. The gown will be designed in a functional way that it can help with the medication. The sleeve of the gown will be used as a kind of bandage hinder the catheter used for the medication being detached from the patient´s body. Another feature that the gown has is a cover, which can be used in order to interact with the paediatric patient or as a blanket body to warm up the body during chemotherapy process.

Figure 2 – Iconography (Source: Author)

2.9.5 Design and sketches selection for clothing manufacturing process:

The process of creating the drawings is very important to the reestablishment and coordenation of design of ideas; it must let in its first moment the creativity flow. Each designer has a different method of creating which can be expressed through different ways such as: drawings, watercolours, collages, etc...

At this point, the designers need to be aware of the piece details, such as shapes, textures, raw materials finishes functionality, they must create a wide range of options so later on, these options go through a selection process in order to meet the objectives and the aesthetic of the presented collection

Having draw numerous possibilities for the clothing piece, one was selected. That meets the requirement that we desired.

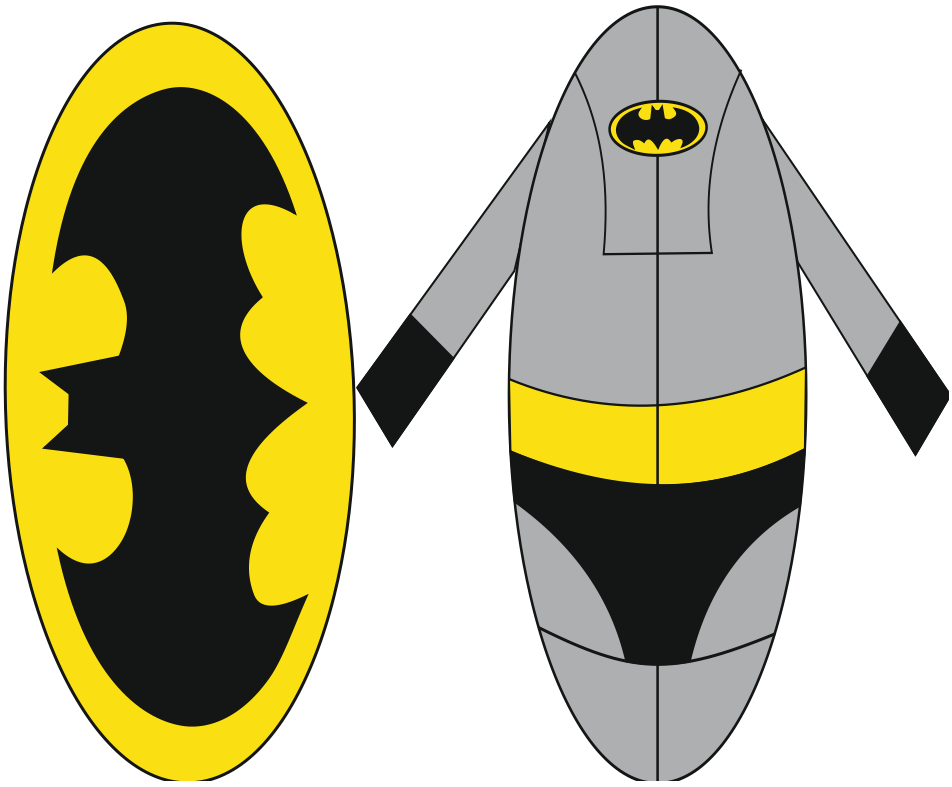


Figure 3 - Artistic sketch - FRONT

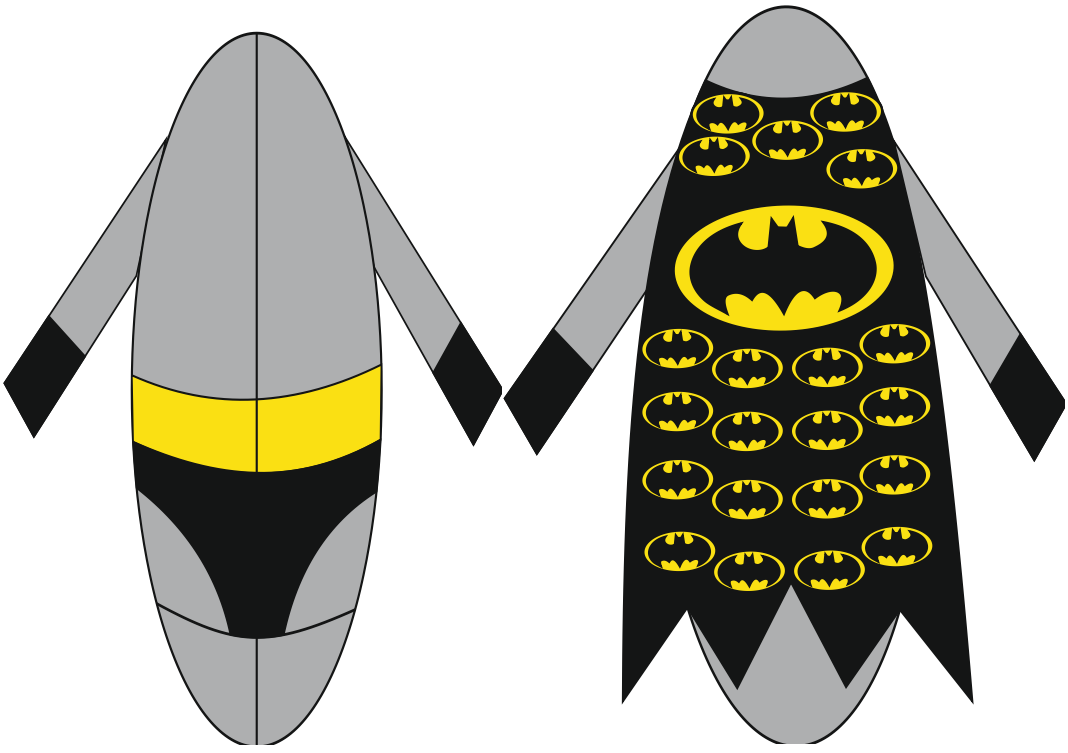


Figure 4 - Artistic sketch - BACK

2.9.6 Technical drawing

Technical drawing during the development of the collection is one of the most important issues. It has to be thought carefully and in detail.

Nowadays, most of the company's design work is performed by the computer although the software can change from one company to another. Technical drawing needs to be clear and with all the technical parameters detailed the type of finish, sewing, the fabric to be developed, product color and measures, sizes scale. It must leave doubt regarding their interpretation.

In a company, there are many professionals involved in the development and implementation, on the different segments of production, so the information contained in the technical drawings must be very specific because it must be understood by seamstress, pattern makers and even by the customers who is asking the job, in case the designer has an outsourced labour as freelancers.

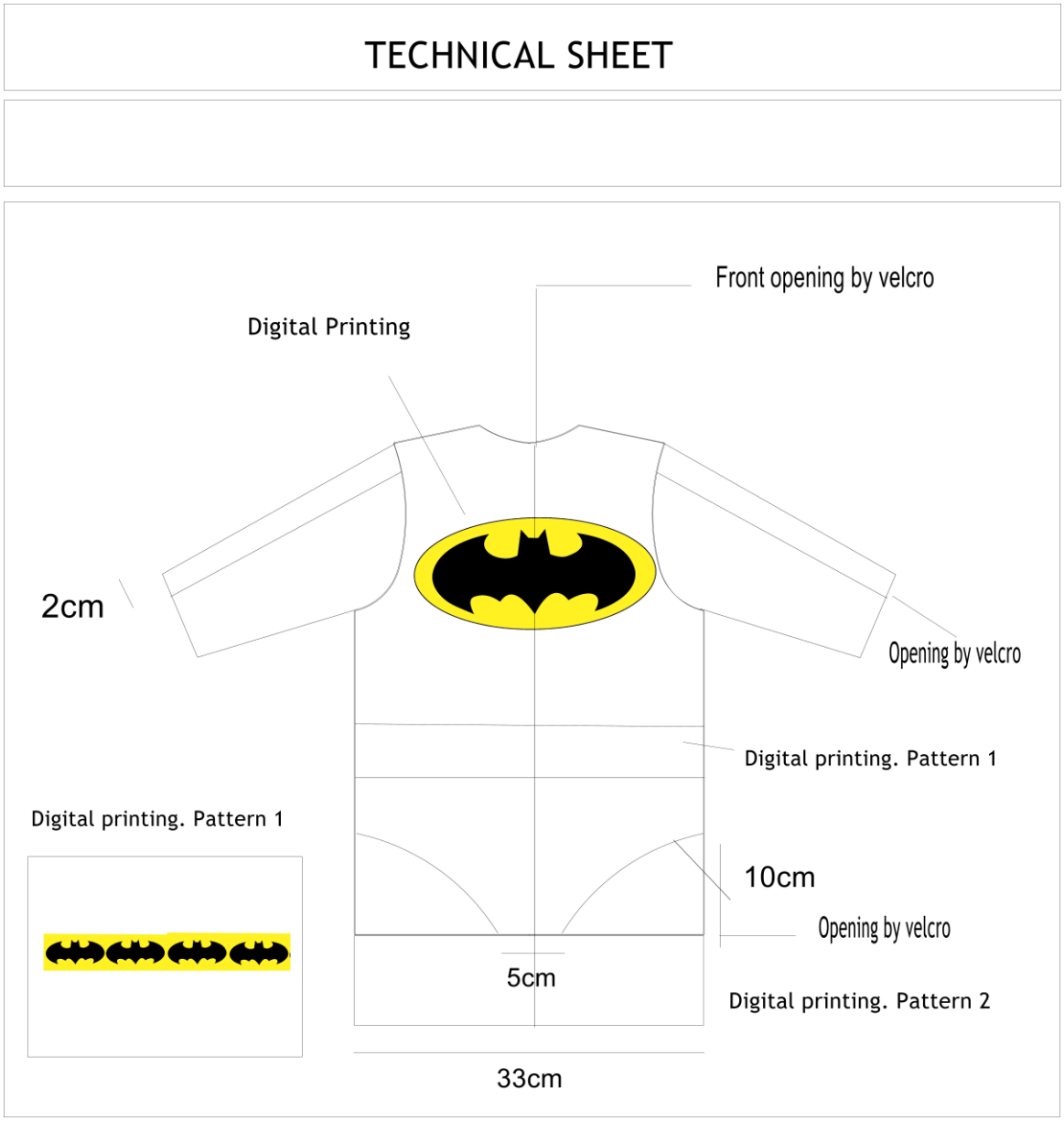


Figure 5- Technical Sheet Front

TECHNICAL SHEET

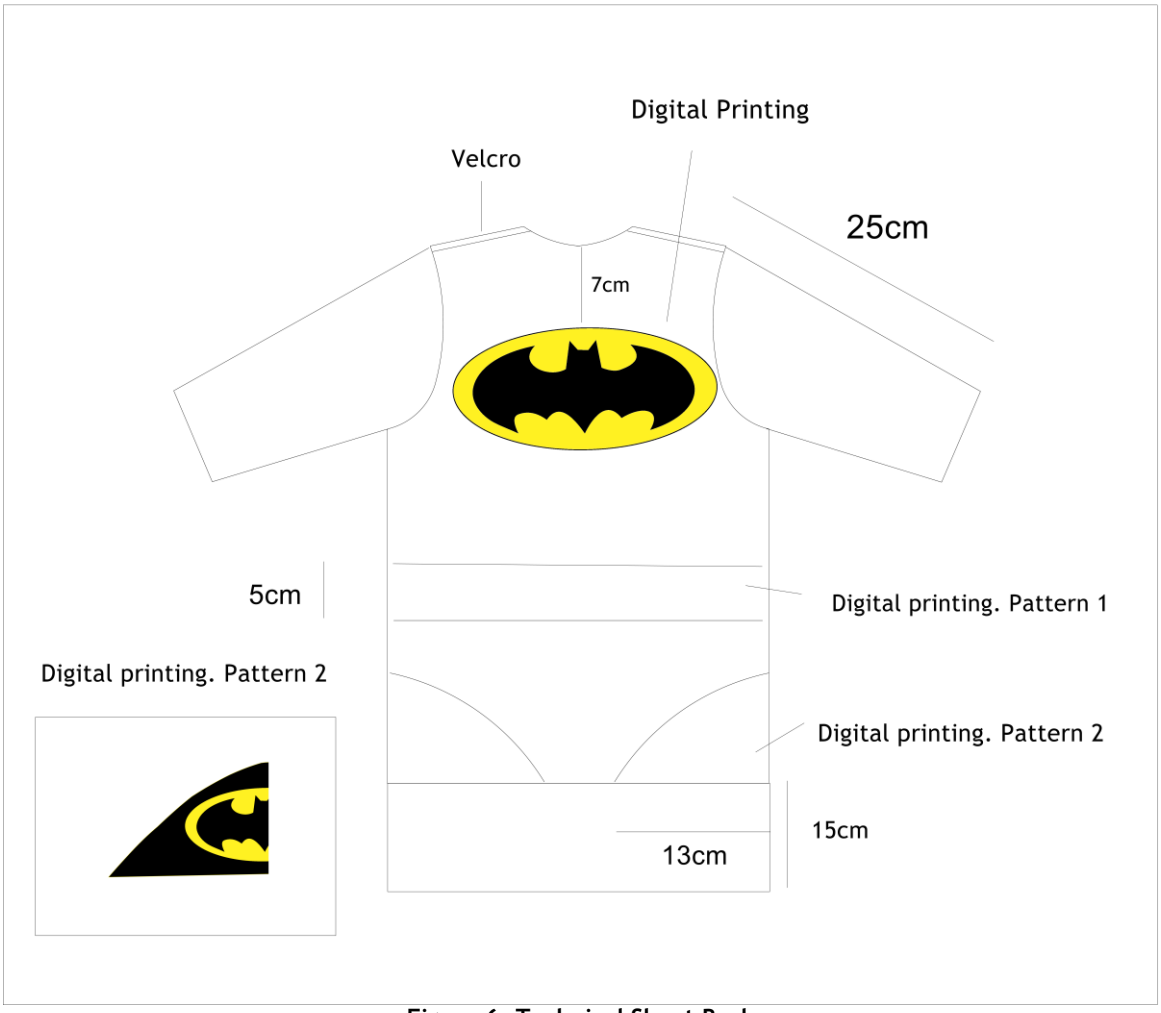
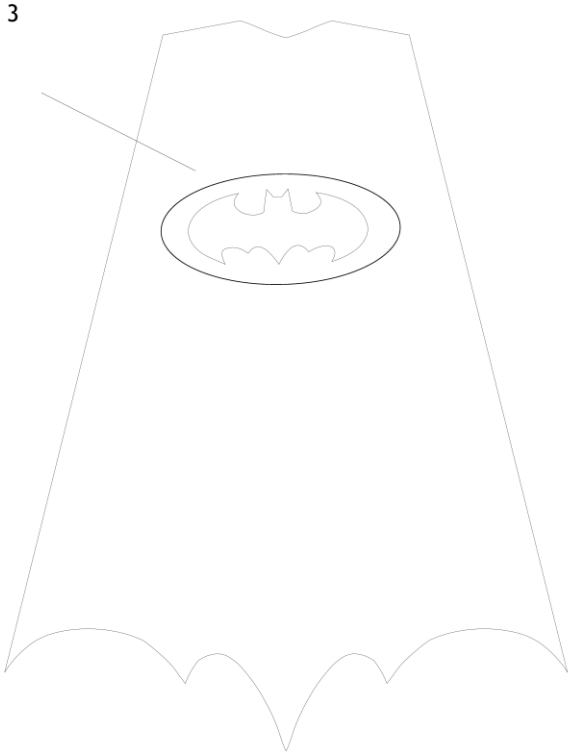


Figure 6- Technical Sheet Back

TECHNICAL SHEET

Digital printing. Pattern 3



Digital printing. Pattern 3

Figure 7- Technical Sheet Cover 1

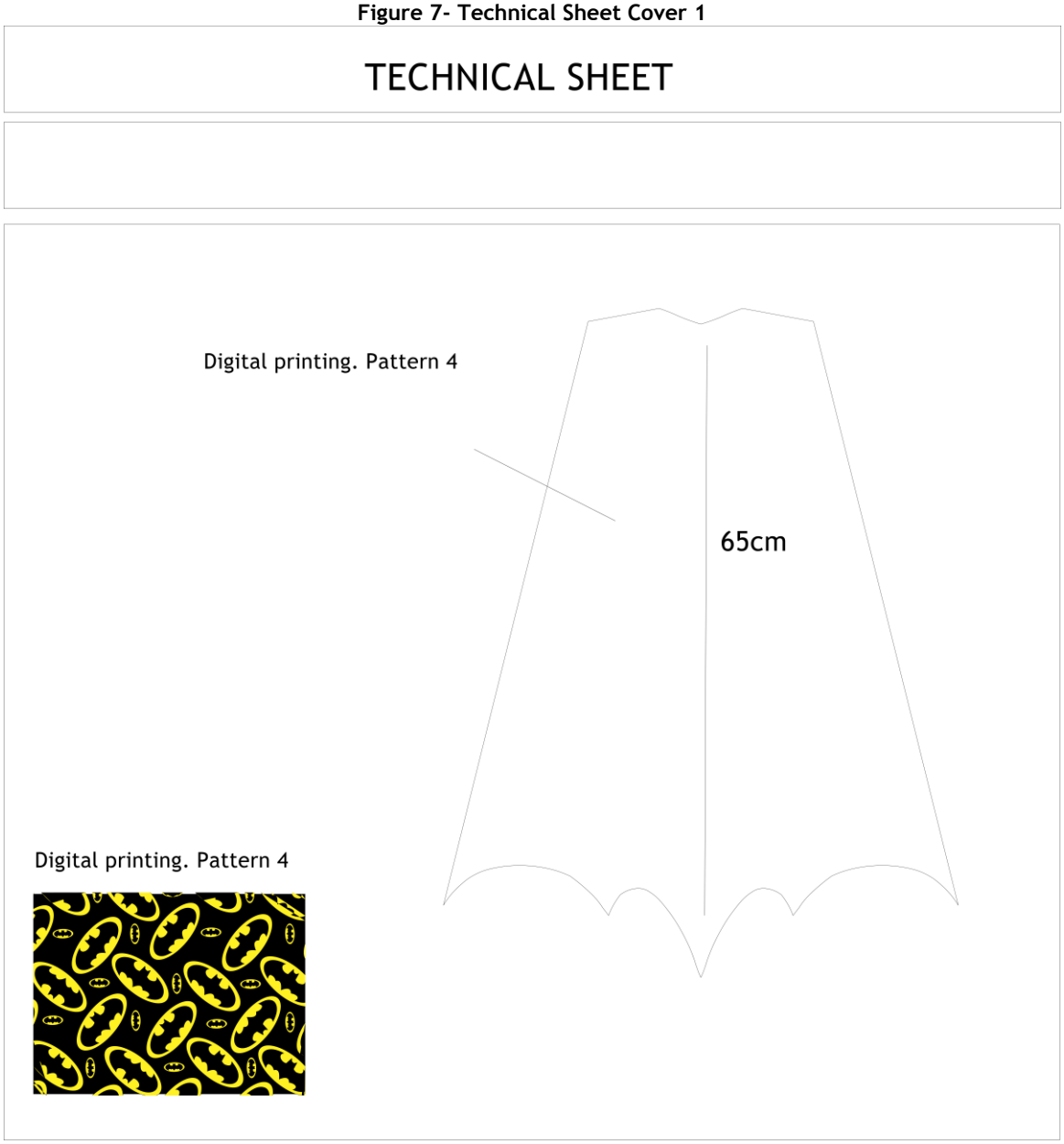


Figure 8- Technical Sheet Cover 2

2.9.7 Design and programming of the computerized knitting machine

After the development of the technical datasheets, the responsible for programming circular machine trigers the process. Technician sataff is responsible for providing and testing knit, so that follow the desire of the designer.

For the development of our prototype a greater tightening of needles is needed, because the structure must be as close as possible, in order to have greater antimicrobial barrier.

Prototyping began with the development of the knit, At this point, we must also have concern regarding in order to optimize the production cost of the prototype and check if the results achieve the wishes and ideas of the designer.

After making the prototype, it was essential to test the piece developed with a real model; in this case, we used a child with the same characteristics of our target group. It is in this step that changes in the size, types of finishes and possible trims changes must be done prior to approval the final prototype. The schematic methodology used in the product development is shown on figure 9:

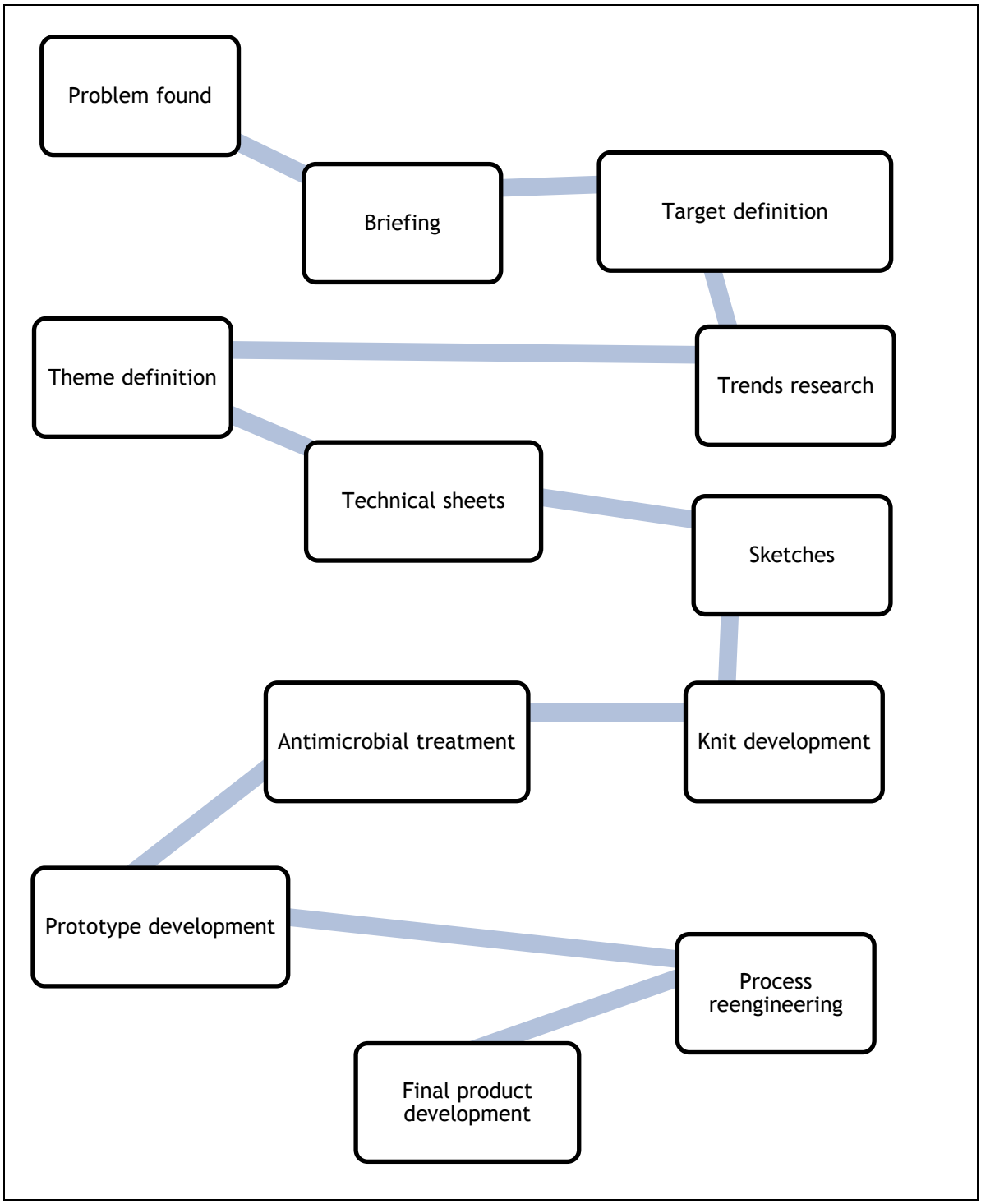


Figure 9 - Schematic methodology (Source: Author)

CHAPTER 3

THEORETICAL FOUNDATION

3.1 Clothing Design

3.1.1 Some considerations about Design

The studies in design history are a popular subject nowadays. The early studies reported were done at the end of the 20s, but there was more development on the research field in the past 20 years. The first considerations about the Design date during the modernist period, however historians exposed their opinion and they defined subjectively design for the time.

Defining the word Design is essentially ambiguous task; however most of definitions on the subject agree that the essence of the word Design is directly related to the act of assigning a material form and at the same time be linked to intellectual concepts. Every designed product aims to meet a need, which is thought out and draw, so that they may subsequently develop a specific product.

According to Cardoso (2004), one of the most traditional definitions of Design defines it as the act of developing or creating objects with the aim of serial reproduction by mechanical artefacts.

Lucie-Smith (1984), affirms that already in antiquity, there was the most basic techniques to the development of products in series. Through the smelting of metals or even ceramic modelling they could have a standardized mould for reproduction of an object on a larger scale.

The use of the word designer was not widely used until the end of century XIX. It arises in that period in England, and the first workers who called themselves designer, were developed patterns for the textile industry.

We cannot talk about design, without mentioning the Bauhaus school. The school was founded in Germany, which ran from 1919 to 1933, a school of architecture, arts, fine arts and was well known for being the first school of design in the world avant-garde for its time. The school influenced the modernist movement in architecture and design.

For the founder of Bauhaus, Walter Gropius, the basis of any art was craftsmanship. He wanted the school to gradually be transformed into a workshop of creation. He believed in a new kind of artist. The major objective was to emphasize the subjectivity of the human being, giving

them creative freedom. He wanted to train professionals, who were attentive to important social and cultural events in the modern world.

The school stood out with prototypes made by its students in a short time. The products left the school workshop and entered the industrial market as a product of duplication and mass production. Aspiring Designers sought this school for it was, in their eyes, an international and multi-cultural school, teachers and students were recruited regardless of their nationality or work style, both were free to exchange knowledge and create new products in architecture, design and fine arts.

> *"(...) the designer endowed with aesthetic sense, who works for the community. Their work is not personal, but group: the designer organizes a working group under the problem should develop."*
>
> (Munani, 2004, ed.70)

With this statement we realize that the designer needs to be constantly updating, observe what society craves and use the designer's aesthetic look to supply it. The Designer seeks for inspiration in the environment where they live. Since society is always changing attention should be given to economic, political and social events.

The designer must be able to work with interdisciplinary elements adjusting it to their project. They should be able to expose their ideas through any media, be it textiles, visual, written or sensory. The product is the materialization of the argument, where the designer seeks to solve a problem inserted in the contemporary context, it has its own aura, speaks for itself, can interact and promote emotions to its spectators. Manzini (1993) believes that *"(...) the complexity of the design task is then to be able to speak the "language" of all (...)."*

Another very important factor in a design project is the concern with sustainability, noted that although the initial concerns with the subject were in the end of the 19th century. It is only in the late 60's that greater concerns about the ecological impairment caused by industrialism arouse. Contemporary designers have presented a greater awareness on relations into ecological issues, which interferes in a direct way on the methodology of the creative process.

Cardoso (2004) notes that designers should also be aware of the life cycle of the objects. On today's market they must create solutions that assist in the sustainability of the product, as well as be concerned in which types of materials should be used. Designers should always give preference to non-polluting or recycled materials and at the same time choose ones that don't require a lot of energy to manufacture. The product developed by the designer must have the potential for recycling, and during its useful life be easy in its maintenance.

3.1.2 Fashion Design

Fashion comes at a time when man feels the need to differentiate themselves from others, we can say that fashion is a translation of our subjectivity. In fashion there are influences from everything around us, even the clothing of our fellow men.

Lipovetsky (1987) states that: "(...) *think that fashion it is also a temporal phenomenon, characterized by constant-change, the new release makes the previous style be discarded."*

Since a long time ago fashion was used as a differentiation factor of social classes, either by patterns, fabrics, finishes or colours.

The clothes at the beginning of human evolution were used as a protective layer with the use of animal leather, tied on the body, protecting man against thorns, vegetation and climate, however it restricted the movements. Historians defend from cave paintings that the men used to wear the skins of animals which they hunted previously, these primitives believed to be acquiring the force of the dead animal (Treptow, 2007).

The earliest civilizations as Assyrians, Babylonians and Egyptians, have a feature in common, these people are the first to develop a proper outfit instead of tying animal leather around their body. They begin to develop fabrics made by natural fibres like linen and wool. As in the contemporary world, clothes are developed starting from raw materials through the available technology. The Egyptians developed their woven linen, because its cultivation was possible in the Nile banks, it was the only material which they had for weaving. The Assyrians, as they were nomads, changed their flock of sheep from place to place, and from the flock they had the necessary raw materials for weaving.

The bourgeoisie were rich from the commercial revolution, and began to have access to the oriental fabrics. According to their social mobility the traders could buy bonds of nobility which in turn directly influenced trends because they adopted a more refined way of dressing.

In this context we talk about fashion as it is today, where people change their clothes because of social influences. Fashion was previously defined by the resources available and accessible technologies, now it becomes a variation by time and society.

> *"(...) The creative professional (fashion designer) should keep watchful eyes to the novelties of fashion, but without ignoring the reality of the company. Must know trends, but rather deeply know their consumer market, their target group. The identification of markets and product development according to a pre-defined public is part of planning and the development of one collection."*
>
> (Treptow, 2007,)

The fashion nowadays is characterized by mass consumption, being a social differentiator. It is the result of social, political and cultural events.

3.1.3 Functional Textiles

The intense competition from countries with cheap labor cost, as well as the increasingly specific and advanced market needs, has driven cooperation between several scientific fields to develop textiles with functional features (Coates, 2005).

According to ABNIT[1], functional textiles are materials consisting of raw material in the form of flakes, fibres, yarns, filaments, etc., in various arrangements (2D and 3D) specifically developed for a certain technical application with a known performance. Those materials are intended to be practical, safe, economics and durables.

The products already marketed and under current developing, possess a broad range of characteristics and applications (Shi and Xin, 2007), (Burg, 2006), (Mattila, 2006). In order to have a better understanding of these materials, a few examples are given:

- **Protection**
- Protection against weather and cold climates;
- UV and other radiation protection;
- Antimicrobial;
- Chemical/physicall protection;
- Fire protection.

- **Performance**
- Waterproof;
- Water-repellent;
- Windproof;
- Water vapor permeable;
- Breathability;

- **Easy care**
- Anti-wrinkle;
- Anti-shrink;
- Anti-stain;

- **Etc.**

Within functional textiles, there is a subdivision dsigned by “biofunctional textiles”. According to (Burg, 2006) “there is no common definition of the term “biofunctional textiles” in the literature, but they comprise materials which are e.g. antimicrobial or fungicidal, due to special finishes or fiber modifications, as well as textiles with cyclodextrin finishes, which act as ‘molecules cage’ and can enclose malodorous substances like sweat components or deliver

[1] Brazilian Association of Nonwoven and Technical Textiles Industries

drugs to the skin."

As aforementioned, these textiles can be used in many different applications. However, in this research work, the focus is set on the biological risk protection and in the promotion of thermoregulation and maximized comfort.

3.1.4 Knitting Technology Concepts

The knitwear industry has been evolving rapidly in most developed countries of the world. Unlike woven, knitwear articles are popular for their adaptative properties so as, by its texture, smoothness and increased bulkiness.

The knitwear industry has become popular in England during the XIV century through the initial manufacture (by hand) of socks and tights. The invention of the first knitting machine is normally assigned to Willim Lee in the year of 1589, England. The Lee machine, used for socks manufacturing, established the principle of the needles machine (W. Choi *et al.*, 2005). In the XIX century, many inventors contributed to convert the manual control machines into steam operated machines, through, which the knitting speed raised, leading to an exponential production growth. The invention of the needle latch and its inclusion in the circular knitting (first machine created in 1808), simplified the whole process and allowed circular knitting machines to be built.

3.1.4 .1 Weft knitting structures industry

In the apparel industry the final knit product is generally a piece of clothing, whose specifications depends upon their final application. The following image 10, illustrates the overall structure of the weft knitting industry.

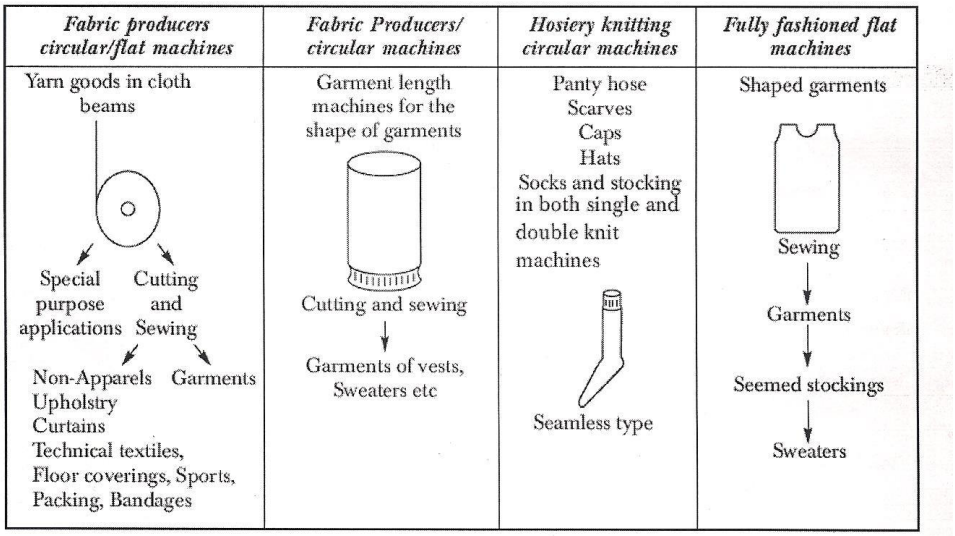


Figure 10 - Weft knitting Industry. (Source: Choi W. *et al.*, 2005)

3.1.4 .2 Woven fabric X Knits

The knitwear industry initially started by using wool as base raw material, but quickly spread to cotton and, subsequently, to non-natural fibres and all types of blend.

The knitting process is comparatively faster and more economical to convert the yarn into planar textiles, and even directly onto apparel, socks, etc. The direct manufacturing of cloths during the knitting process is already possible, which does not happen in the weaving process.

Besides being more economical, the garments made with knits are more flexible and offer greater comfort due to its excellent ability to adjust theire shape. Through modern technology and based upon a continuously growing automation, knitting design possibilities are immense. The knit industry is also characterized by his mass production capability.

The following considerations set forth a summary comparison between knits and woven fabrics:

- The woven fabrics are produced by the interlacing of warp and weft yarn, which requires the use of at least two yarn systems for its production. The knit manufacture requires only one yearn (knit fabric);
- The elasticity and flexibility of woven is significantly less than in knit fabrics, except for the use of special elastic yarns. The knits have the ability to “wrap” the body and adapt well to movement;
- Woven fabrics have higher durability when compared to knits and they are directly dependent upon yarn regularity, torsion and woven structure. The knit durability depends upon yarn tenacity, structure and row and column density.

- The moisture absorption is higher in knits than in woven fabrics due to their high bulkyness.

The image 11 shows a systematic classification of weft knittin machine:

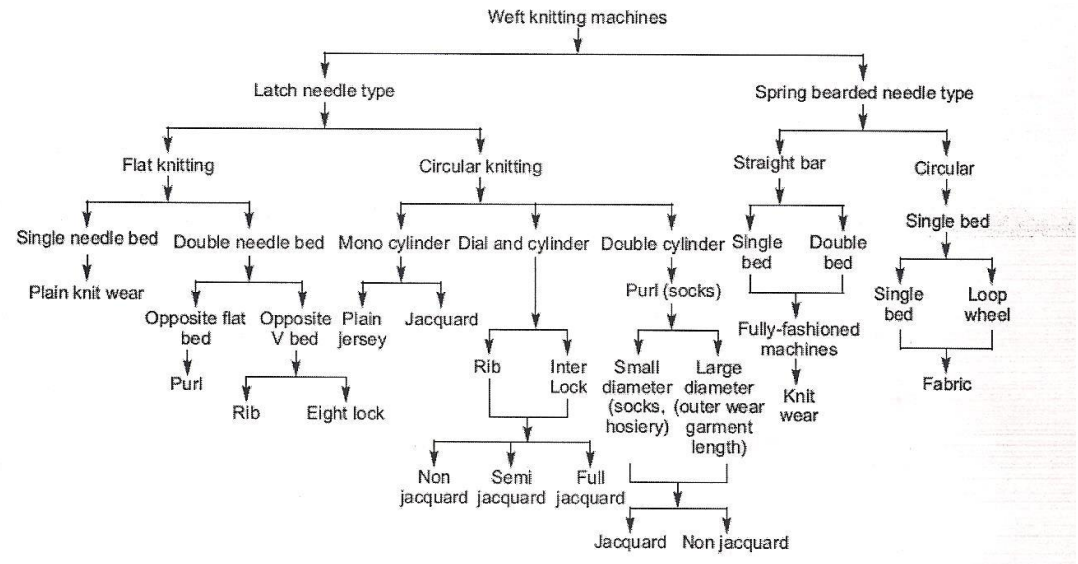


Figure 11 - Systematic classification of weft knitting machine. (Source: Choi W. *et al.*, 2005).

3.2 Physiology of the skin and its interaction with textiles

Our skin is, even when healthy, being colonized by non-pathological microorganism.

The skin is considered the largest organ of the human body. In an adult it can weigh up to 10 kilograms and can measure approximately 1,8m^2. Its functions among others are to protect the body against infections caused by fungi, bacteria, viruses and parasites. It is a protective barrier against physical and chemical agents in the environment in which we live. An important characteristic of the skin against infection is its pH level, which physiologically is around 5-6 (Runeman, 2000, p.421-424). Some areas of the human body have higher pH and they are more prone to infection caused by bacteria, such as axils, anal and genital regions and toe webs. (Bibel, 1993, p.407-411).

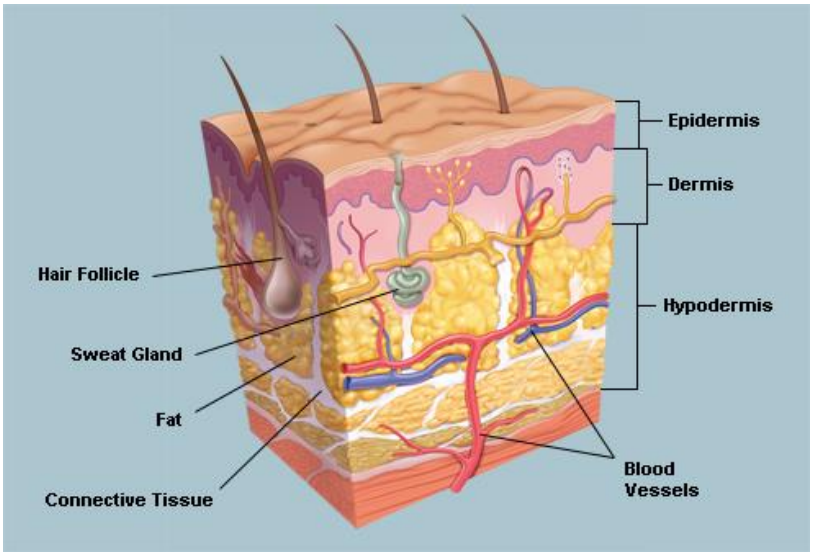


Figure 12 – Schematic of human skin. (Source: http://www.webmd.com/skin-problems-and-treatments/picture-of-the-skin)

There are several factors that may aid in the skin pathogen contamination development such as environmental factors (temperature and humidity), medication in case that the patient is being treated for a long period of time, impaired immune system of the individual (people who are in treatment of HIV[2] virus or diabetes), and last but not least the hygiene and cosmetics with antimicrobials (Burg, 2006)

We must be aware of the clothes and the skin infection risks, as it is already proven, when clothes are contaminated, germs and bacteria can spread through direct and indirect contact. In an environment which has high temperature and humidity it can help the proliferation of skin infections.

The textile, particularly gowns, interacts dynamically and directly with the skin. One of the most important interactivity of textile-skin is the thermo-regulation, which is caused by the heat evaporation and local blood flow. We must pay attention to gender, age and activity which will be performed by the user, so that we can adjust them, because these factors directly affect the skin thermo-regulation.

The quality of fabrics such as surface roughness can cause discomfort and even interfere with the integrity of the skin. The major forces that we must be careful of, when discussing the interaction of clothes with the skin surface in a mechanical way, are the pressure and friction. Smooth fabrics are more comfortable than the rough.

One of the most important factors in the functionality of the clothing is thermal insulation which is directly related to the thickness of the fabric and also to the volume of air retained (Havenith, 2003, p.35-49). The cutaneous sensibility is not evenly distributed throughout the

[2] HIV – Human Immunodeficiency Virus.

body, this sensitivity can be calculated in specific regions by changing the perspiration level and heat discomfort (Cotter, 2005, 335-345).

The more extreme environment combined with intense exercises higher the impact of clothing thermo-regulation (Barker, 1999, p.32-37). Fabrics should be able to assist the body in climatic changes. The comfort of the clothing is negatively associated to moisture, but positively to heat (Li, 2005, p.234-248).

Through the skin moisture, local blood flow and mechanical alterations of the functional barrier, the clothes can harm the skin antimicrobial defence (Adams, 2002, 309-321).

Fabrics should be thought to assist the body's functions and remain stable even in unfavourable environments.

3.2.1 Clothing and thermo-regulation

Thermo-regulation is the ability that humans have to regulate body temperature, it is usually maintained at 37ºC by nerve stimulation. Thermo-regulation in humans occurs through the transpiration or increased peripheral blood flow. The higher body temperature, the greater the heat loss.

> *"(...) As the ends have a large surface area, play a more effective role in thermal losses than any other body part. Due to vasodilatation*, increased *volume of blood is directed toward the skin, that is, a greater amount of heat is dissipated per unit of time*, and *then released to the environment."*
>
> (Geraldes, 2000)

After the decrease of body temperature, the heat transpiration is decreased, and heat production is enabled again (Piller, 1986, p.412-416).

The mechanisms of perspiration can be classified into:

- **Thermal Transpiration:** due to high temperatures;
- **Mental Perspiration**: occurs due to psychological reasons;
- **Unconscious Perspiration:** occurs automatically by the human body, it's a permanent function.

When we are dressed and have skin moisture, discomfort is increased (Van Der Berg, 1975, 166-167). To have a higher sense of comfort, the textile should mechanically, assist in sweat evaporation, that is, the fibres constituting the fabric needs to absorb sweat from the skin surface and expel it to the environment (Geraldes, 2000).

The textile can be divided into:

- **Dynamic Textiles:** it has low thermal insulation when the skin is hot and humid and high thermal insulation when the skin is dry and fresh. This textile absorbs moisture from the skin and transports it to the exterior, causing the textile return to the dry state.
- **Non-dynamic Textiles:** moisture absorbed by the textile remains static, thermal resistance is high when the textile is dry.

"(...) *The rate of heat transfer depends on the temperature difference per thickness unit and of the area of material through which the heat flows*".

(Geraldes, 2000)

3.3 Physiological comfort of functional textiles

The comfort of a garment is not measured only by its sensory component and thermo physiological comfort. Another component of comfort that's very important to develop a psychological one. This component of the clothing comfort is given by the user satisfaction with the clothing in itself, as the level of aesthetics, colours, fashion, etc... This is one of the most important in our work and is directly linked to social and cultural factors. It is the subjectivity of the individual.

The sensory comfort is defined by the perception of mechanical and thermal contact of the textile with the skin. It is a subjective result, where the user qualifies the touch: as soft, rough, smooth or even rough (Kawabata, 1980).

The thermal component is also an important component, because it defines the ability that the textile has to transpire, in other words, it's the favourable thermal sensations of the use of the textile on the skin, not too hot not too cold.

Another component, also very important, for the classification is the ergonomic comfort of the garment, which is defined by the shape of the garment relative to the body such as freedom movements and if the clothes pattern supports the natural forms of user's body.

This mechanical contact with the skin can cause its irritation, which should be avoided, because the chemotherapy patients have a debilitated immunological system due to the treatment, it may aggravate their condition or even develop other wounds infections.

The sensorial comfort is not a result only by the mechanical properties, it must also be related to the thermal physiologic properties. In the sensorial comfort equation below (1), we have a value which can range from 1 (best) to 6 (worst). This equation was published by the Institute of Hygiene Clothing Hohesntein (Umbach, 1997, p.73-81). Sensorial comfort can be determinate as follow the equation 1:

$$K_s = 0.360 - 2.54i_{mt} + 0.230i_b + 0.0188i_k + 0.0210i_o + 0.0170n_k + 0.0386i_f \quad (1)$$

LEGEND OF THE EQUATION:

K_s= Sensorial Comfort;

i_{mt}= Penetration water vapour rate;

i_b= Rate tackines;

i_k= Speed of liquid water absorption by the textile;

i_o= Rate defining surface properties of textile;

n_k= Number of contact points between the skin and the textile;

i_f= Level of flexural strength.

3.3.1 Skin Model

Skin Model is an international standard for measuring thermal physiologic comfort of textile materials, it is the only breathability test which is accepted by the European standardization in thermo-regulation, ISO 1993 (Bartels, 2003, p.2008-2010)

The Skin Model appliance assumes an average body temperature of 35ºC. In this apparatus several small holes are found, where upon the water can evaporate through it, this mechanism aims to simulate the real conditions of skin perspiration. Several conditions can be simulated, such as:

- Normal wear situations ISO 1993: Is perspiration in which the user does not feel himself sweating;
- Heavy sweating: A large amount of sweat on the skin surface;
- Heavier sweating: the user clearly perceives that he's sweating. There is a production of sweat vapours impulses made by the skin;
- After an exercise: there is a lot of sweat. This test is very important for sports fabrics. Loses the capability of thermal insulation (Bartels, 2006, p.54-56).

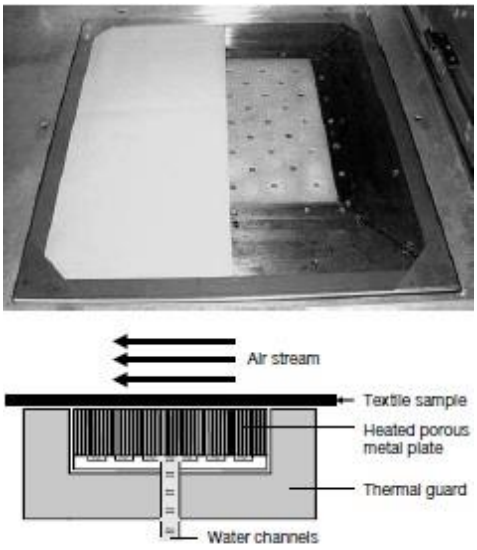


Figure 13 - Schematic drawing of the Skin Model. (Source: Bartels, 2006, p.54)

3.3.2 Alambeta

It is a relatively new apparatus developed in the Czech Republic for measuring the heat flow, it allows to measure specific properties such as heat and thermal diffusivity. With the use of Alambeta, we can also measure the thickness of the textile material used in the test.

The appliance has a metal block at a constant temperature of 32°C. A sample of textile at 20ºC (average temperature of the samples). When the measurement starts the sensor head is lowered from the top of the equipment until it touches the fabric sample. There is a sudden temperature change in the sample surface. It is at this point that the device records the evolution of the heat flow. The data obtained in the measurement is processed by computer through a specific software. Follow the table 2:

Table 2 - Quantity measured by the Alambeta device

Symbol	**Quantity**	**Equations**	**Unity**
h	Thickness	-	Mm
$\boldsymbol{\lambda}$	Thermal conductivity	$\lambda = (q.h)/(\Delta t)$	$[W/m.K]$
r	Thermal Resistance	R= h/λ	$[m^2K/W]$
a	Thermal diffusion	$a = \lambda/\rho.c$	$[m^2/s^{-1}]$
b	Thermal absorption	$b = (\lambda.\rho.c)^{1/2}$	$[W.m^{-2}.K^{-1}.s^{1/2}]$
q	Heat Flow	$q = b.\Delta t/(\pi.\tau)^{1/2}$	$[W.m^{-2}]$

3.3.3 Thermophysical Properties

3.3.3.1 Thermal Flow (q)

Some properties are very important for analysing the behaviour of textiles, these components can be transitory or stationary, first we analyse the heat flow measured when the textile is in touch with human skin, the feeling hot/cold. In the case of stationary the properties measured are resistance and thermal conductivity.

One of the most important components of the fabrics touch is in the transitory components; in sum the value (q_{max}) is the maximum value of the heat flow exchanged between the textile and the human skin. The first researchers to defend it were Yoneda and Kawabata. We can evaluate the thermal flow by the following equation 2:

$$q = \frac{b \times \Delta t}{(\pi \times \tau)_2^{1/2}} \qquad [\mathrm{W.m^{-2}}] \qquad (2)$$

LEGEND OF THE EQUATION:

$q =$ Thermal flow;

$b =$ Thermal absorption $\left[\mathrm{W.m^{-2}.K^{-1}.S^{1/2}}\right]$;

$\Delta t =$ Gradient of temperature;

$\tau =$ Time $[\mathrm{s}]$.

3.3.3.2 Thermal absorption (b)

The thermal absorption is a dynamic property, it represents the value of the thermal flow measured when there is contact between two semi-infinite bodies with different temperatures. It's directly related to the initial contact feeling of textile when it comes in contact with human skin. The structure and composition of the yarn for the development of the textile is related to the thermal absorption.

In the textile material, the values of (b) can vary between 30 and 300. The value of (b) is greater in the fibres in dry state. This concept of feeling hot/cold was appointed by the Technical University of Liberec as (b) thermal absorption.

Due to the high thermal conductivity of water, we can say that, it interferes directly on the thermal absorption. The value of (b) is greater in the fibres in the wet state than fibres in the dry state. A high value (b) means that the surface is cold. The higher value of (b), the higher the thermal flow is. To determine the value of thermal absorption, we use the following equation 3:

$$b = \sqrt{\lambda \times \rho \times c} \qquad \left[\mathrm{W.s.}\frac{1}{2}\mathrm{m.K}\right] \tag{3}$$

LEGEND OF THE EQUATION:

$b =$ Thermal absorption $\left[\mathrm{W.s.}\frac{1}{2}\mathrm{m.K}\right]$;
$\lambda =$ Thermal conductivity $[\mathrm{W/m.K}]$;
$\rho =$ Specific mass or density $[\mathrm{Kg.m^3}]$;
$c =$ Specific heat $[\mathrm{J/Kg.K}]$.

3.3.3.3 Thermal conductivity (λ)

Thermal conductivity is the quantity of heat flowing through the material per length unit for a temperature variation in Kelvin degree.

The higher the value (λ) the greater its ability to produce heat. The thermal conductivity is higher in pure metals than in gases and vapours. Due the fact of the fibres are more insulating, it presents a low thermal conductivity.

We can calculate the thermal conductivity by the following equation 4:

$$\lambda = \frac{q \times h}{\Delta t} \qquad [\mathbf{W} \,/\, (\mathbf{m.K})] \tag{4}$$

LEGEND OF THE EQUATION:
$\lambda =$ Thermal conductivity;
$q =$ Heat flow [W.m-2];
$h =$ Thickness [m];
$\Delta t =$ Gradient of temperature between two surfaces [K];

3.3.3.4 Thermal diffusion (a)

During the transfer of heat from the user's body to the environment through the clothing, the propagation speed of the temperature can vary until it gets to a steady state.

It's the thermal diffusion that determines the value of the temperatures propagation velocity through the material, this thermal impulse can be calculated by the following equation 5:

$$a = \frac{\lambda}{p \times c} \qquad [\mathbf{m^2/s}] \tag{5}$$

LEGEND OF THE EQUATION:

$a =$ Thermal diffusion $[\mathbf{m^2/s}]$
$\lambda =$ Thermal conductivity [W / (m. K)];
$p =$ Specific mass or density $[\mathrm{Kg.\,m^3}]$;
$c =$ Specific heat [J / kg.K].

3.3.3.5 Thermal resistance (R)

The thermal resistance is the resistance to heat flow through the material is inversely proportional to thermal conductivity.

For the purpose to obtain wearing apparel with specific properties as insulation and thermal contact, most often the textile products are developed with multiple layers that react directly with each other. The manners in which these layers are overlapping affect directly the value of the thermal resistance.

The final result of thermal resistance is calculated by the equation 6:

$$R = \frac{h_t}{\lambda_t} \qquad [\,\mathbf{m^2.K/W}] \tag{6}$$

LEGEND OF THE EQUATION:
$R =$ Thermal resistance $[\,\mathbf{m^2.K/W}]$;
$h_t =$ Total thickness $[\,\mathbf{m}]$;
$\lambda_t =$ Thermal conductivity resulting [W / m.K];

3.3.3.6 Thermal permeability

In the dry state, the thermal permeability of a textile structure is given by a function of thermal resistance and the heat transfer resistance by convection (the transfer of heat from one place to another is given by the movement of fluids).

The movement of the fluid volume increases the heat transfer between a solid surface and the fluid.

This property can be set in three different states:

- Thermal permeability in the dry state: πd;
- Thermal permeability in the wet state: πw;
- Thermal permeability to water steam: πv.

3.3.4 Physiological properties

The presence of moisture in textiles can be found as liquid and vapour. This humidity interferes directly in the comfort of textiles.

When sweat is evaporated to the textile substrate in the form of vapour, the air circulation in the pores of the textile substrate is facilitated while maintaining isolation of the article, but when sweat is evaporated to the textile substrate in liquid form, the sweat is evaporated only when it can reach the air layer present on the surface of the textile substrate, which consequently reduces the feeling of comfort once that the moisture is perceived by the sensory nerves of the skin. We feel that the clothing is wet, moreover the air pores, will be filling out by the moisture, impairing the evaporation and losing the insulating capacity, giving us the feeling of cold.

The knowledge of the properties of permeability to water vapour and evaporative resistance is of great importance, so that we can have an piece of clothing with the most sensorial comfort as possible.

3.3.4.1 Water Vapour Permeability

The permeability of water is what influences most the thermal physiologic comfort on the textiles.

It is very important that the sweat generated by the skin as vapour pass through the textile substrate, aiding in thermoregulation. Prevents sweat generated by the skin be retained between the skin and the textile substrate, increasing the feeling of comfort (Dhinakaran, 2008)

The permeability to water vapour is given in (%) and can be calculated by the following equation 7:

$$pv = 100\,\frac{qWs}{qw0}\ [\%] \qquad (7)$$

LEGEND OF THE EQUATION:

$pv =$ permeability to water vapour;

$qWs =$ heat flow measured by the thermal flow sensor in the presence of the specimen [W/m2];

$qw0 =$ heat flow measured by the thermal flow sensor in the absence of the specimen [W/m2].

3.3.4.2 Evaporative resistance

In physical terms evaporative resistance is the inverse of permeability of water vapour. It is also measured by the device Permetest. The evaporative resistance calculation is obtained by the following equation 8:

$$R_{et=\frac{pw_{sat}-pw_0}{qw_2}} \qquad [m^2 Paw^{-1}] \tag{8}$$

LEGEND OF THE EQUATION:

$R_{et} =$ Evaporative resistance;

$pw_{sat} =$ Saturated partial pressure of water vapour to a laboratory temperature from 20 to 22°C [Pa];

$pw_0 =$ Partial pressure of water vapour laboratory to a moisture percentage of 60 a 65% [Pa].

3.4 Permetest

This equipment is used for measuring water permeability and of the water vapour permeability of textiles. The use of this device is important because it has a high sensitivity and the results are given in a short period of time.

The measurements are performed according to the international standards ISO 11092. In terms of heat, this device simulates genuinely the human skin. The test arising of this device occur in a laboratory temperature ranging from 20 to 22°C rather than 35°C for resistance to water vapour, and a variation of environmental humidity between 60 to 65%, instead of a humidity level 40%.

3.5 Antimicrobial textile materials

One of the biggest concerns that industries have today is the negative effect that the presence of microorganisms in textiles may cause. Most often the type of textile fibre coupled with environmental factors such as temperature and humidity, can favour the development of these microorganisms.

The research carried out, in recent years has aided the development of textiles which contribute positively to: reduction of fungi that are present in hospitals, to reduce the odour caused by perspiration controlling microorganisms that can cause unsightly staining, to promote a barrier to the body and avoid possible cross-infection between patients. In addition, to support the new technology of antimicrobial product type antibiotic used during treatment, may determine different applications of antimicrobial textiles in the hospital environment such as: air conditioner filters, masks, clothing, shoes, decoration, furniture, sheets, etc.

The human body has natural nutrients, moisture and temperature suitable for the growth of microorganisms.

When we talk about medical textile, we should be aware about the toxicity. The textile combined with active antimicrobial agents, when in contact with human skin may cause localized irritation or even worsening certain diseases.

In order to develop functional textiles focused on healthcare, most of the time is used high-tech antimicrobial agents, these agents can be: Nano silver particles, Sanitized® Palladium, Silver Freshness, Agiene®, Bionyl®, Chitosan, etc. … The antimicrobial agent and the type of technology to be used is chosen by the role that textiles should perform. When we applied antimicrobial products in textile we seek to inhibit the growth of these microorganisms by changing the permeability of the cell membrane, damage the cell wall, provide protein denaturation, preventing the synthesis of lipids and prevent enzymatic activities. In the following table 3 we can observe the spectrun characteristics of antiseptic agents.

Table 3 - Antimicrobial spectrum and characteristics of hand hygiene antiseptic agents. (Source: Biofunctional textiles and the skin, p. 39)

Group	Gram-positive bacteria	Gram-negative bacteria	Myco-bacteria	Fungi	Viruses	Speed of action	Comments
Alcohols	+++	+++	+++	+++	+++	fast	optimum 60–95%; no concentration persistent activity
Chlorhexidine (2% and 4% aqueous)	+++	++	+	+	+++	intermediate	persistent activity; rare allergic reactions
Iodine compounds	+++	+++	+++	++	+++	intermediate	causes skin burns; usually too irritating for hand hygiene
Iodophors	+++	+++	+	++	++	intermediate	less irritating than iodine; acceptance varies
Phenol derivatives	+++	+	+	+	+	intermediate	activity neutralized by nonionic surfactants
Triclosan	+++	++	+	–	+++	intermediate	acceptability on hands varies
Quaternary ammonium compounds	+	++	–	–	+	slow	used only in combination with alcohols; ecological concerns

+++ = Excellent; ++ = good, but does not include the entire bacterial spectrum; + = fair; – = no activity or not sufficient. Hexachlorophene is not included because it is no longer an accepted ingredient of hand disinfectants.

A great challenge for textiles researchers is to achieve control and simulate the conditions, which may be encountered in a real hospital environment, in the laboratory.

Textiles used for healthcare purposes must have a strategie to counter the growth of microorganisms existing in garments, beddings, and linen surgical fabrics. The antimicrobial agents used for this particular function must kill microbes but do not eliminate them completely, because our micro flora's body need some specific microorganisms for the

protection and immune system functioning. When humans are exposed to these microorganisms without any control, various reactions may occur, such as: irritation of the skin and eyes, interference in respiratory system and even aggravate the patient's condition. In favourable microorganisms growth conditions it can proliferate from one organism to over a billion in 24 hours.

People with low immune system, respiratory problems, new-born, sick, very invasive medical treatments as in the case of chemotherapy or after surgery should minimize contact with microorganisms. Curtis (2002), states that the challenges faced for the right choice of technology and antimicrobial agent for the development of medical textile depends on:

- **Durability:** the medical textiles must be treated with antimicrobial agent that resist abrasion, sterilizing, washing and drying;
- **Waste Control/ Toxicity:** antimicrobial treatments should not affect good and helpful microbes. The treatments based on heavy metals should be avoided, as in the case of silver, in high concentration may interfere directly on the cell walls;
- **Spectrum activity:** antimicrobials agents should fulfil a specific activity;
- **Adaptation:** during the development process of the textile should be attentive to capacity of the cell mutation, which is to adapt to antimicrobial agents making them void.

The research and development of new technology for the optimization of medical textiles is of major importance for society in general. Medical textiles must provide the best care possible for patients and sufficient security for medical personnel.

3.5.1 Type of activity of antimicrobial textiles

The technology and the antimicrobial agents used for the development of medical textiles should be considered even before the testing antimicrobial activity. It was established three basic procedures:

- The bioactive substance applied directly to polymer mass.
- The bioactive substance applied to the fibre surface.
- Textile, non-woven and knits coated with finishes containing bioactive substances,
- According to the technology used and the antimicrobial agent applied to the textile materials can be divided into passive and active materials effects (MUCHA, 2002, p.238-243).

3.5.1.1 Passive antimicrobial principles

Are those who have no antimicrobial additives.

The cell walls of the microorganisms are not affected; the microorganisms are prevented from adhering to the surface of the fibre. Examples include antimicrobial polymers linked by polycationic components that interact with the cell wall (Thölmann, 2003, p.105-108).

3.5.1.2 Active antimicrobial principles

Are applied in most tissues for healthcare application. They possess antimicrobial agents which act directly on the cell membrane.

The antimicrobial agents commonly used are based on silver nanoparticles, other products have antimicrobial activity such as Quartenary Ammonium and Chitosan, the last one is a natural antimicrobial agent found in the exo-skeleton crustaceans, a sustainable and renewable alternative for applications in healthcare.

The effectiveness of active antimicrobial products is through the exchange of ions by replacing actions of perspiration (Takai, 2002, p.75-81)

3.5.2 Evaluation of effectiveness of antimicrobial textiles

The efficacy of antimicrobial textiles can be evaluated by the following standards:

Table 4 – International standards for antimicrobial activity evaluation

DESIGNATION	TITLE	PRINCIPLE
ISO 20743:2007	Methods to determine the antibacterial activity of antibacterial finished textile products including nonwovens	Agar diffusion test
SN 195920-1992	Determination of antimicrobial activity	Agar diffusion test
SN 195921-1992	Determination of anti-mycotic activity	Agar diffusion test
EN 14119:2003-12	Evaluation of the antifungal action	Agar diffusion test
ASTM F 2149-01	Standard method for determining the antimicrobial activity of antimicrobial agents without dynamic contact conditions	Suspension test
JIS Z 2801	Test for efficacy of antimicrobial products	Suspension test
JIS L 1902-2002	Testing of antibacterial activity and efficacy in textiles	Suspension test

This research was carried under the conditions of the European standard: ISO 20743:2007.

3.5.2.1-Test Agar diffusion

Kirby and Bauer were the first to observe and described Agar diffusion test in 1966. It is a method widely used in microbiology laboratories, because it is simple and reliable (Brazil ANVISA, available in www. portal.anvisa.gov.br). It is a test which can be done in various microorganisms.

The test determines the anti-microbial activity by the zone of inhibition growth of bacteria surrounding the sample, or lack of antimicrobial activity, no inhibition zone is visible.

3.5.2.2 Suspension test (Challenge Test)

Initially, the test was developed for application in textiles, but soon it was noted that the great contribution to the investigation of antimicrobial textiles due to its excellent ability to evaluate the degree of antimicrobial activity.

It can also be used to determine the antimicrobial activity of passive type textile.

For the calculation of antimicrobial activity is required the same concentrations of the bacterial inoculum and the same concentrations of antimicrobial agent mus be equal in the investigated samples, once that the calculation to evaluate the antimicrobial activity is done by starting the weighted average of eight samples used.

3.5.2.3 Test for specific antibacterial activity

To evaluate our test we followed the standard 20743:2007. This standard provides the result in logarithmic units. Therefore indicates how many orders of magnitude the microbial load compared to negative control (unfinished fabric antimicrobial) have been reduced. With the results of number of CFU[3] of the samples is calculated the value F and G.

With negative control was calculated the value of growth (F), follow the equation 9:

[3] Colony forming units.

$$F = (\text{Log } Ct - \text{log } Co) \quad (9)$$

LEGEND OF THE EQUATION:

F= the value of growth

Log Ct = (half the decimal logarithm of the number of bacteria obtained from the three negative control fabrics after incubation for 24 hours)

Log Co = (half the decimal logarithm of the number of bacteria obtained from the three negative control fabrics immediately after inoculation)

With the samples it was calculated the value of growth (G), where in the equation 10:

$$G = (\text{Log } Tt - \text{Log } To) \quad (10)$$

LEGEND OF THE EQUATION:

G= the value of growth

Log Tt= (half the decimal logarithm of the number of bacteria obtained from the three samples treated with an antibacterial treatment after 24 hours incubation)

Log To= (half the decimal logarithm of the number of bacteria obtained from the three samples treated with antibacterial treatment immediately after inoculation.

From the value of F and G the value of A is calculated, that indicates the bacterial activity of antibacterial fabric, follow the equation 10:

$$A = F - G \quad (10)$$

Where:

A = (Log Ct – log Co) – (Log Tt – Log To)

The results can also been analysed with the percentage reduction formula. This formula is used in other antimicrobial standards such as ATCC 100 or ASTM E 2149. Equation 11 - Antimicrobial activity in %:

$$R(\%) = \frac{B-A}{B} \times 100 \quad (11)$$

LEGEND OF THE EQUATION:

R= Animicrobial activity

B= cfu/ml at t=24 hours (negative control)

A= cfu/ml at t=24 hours (treated samples)

3.5.2.4 Evaluation of safety of antimicrobial textiles

As previously mentioned, the antimicrobial and hygienic textiles industry is increasing every day. To assure the advantages of using these products, it is necessary to perform tests of the interaction between finished antimicrobial textiles with human skin. The fabric safety is of great importance for the development of our prototype antimicrobial gown, as in patients with debilitated immune systems they may develop irritations, allergies and even aggravate the disease, by these and other reasons we must ensure that the textile does not provide any toxicity to the skin.

3.5.2.5 Biological safety tests

Tipically the safety test of antimicrobial textiles standart used is EN ISO 10993. This standard determines the type of risk that should be evaluated based on application of the textile and the contact time with the user's skin.

3.5.2.6 Cytotoxicity

When developing articles for medical purposes, it is very important to be attentive to the effects that antimicrobials can cause, they can release some toxic substances to the cells of the skin during the use.

To assess this feature, standart EN ISO 10993 is used, the test simulated artificial perspiration solution, which can provide information on the cytotoxicity of the substances present in textiles when analysed fibroblast and keratinocytes derived from human skin.

3.6 Technology of knitwear manufacturing

3.6.1 Generalities

The development of functional knit is very important for the world market, since it allows the meeting of specific needs in different fields of industry. The advancement of new technologies, coupled with the investigations come further along to improve the level of safety and comfort for the users of these articles.

The rich and emerging countries have been investing new technologies for functional knit, especially growth regarding the antimicrobial knit for applications in the medical field, and also, no less important, for hygienic clothing as in the case of clothing focused on the food industry.

3.6.2 Historical Perspective

Most historians says that the knit was originated in the Middle East and then, with the beginning of the market routes in the Mediterranean Sea, this technique came to Europe and was later spread to America, due to the European colonization (Zilboorg 2001). The oldest knit dated from the XXI BC, in Egypt.

In Europe the origin of the knit was different depending on the region. In Holland it was worked into naturalists' patterns, which later was taken by the Dutch women and taught the women of Denmark. In Austria and Germany, were developed embroidered knit in colourful and heavy costumes.

In South America, particularly Peru and Bolivia, the knit of the Andes was developed, which was marked by the predominance of men during the development process, unlike Europe which was made mostly by women. This region developed knit not only for the purpose of wearing, but also as an ornament, for example is the millinery and ear protective due to very cold weather during the winter.

After the Industrial Revolution in Europe and in the U.S., knits began to be produced by machines, which increased the production capacity in large-scale and improvement of the finished product.

The first knitting machine was developed in 1958 by the Englishman Rev. William Lee. The machine was developed in England, but with the lack of interest of Queen Elizabeth to patent the invention, Lee took his invention to France, where his idea was sold and thrived. During this period slight changes to the knit production setting were made, what was previously considered women work became a man's' work, since they are stronger and able to do heavy manual labour in the industry. Typically, women had functions related to the knitwear finishing, such as pattern making and sewing.

In the 80s, there is a decline in the production and consumption of knit, because people thought that this technique was already outdated and out of standards for that time. At the beginning of the century 21, there is a resurgence of this technique. The threads industries are performing new technologies to develop new threads blending different materials, which will later on be crafted by designers, creating patterns, textures and knit finishing to please a group with specific needs.

3.6.3 Brief of knits manufactured technology

The knitting developed for this research was made in the Textile Engineering department at University of Beira Interior. The equipment used was a single cylinder circular knitting machine, Vanguard Supreme. With this equipment is only possible to develop knitting in Jersey structure, varying the tightness of the loops.

Using the circular machine, the knitting can be developed in almost any reasonable diameter. The diameter of the machinery can vary according to special purposes.

Jersey is one of the simpler knitting structures. Smirfitt (1975) says, *"Weft Knitting is the process of making a fabric by performing a set of loops from connected weft yarn inserted into successive row across the width of the fabric (…)"*.This simple structure is the base from which further elaborated structures are built from.

When mentioned knitting fabrics, it is important to say that there are two kinds of knitted stitch, called weft and warp knitting which are defined as:

- Weft is when the loops are made horizontally across the knit and can be made by single thread.
- Warp is when a different system of knitting is to supply at least one thread to every needle. The ends of the fabric run down.

This investigation was made in weft knit.

When we observe the surface of the jersey knitting, we note that it has vertical columns of loops, these vertical columns are called wales, and the horizontal are called row courses. In the process of making knits the tightness of the mesh can vary, it can be tighter or a bit looser between itself. The tightness of the loops influences directly the behaviour of knitwear. The tighter the loops are, the stiffer the malleability is and, the larger space between the loops, the greater is the flexibility on the knit surface.

The knits gradually has the ability to recover from its distorted state when the deforming force is released.

The needle spacing of the circular machine which was used to build the knits for this research, according to the gauge chief system is 14 needles per inch.

CHAPTER 4

EXPERIMENTAL DEVELOPMENT

4.1 Design and gown development

During the conception and development of the we seek to provide easy medication access and, also to promote sensory, psychic and ergonomic comfort to the patient. Another important feature is its antimicrobial behaviour, and especially to avoid cross infection among workers and patients that have a very weak immune system.

Other considered issue in the development of the prototype was sustainability and the environmental concern.

The prototype has in the chest part an opening for easier application and handling of the chemotherapy catheter. The prototype sleeves are in Velcro designed to facilitate opening the gown for the serum medication. In the lower front part, there is a cut-out all around its circumference, so that the children can interact with their clothes, increasing or decreasing the length.

The prototype development entailed the following guidelines:

- DESIGN: we sought to create a product aesthetically viable, meeting the needs of a functional product for application in hospital environment. Comfort and functionality were the key words of the prototype. Avoiding chemicals, colours was worked out the hemp natural colour (greyish) mostly. Small and colourful details has been applied through digital printing.
- SHAPE: It was developed in order to obtain the greatest ergonomic comfort possible and to facilitate the movements of the patient´s moviments while being dressed/undressed in case of needing urgent/emergency care.
- MATERIALS: The selected materials are tought to provide an optimal antimicrobial activity, beeing environment friendly, and assist in thermoregulation and patient comfort.

4.1.1 Characterization and conceptual development of the gown

The gown has been developed through different stages during the process of conception and manufacture. The first phase stage in the design of the prototype was: drawing the garment by itself and developing the pattern making, both processes have been done in specific software, to the purpose desired.

During the conception of the prototype we always sought to suit the highest level of comfort and interactivity of the patient/clothing. Another function which was also prioritized: the flexibility of movements.

For the development of the very first drawings of the prototype we used *Corel Draw*, which greatly facilitates the design and the understanding of it. The pattern making used in the prototype was created in a different program, called *Modaris* (which is a specific software of Lectra Systems for the preparation of the pattern making and the development of scales for clothing).

The pattern making of the developed gown can be viewed in the following image 8:

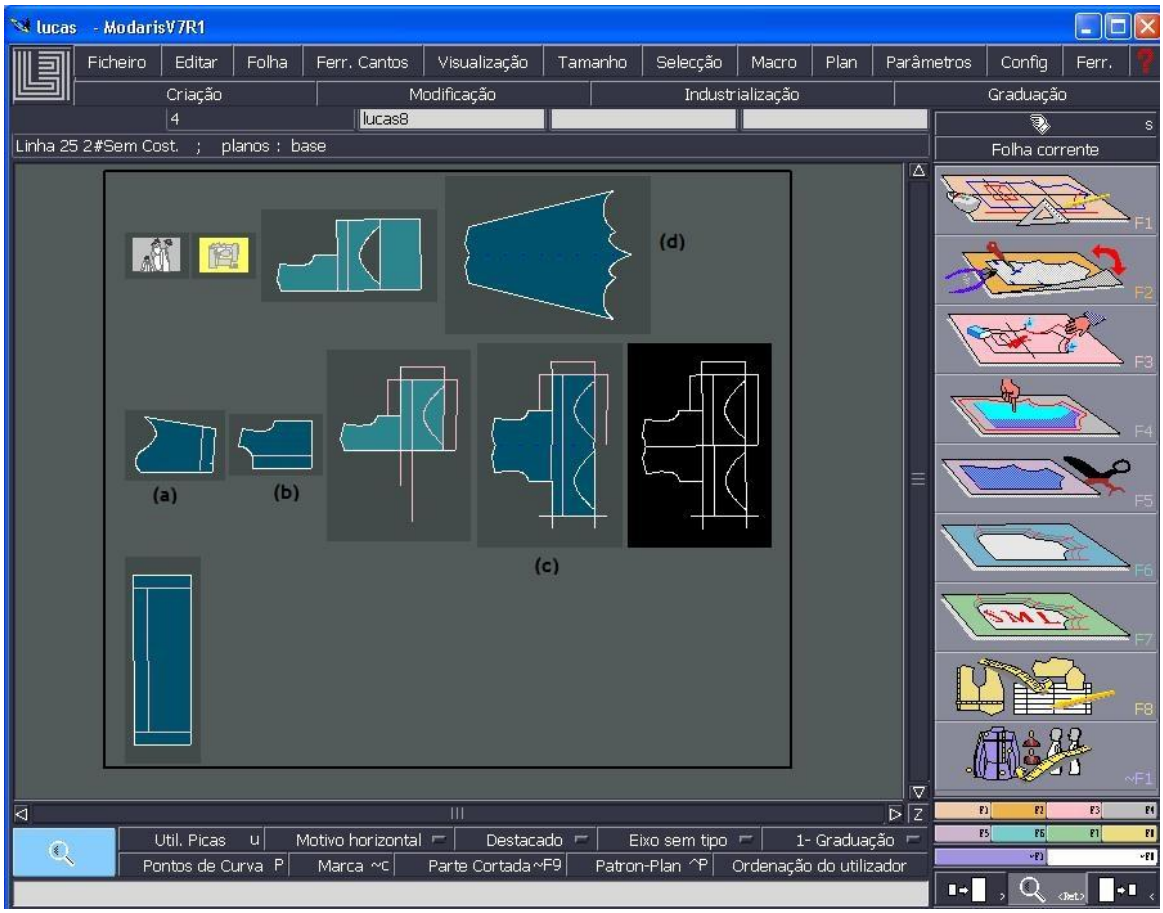


Figure 14 – Pattern making. (a) Sleeve (b) Front (c) Back (d) Cover

4.1.2 Anthropometric measures

Today, in the apparel market, there are already patterns with measurement scales for the age group 2-8 years, however, these measures may vary from one country to another because of the local people characteristics, so the measures presented in the table below, follow no standard established earlier. We measured 31 children for each age. The data is shown on table 5:

Table 5 - Clothing anthropometrics- Analysed measures.

	AGE			
MEASUREMENT (CM)	**2**	**4**	**6**	**8**
Chest	46	49	52	55
Shoulder	6	7	8	9
Waist	44	46	48	50
Hip	49	52	55	58
Overall height of the Clothing in front	40	43	48	50
Total height of the cut-out in front of the Clothing	27	30	35	37
Height Long sleeve	30	36	40	45
Height of cut-out of the Long sleeve	15	18	20	22.5
Width of the fist	10.2	10.5	11.5	12

4.1.3 Characterization of the raw material and knit structure

The selection of fibres, that we worked can be justified due to their intrinsic properties for the development of this dissertation. Cotton is already widely applied in the development of hospital textile and hemp was a possible viable alternative, in which was selected to investigate for replacing cotton as more eco-friendly and sustainable fibre.

4.1.3.1 Cotton and its main properties

The cotton fibre is a white or whitish, some species of the genus *Gossypium*, family *Malvaceae*. It's a natural fibre coming from the cotton plant consisting of approximately 94% cellulose. The material produced is organic and takes around three months to decompose, presents a moderate difficulty regarding their recycling, due to difficult access to the technology to make the recycling process.

For the environment cotton production is not very viable, since it requires a large area for its cultivation, a great need for water and the fact that the fibre is widely attacked by fungi and bacteria (but resists moths and insects). During its cultivation it's necessary to use various types of anthelmintics, insecticides, agrochemical and other chemical fertilizers, which can weaken the soil making it difficult for subsequently uses and cultivation for other crops.

The cotton fibre is a seed hair, formed by elongating a single epidermal cell. The cotton shape is tubular flattened and twisted. The fine fibres are twisted even more. The surface is slightly irregular, sometimes has a small transverse striations. Cotton fibre is soluble to sulphuric acid. When the fibre is burned, it burns rapidly and has very little waste, the ash is grey-yellow very thin. Its heating behaviour the fibre decomposes before melting (350°C). It does not melt. Its burning smell is like burned paper.

The fabric made by cotton has better moisture absorption capacity and is adequate for hot and humid weather. The body perspiration is better absorbed when using cotton fabric in its

composition; it has a soft touch and is extremely comfortable and durable. The fibre is very easy to be washed, but it doesn't resist to chemicals very well.

The culture of the cotton fibre is one of the most destructive to cultures environment. Researches prove that only in the U.S. annually, are used more than 124.74 million kilograms of pesticides in cultivation of cotton and added to this, there is also the need for massive amounts of fertilizers, growth regulators and biocides in general as methyl bromide. Cotton production requires large quantities of water, which can deplete this resource and even cause deposit of salts in the soil, preventing future crops. The area where cotton plants grows on can cause dry and oxidize soil there, releasing carbon to the atmosphere decreasing fertility of the soil.

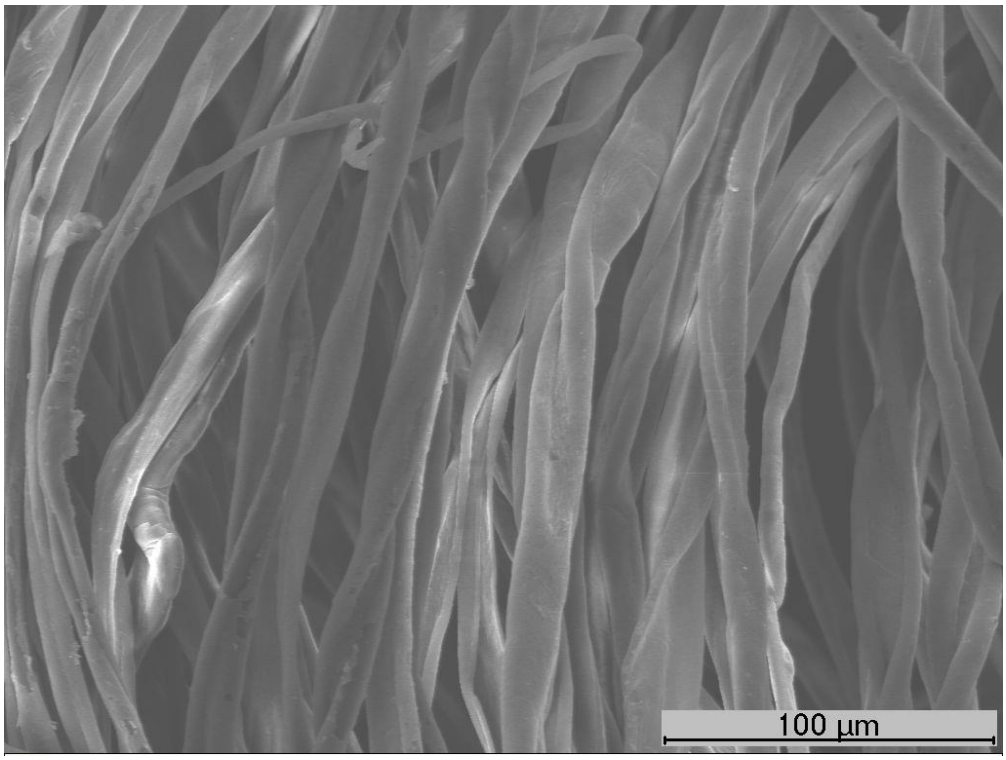


Figure 15 – Cotton fibre without any treatment (Magnification: 400)

4.1.3.2 Hemp and its main properties

Hemp fibre is a natural fibre. The common hemp stalk is derived from the *Cannabis Sativa* it is a mistake to compare the fibre hemp with marijuana, because hemp fibres contains very low levels of the psychoactive chemical tetrahydrocannabinol (THC). The elementary fibres are similar to linen in size and general appearance.

The hemp surface is irregular, smooth, flat to touch, and cold, has a very low elongation due to its high resistance. Nodules may or may not be present depending on the fibre. Note an inner medulla. The fibre is soluble in sulphuric acid. Their burning reaction is very rapid and leaving flashpoints. It leaves very little ash, which is grey-yellow very thin. When the fibre is burned, it

smell is like burned paper as cotton fibre. It does not have a melting point, due to the fact that the fibre does not melt.

When hemp fabrics are wet their resistance is increased. The fibre length is varied. Fibre simple: 20 to 25mm long fibre 100 to 300 mm, tow 30 to 40 cm.

Hemp products are primarily used for technical items such as lines to tie, cords, cables and ropes for navigation. The hemp fabric has the property, once the wetting fibres are swollen, to be a more compact tissue.

The cultivation of hemp has been widely investigated by scientists. It is proven that it is a great fibre for cultivation due to being environmental friendly. For the cultivation of this fibre an authorization is required by law. Depending on the laws of each country in the European community the cultivation is supported and subsidized, in addition to certified seed (which ensures legal THC level), you must have an agreement (purchase and sale) with a transformer authorized by the state, which is only found in France and Spain.

The hemp fibre has a huge potential, it is a natural fibre and biodegradable. The harvest farming is faster, it is good for the soil and uses no chemicals in its cultivation. It provides an environmentally friendly alternative to non-organic cotton which is environmentally destructive. Hemp growing provides soil enrichment by Nitrogen deposits, which can benefited with rotary crops of soybeans and corn for example. In the cultivation of hemp is not used practically any pesticide, and in its cultivation, in the same area, is possible to obtain 250% more hemp fibre then cotton.

Hemp has the longest fibre found in nature, is naturally resistant to mould UV ray. Each washing the fibres becomes softer, once it relaxes in presence of water. In 2006, a study was published by the International Journal of Phytomediation (Campbell *et al*. 2006), in which scientists have found that Industrial Hemp, can assist in *Phytoremediation* of contaminated soil, which is an emerging technology to clean up contaminated soil. This technology is very viable and inexpensive. The study Showed que industrial hemp (*Cannabis sativa*) has a very tolerance to benzo [a] pyrene and crysene. Hemp would be a prime candidate for remediation of PAH-contaminated soils.

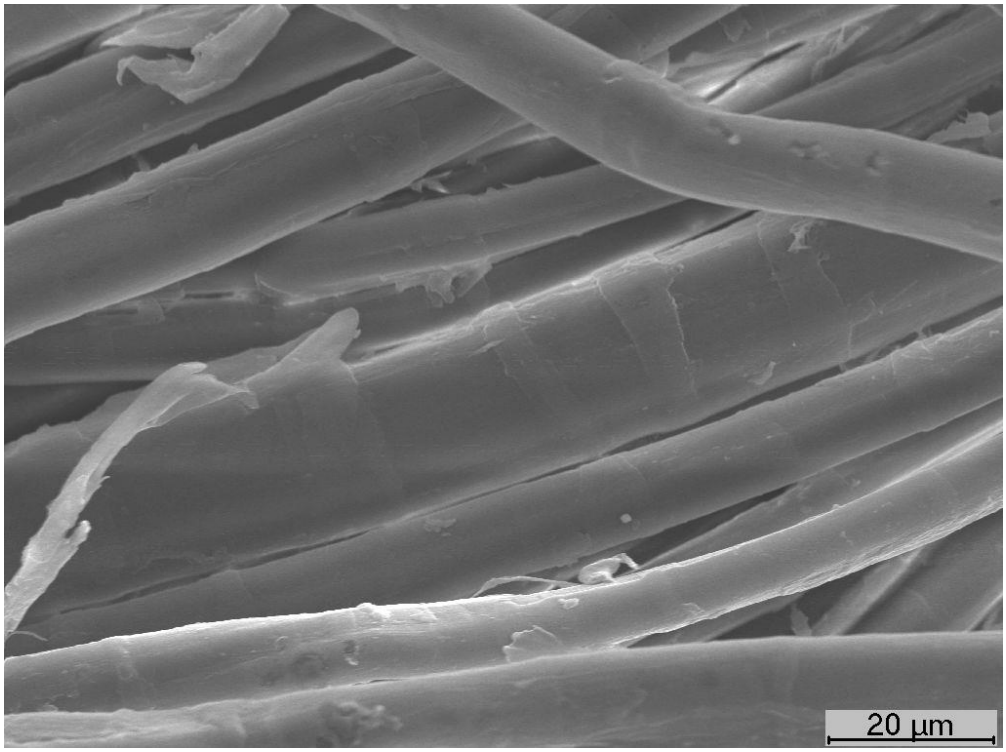


Figure 16 – Hemp fibre without any treatment (Magnification:1000)

4.1.3.3 Characterization of the produced knitwear structures

After the selection of fibres that have been previously characterized, the yarns were aiming to develop the knits for this study and later on, when the result is approved, follow the development of the prototype.

The yarns used to the knit production were bought. The charecteristics of those yarns are expressed in the table 6:

Table 6 – Technical characterization of the yarn

YARN	COMPOSITION	YARN COUNT (Nm)	TWISTING (turns / m)
A	100% Hemp	1/30	500
B	100% Cotton	2/60	520

The knits produced have the following dimensional properties, show in the table 7 and 8:

Table 7 - Morphological structure of Hemp knit

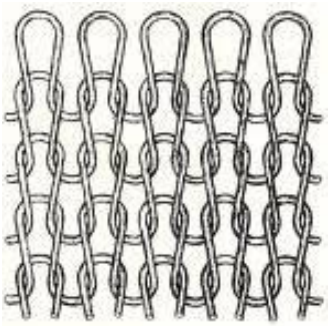
Fiber	Hemp
Weight	1.9g
Mass/ surface unit	173g/m^2
Density of rows	13
Density of columns	8
Loop length	1.22cm/loop
TEX	35
Nm	1/30
K	4.85
Structure	Jersey 

Table 8 – Morphological structure of Cotton knit

Fiber	COTTON
Weight	2.33g
Mass/ surface unit	211g/m^2
Density of rows	17
Density of columns	9
loop length	1.13cm/loop
TEX	18
Nm	2/60
K	3.75
Structure	Jersey 

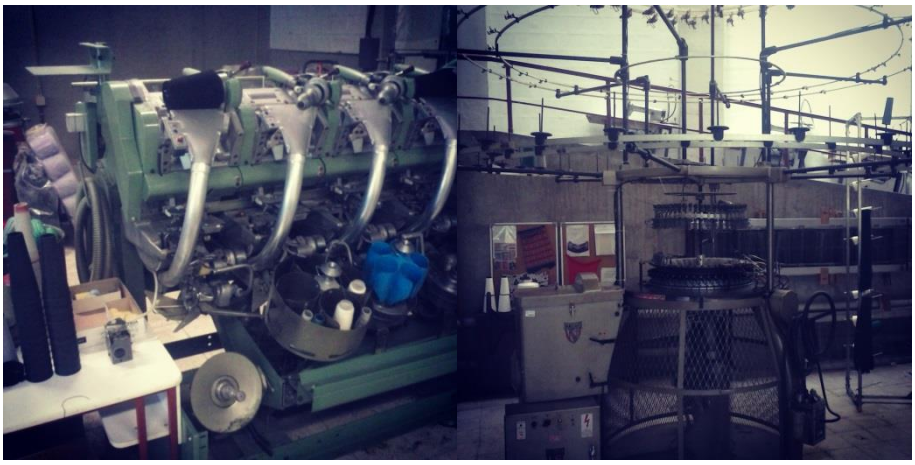
4.1.4 Experimental methodology

After the drawings approval for its technical features, we initiate the second stage of the process, the knitting phase.

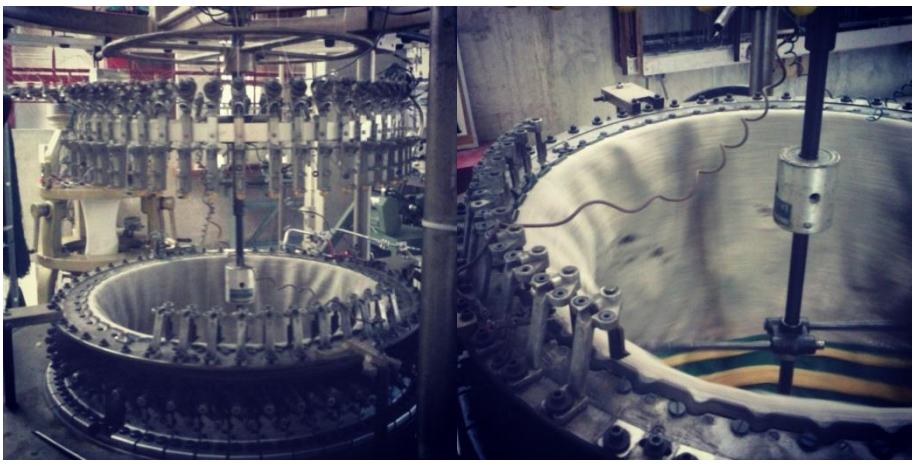
The knits developed in this research were made in the Department of Science and Textile Technology at University of Beira Interior. The machine used was a jacquard circular machine, called as Vanguard Supreme, which is a single drum roller; it has 14 needles per inch and can develop only Jersey structured grids. The characteristics of the machine were adjust for this performance by tightening of the loops and the speed of production per minute.

Another important process for the yarn was waxing for better knitting is covered with paraffin, in the winding machine with predefined specifications.

The machinery used to the knits production can be seen through the following image 17 (a), (b),(c) and (d).



(a) **(b)**



(c) **(d)**

Figure 17 – (a – b) Winder machine (c - d) Knitting machine

4.2 Antimicrobial agents

After the confection of the knits, they were separated and treated with different antimicrobial agents in order to facilitate studies of the antimicrobial activity of each, and better characterization of which agent should be used to perform this particular application (clothing for children under chemotherapy treatments). The antimicrobial agents used were: Bionyl®, Agiene® and Chitosan, their properties and application method on the textile surface will be further detailed.

4.2.1 Bionyl®

The antimicrobial Bionyl® 650 F1P1, is a powder product based on polyamide polymer 6 powder (very porous) coated with antibacterial agent (quarternay ammonium type) manufactured by DDG S.L, Spain. This product is not water soluble and has twice stronger anti bactericides properties that quaternary ammonium salt. It is an inorganic based powder or thermoplastic polymers or thermosetting. The fabrics treated with Bionyl® can also be used in many hospital applications: home care, hospital and other environments.

The product Bionyl® can be applied in mask for uses in medical environment, due to the fact that even with the presence of breath humidity it does not interfere with its antimicrobial activity because the product is not water soluble.

It is a product that is resistant for several washing cycles, ideal for use in long-uses textiles without losing the effectiveness of the antimicrobial activity.

4.2.2 Agiene®

Agiene® is an advanced silver antimicrobial treatment for textiles. Agiene® Micro Silver Crystal Technology was developed by Anovotek, LLC and is distributed and supported worldwide by Pulcra Chemicals. Unlike most antimicrobial products, the active ingredients in Agiene® treatments can be recycled by textile manufactures which is another plus for environment. 35% of global consumers have purchased a product with antimicrobial properties, 38% of global consumers would pay more for an antimicrobial treatment product. Therefore it is a great importance join a product with antimicrobial functionality and simultaneously eco-friendly.

Agiene® product is engineered with particle size and optimal use of this precious metal while creating superior antimicrobial protection.

Is a product that aims to eliminate bacteria present in tissues and simultaneously combating odour caused by them. At a temperature of 250C it has a white emulsion appearance, of ionic nature, slightly anionic. pH: 4.3, It is a safe and effective product, sensitive to light.

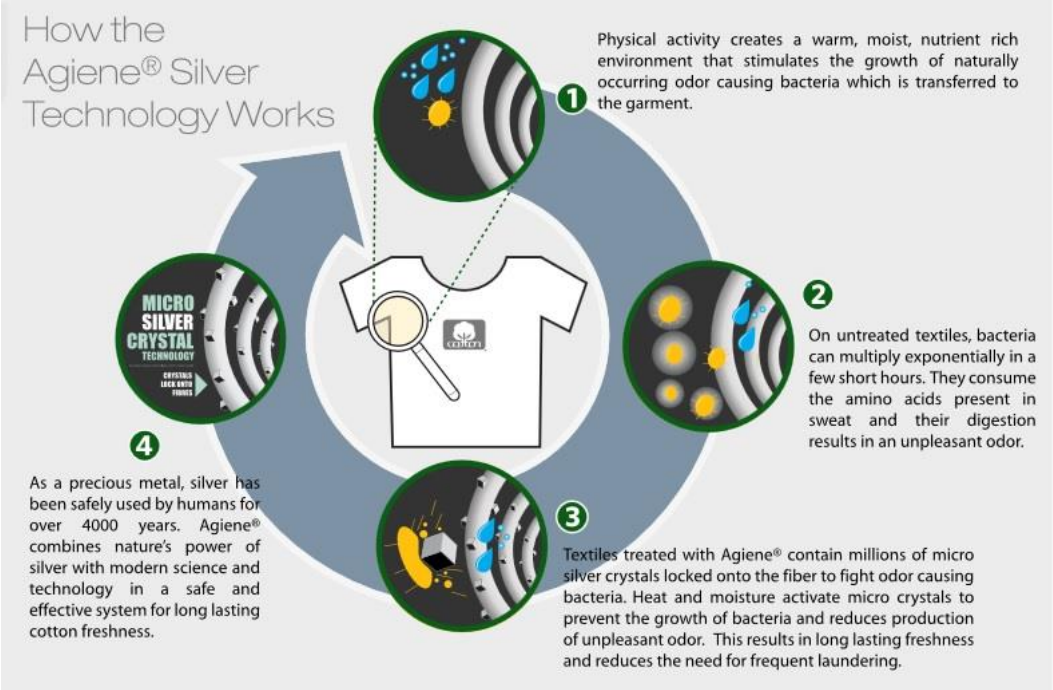


Figure 18 – How Agiene® acts (Source: www.agiene.com/how-agiene-fights-odor/)

4.2.3 Chitosan

Chitosan is produced by deacetylation of chitin, which is the structural element in the cell walls of fungi and also in exoskeleton of crustaceans, it is a renewable natural resource (it's a nontoxic natural polymer and biodegradable to natural body components), can be a natural polymer transformable into fibres with wide application fields in medicine, pharmacy, food technology, biochemistry, etc.

In medicine it may be used as an antimicrobial agent, and bandages to be used in order to stop bleeding, but it can also be used to deliver certain drugs through the human skin.

The agents of chitosan works interactively between erythrocytes and cell membrane, which possess negative charges and chitosan has positive charges, which leads to rapid formation of thrombi and also the involvement of platelets.

The lack of positive charge means that the chitosan is insoluble in neutral and basic solution. However, when this substance is found in acidic solution, protonation occurs at amide groups, leading to improved solubility, which is of great importance to the biomedical field.

4.3 Antimicrobial application methods

4.3.1 Bionyl®

The treatments will be discriminated as follows.

4.3.1.1 Print - Screen

The method of printing consists in stretching the fabric in the stamping table, where posteriorly will receive the chemical agents. With a printing screen and the product placed on it, the screen is overlaid on the fabric. A manual pressure is applied, with the purpose to spread equally the chemical agents throughout the screen surface, so the fabric absorbs it. With the fabric already treated, it is necessary to fix the product on the fibre. The tissue is moved to a warm kiln which aims to facilitate the drying and chemical fixation of it on the tissue. To prepare the solution for Screen Print, follow the recipe in table 9:

Table 9 – Screen Print recipe

Product:	Weight (g)
Bionyl®	5
Resin Centre 441 (latex)	20
Clear HC (thickening agent)	3
Distilled water	72

For the solution, the products are placed in the order of the table above. Operating the machine need to use the following values: pressure of 2 (value indicated on the equipment), scrolling speed 10% (value indicated in the equipment = 0,026 m.s -1). Once the emulsion is applied, we need to dry the examples of knit, at a temperature of 80ºC. Once the knits are completely dry, it should be cured for one minute at a temperature equal to 120ºC.

Note that with the finished knit we can perceive the touch and the presence of a thin resin layer where it was applied. The product is concentrated on only one side of the knit. This treatment may not be as effective, because is not found the product in the other surface. Images 19, 20 (a) (b) ilustrated the machinery, cotton and hemp printed with Bionyl respectively:

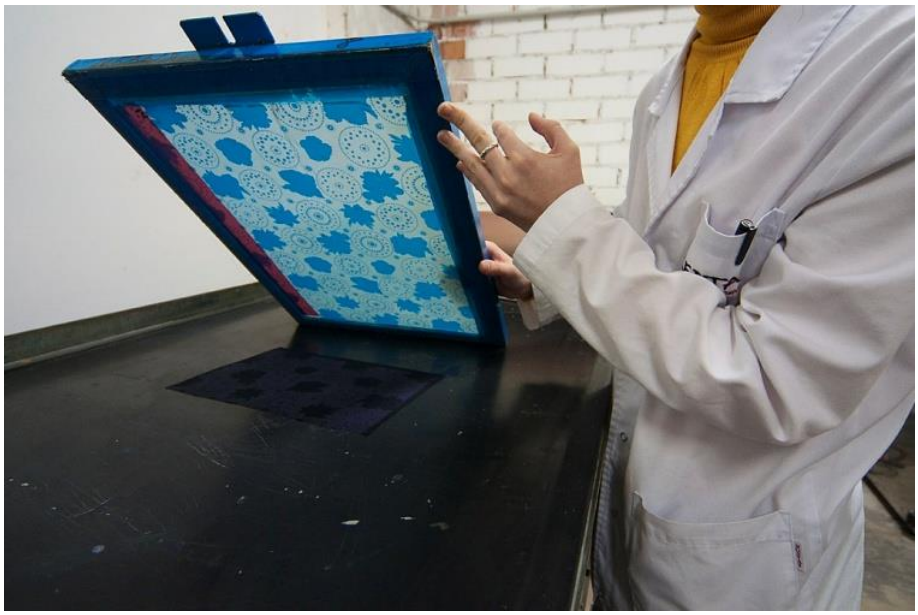
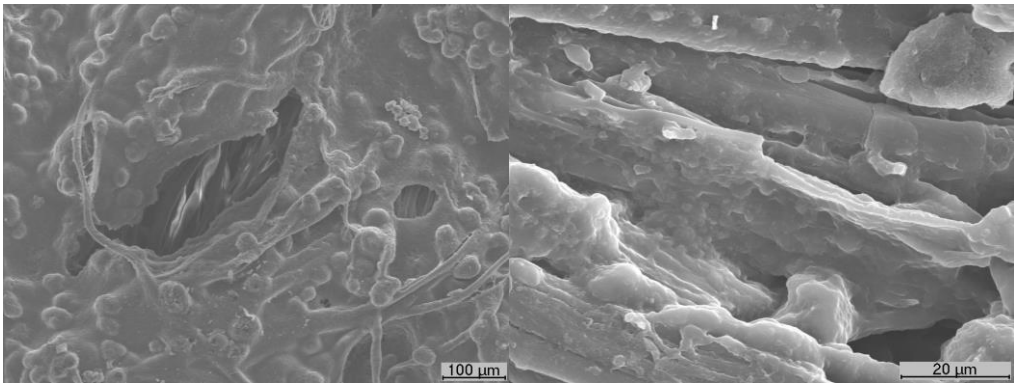


Figure 19 – Print Screen lab machine view. (Source: Leitat Technological Centre archive)



(a) **(b)**

Figure 20 – SEM - Fibres treated with Bionyl® by Print Screen (Magnification: 1300) (a) Cotton fibre (b) Hemp fibre. (Source: Optic Center of UBI)

4.3.1.2 Spray-powder

This practice consists of making a resin Centre 441(latex) solution of 60g/l and adding one litre of distilled water. To apply the solution on the surface of the knit we need to use a painting scroll.

Inside the machine an antimicrobial powder is placed which will be sprayed electrostatically to the surface of the fabric.

The first step was to apply the resin with distilled water using a painting scroll. Trying to apply as uniform as possible throughout the surface of the knit. The aim is to humidify the fibre knit and to achive a more feasible penetration of the antibacterial agent powder. After that, we have to use the electrostatic spray gun to apply a thin layer of powder over the surface of the knit samples. The machine must be programmed = 70 KV, Air = 1.8, Powder= 0.5.

When the essay are done, need to dry each sample in a kiln during 14 minutes at 80^0C. After the samples were dried is necessary to cure them at a temperature of 120^0C for one minute.

Difficulties faced:

- Applying a uniform layer of resin and a regular layer of Bionyl® Powder over the whole surface of the knit. Found that the product becomes more dispersed in certain areas than in others.

Note: This process is not very viable. We perceive clearly that in the manipulation of the samples, the finishing leaves the knit, because it is not completely fixed. It is suggested to increase the concentration of resin per litre of water, decreasing the amount of Bionyl® powder applied or applying a thin layer of resin on the finished Knit, which also can not be so good, because the application of the resin can inhibit the action of micro particles to perform their functions, when it is applied in the finished sample.

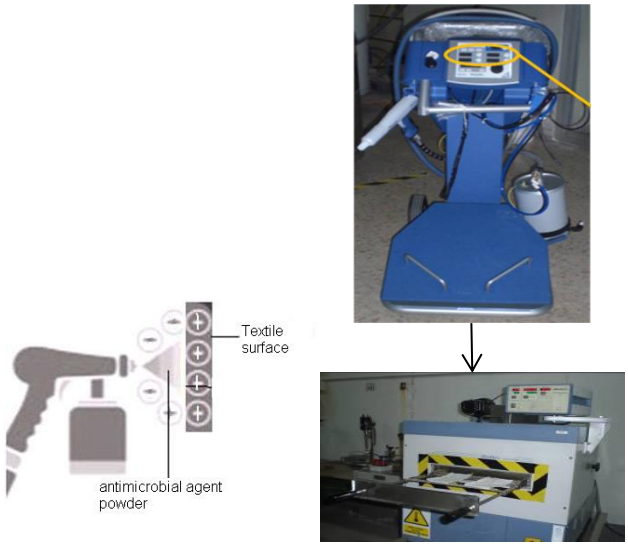
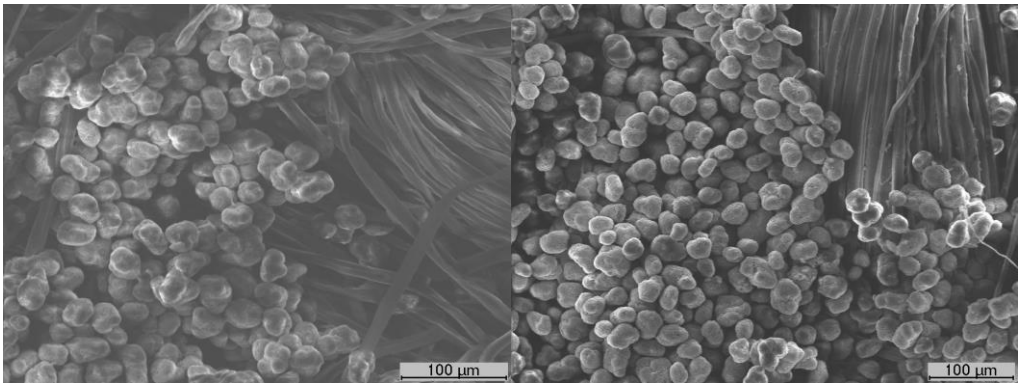


Figure 21 - Spray powder sytem. (Source: Leitat Technological Centre archive)



(a) **(b)**

Figure 22 – SEM - Fibres treated with Bionyl® by Spray Powder (Magnification:250) (a) Cotton fiber (b) Hemp fiber. (Source: Optic Center of UBI)

4.3.1.3 Pad-Batch

The process undertaken to Bionyl® Pad Batch is held for the same process of Agiene® Pad Batch, but what changes in this process is the formula relation of amount/m^2. Follow the formula 12, below:

Bionyl® 5 g/m^2.

Knit surface = A m^2

Knit weight = B grams.

Pick up = x % = C grams of water in 100 grams of knit.

$$\frac{5g\ of\ Bionyl}{1\ m^2\ knit} \cdot \frac{A\ m^2\ of\ knit}{Bg\ of\ knit} \cdot \frac{100g\ of\ knit}{Cg\ of\ water} \cdot \frac{1000\ ml\ of\ water}{1\ ml\ of\ water} = \frac{Xg\ of\ product}{1L\ of\ water} \qquad (12)$$

After the Knits pass through the Pad Batch treatment it's necessary to dry the samples which are taken to a kiln in a temperature of 110^{0}C for 14 minutes, then thoroughly dried the samples, we need to cure the fabric for 30 seconds in a temperature between 130^{0}C to 180^{0}C, the knit was cured at 150^{0}C. The process is shown in images 17 and 18 (a) (b):

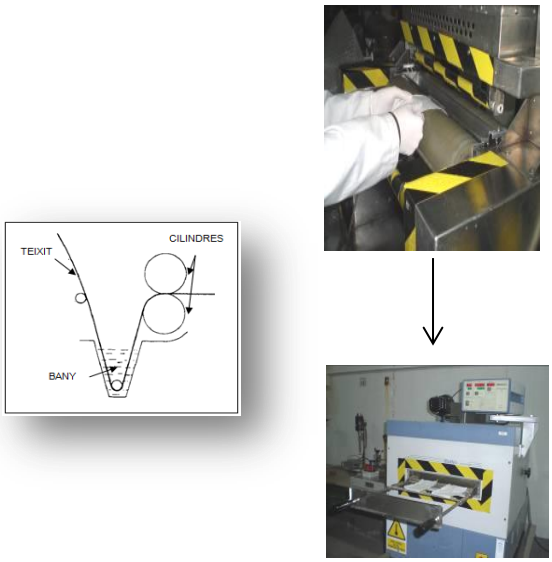
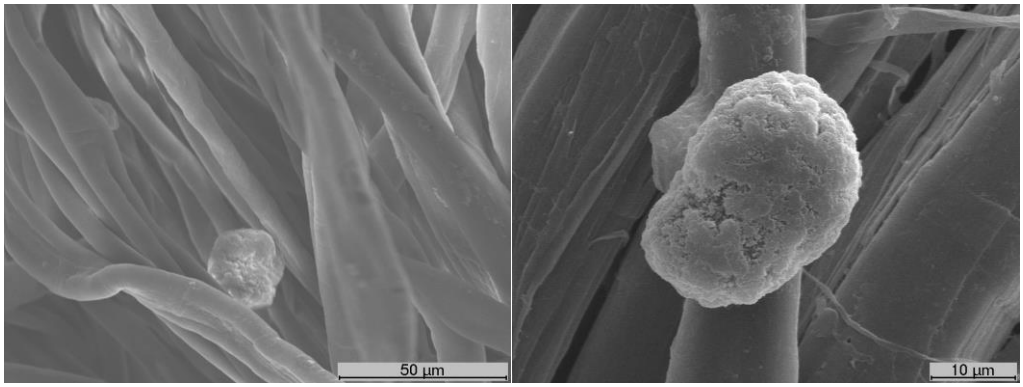


Figure 23 - Pad Batch System (Source: Leitat Technological Centre archive)



(a) **(b)**

Figure 24 – SEM - Fibres treated with Bionyl® by Pad Batch (Magnification: 800) (a) Cotton fibre (b) Hemp fibre. (Source: Optic Center of UBI)

4.3.2 Agiene®

The treatments will be discriminated as follows.

4.3.2.1 Exhaustion

The anti-bacterial product dissolved in the liquor is first absorbed, only on the surface, then penetrates in the core of the fibre and finally migrates thus allowing good uniformity and consistency. The process works by operating temperature and time. While the process is developed, thermodynamic and kinetic reaction interacts. Follow the image 19:

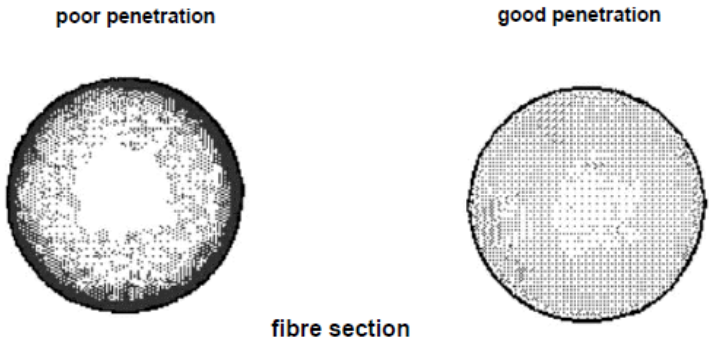


Figure 25 – Exhaustion (Source: Finishing Reference books of textile technologies, p.48)

Operations must be carried out for exhaust and pad application:

- Disperse or dissolve the anti-bacterial product in water and filter;
- Have a homogeneous contact between the liquor and the fibre;
- Make to penetrate the product into the fibre;
- Fix the product in the core of the fibre;
- Washing.

In this treatment, the samples of knit are cut, so that each sample has a maximum weight of 42 grams, because we have to follow the proportion of 1:7, which means: for each gram of knit, it has 7 ml of anti-bacterial solution. The maximum solution weight added with the weight of the fabric which can be placed in each capsule of the Exhaustion machine is 300 grams or 300ml.

Products concentrations for Exhaustion process:

Agiene® 300-A 0.28% w.f = x g/L.

Nonax 3009-A 0.1% w.f =x g/L.

MgCl2 0.5% w.f= x g/L.

Adjust pH 3.8- 4.2

After the calculations and preparation of solutions, each sample of Knit was placed in a capsule separately, adds up the antimicrobial solution. The exhaust treatment is made for 20 minutes at 50°C, using 40 RPM (rotations per minute), and a gradient of 2.5, which means that the temperature of the exhaustion chamber will increase gradually every minute 2.5°C until the temperature of 50°C which is the temperature suitable for the process. After this time the knits are drawn from inside the capsules and taken to kiln, in order to completely dry the fabric at a temperature of 110°C for 14 minutes. The fabric is cured for 45 seconds at a temperature of 180°C. The whole process is illustrated by images 26 and 27 (a) (b).

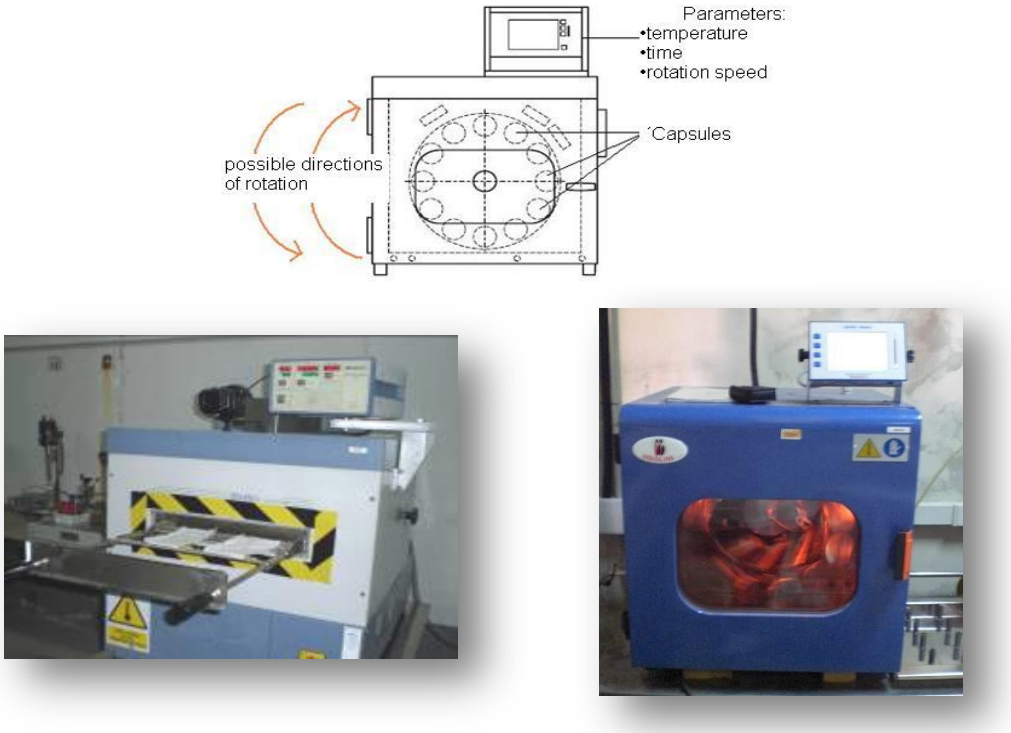
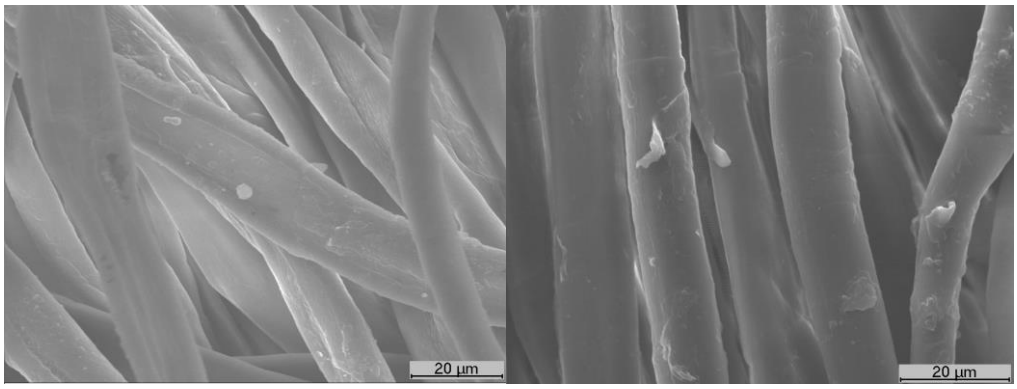


Figure 26 - Exhaustion machinery system. (Source: Leitat Technological Centre archive)



(a) **(b)**

Figure 27 – SEM - Fibers treated with Agiene® by Exhaustion (Magnification: 1100) (a) Cotton fibre (b) Hemp fibre. (Source: Optic Center of UBI)

4.3.2.2 Liquid Spray

It consists in a jet spray containing the chemical with the intended functionality. This process is normally used for automotive painting, is performed by an air gun that stands out against the fabric the product that you want dyeing, the air gun need to be approximately 45 degrees of

inclination of the knit which whether to make the finishing. This method is not very effective because the products do not spread uniformly on the tissue. Laboratories analyses have shown that this method sets the chemicals in the fabric unevenly. When the wire is analysed in microscope can perceive that at certain points there is an excess concentration of micro particles. Those micro particles are combined in an irregular manner, with increasing its weight causes a partial fixation or even partial detachment of the micro particles. Follow the equation 13 and table 10:

$$\boldsymbol{Pick\ up} = 100 . \frac{dry\ state\ weight}{wet\ state\ weight} - 1 \quad (13)$$

Found the following values to pick up the knit samples, in table 10:

Table 10 – Pick up of cotton and hemp fibres by Spray Liquid application

Fibre	Pick up
Cotton	60%
Hemp	66%

Products concentrations for Spray Liquid process:

Agiene® 300-A 0.28% w.f = x g/L.

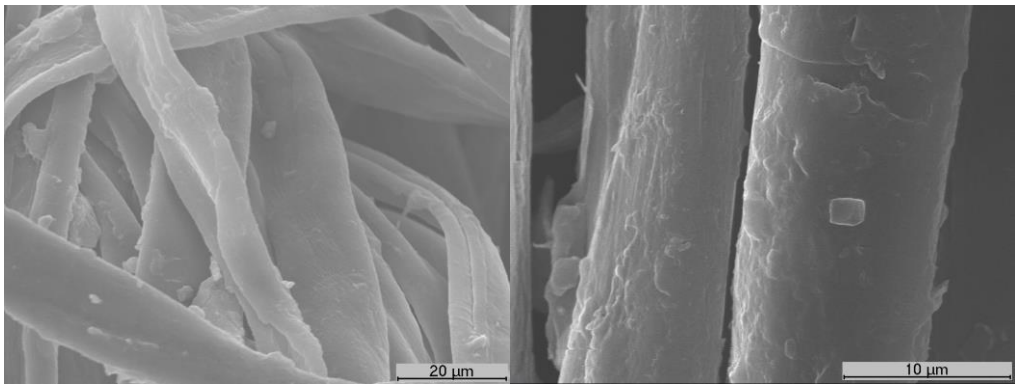
Nonax 3009-A 0.1% w.f =x g/L.

MgCl2 0.5% w.f= x g/L.

Adjust pH 3.8- 4.2

Note: After finished treatment, the knits were taken to the kiln, where they were dried at a temperature of 110° C for 15 minutes. It was subsequently cured for 30 seconds at a temperature of 150° C.

Figure 28 - Liquid spray equipment (Source: Leitat Technological Centre archive)



(a) **(b)**

Figure 29 – SEM - Fibres treated with Agiene® by Liquid Spray (Magnification:1300) (a) Cotton fibre (b) Hemp fibre. (Source: Optic Center of UBI)

4.3.2.3- Pad-Batch

When working with Pad Batch treatment, it was first necessary to obtain the degree of moisture absorption for the treatment in question which is called Pick-up. Consists in weighing a sample each fibre knit in the dry state, thereafter the samples pass through the Pad Batch machine using only distilled water. After the samples are weighed again, with the difference of

the final weight and the initial weight, is possible to calculate the pickup of each knit by formula 12.

Found the following values to pick up the knit samples, in table 11:

Table 11 – Pick up of cotton and hemp fibres by Pad-Batch application.

Fibre	Pick up
Cotton	60%
Hemp	66%

After calculating pick up was developed a solution for each sample of knit, respecting the following concentrations:

Agiene® 300-A 0.28% w.f = x g/L.

Nonax 3009-A 0.1% w.f =x g/L.

$MgCl_2$ 0.5% w.f= x g/L.

Adjust pH 3.8 - 4.2.

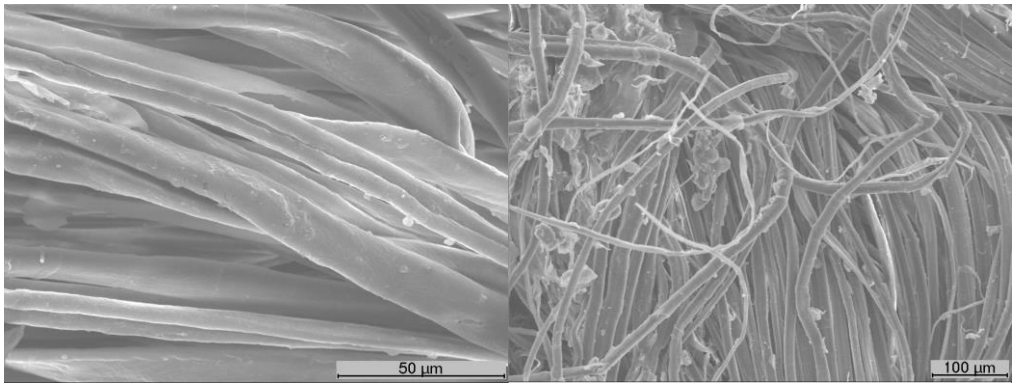
Relation product and Pick up by 1 litre of solution, follow the equation 13:

$$\boldsymbol{Grams\ of\ product/L}\ \frac{\%\ of\ product}{100g\ of\ knit}\ .\frac{100g\ of\ knit}{pick\ up}\ .\frac{1000\ ml\ solution}{1L} \qquad (13)$$

Applications of solutions:

The Knit is conveyed to spreading and stretching units which prevent the creases formation, then into the machine containing dye bath and finally crossing to rollers that is heavy, with the objective of squeeze out the excess liquor, impregnating agent in this process allowing one efficient impregnation on the fabric in a short time, when the knit is wet with the anti-bacterial product it needs to go to one kiln with the highest possible temperature, to facilitate the penetration of the chemical agent into the fabric (Gao *et al.,* 2008, p.60-72) (Asanovic *et al.*, 2010, p.1665-1674).

After the Knits pass through the Pad batch machine is necessary to dry the samples which are taken to a kiln in a temperature of 110° C for 14 minutes, then thoroughly dried the samples, we need to cure the fabric for 30 seconds in a temperature between 130° C to 180° C, the knit was cured at 150° C.



(a) **(b)**

Figure 30 – SEM - Fibres treated with Agiene® by Pad Batch (Magnification:800) (a) Cotton fibre (b) Hemp fibre. (Source: Optic Center of UBI)

4.3.3 Chitosan

The treatments will be discriminated as follows:

4.3.3.1 Exhaustion

The Chitosan treatment consisted primarily on a pre-treatment of knit samples with citric acid (99%) 100g/L add Na2HPO4.12H2O or NaH2Po42H2O 60g/L. After performing the treatment, by Pad-batch, had to dry the fabric 90^0C for 5 minutes and then curing at a temperature of 180^o C for 5 minutes.

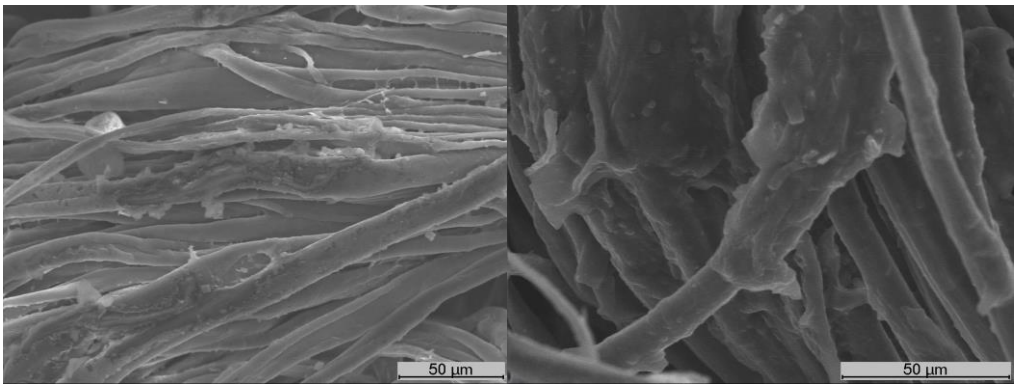
After performing the pre-treatment with acid began the treatment with Chitosan. The method was performed by Exhaustion, where we had to prepare a solution of Chitosan 2% v/v, Acetic acid 2% v/v, stirring it for 1 h at 60^o C. The emulsion ready to place the emulsion within the knit and capsules into Ugolini equipment, expose the fabrics to a temperature of 60^o C for two hours. After completing treatment leave the knits drying at room temperature.

Problems faced with chitosan treatment:

- During the execution of treatment with Chitosan antimicrobial agent, we realize that it stirring for 1 h at 60^o C was not sufficient enough to completely dissolve the solution of Chitosan. We made an optimization of the temperature raising it from 60^o C to 80^o C during the same period of time.
- When we analysed the knits already treated with Chitosan, perceive a touch too rough and hard, losing much of the initial aspect of the mesh. Aiming to improve the touch we chose three ways of investigation. First investigate the concentrations of Chitosan. Chitosan initially tested with 2% v/v, decided to decrease the concentration for Chitosan 1% v/v Chitosan and 1% v/v, further investigation in which would be the best

way to improve the touch. Washed the knit sample already treated with 0.1M Acetic acid and another sample of tissue with only distilled water.

- After both treatments we concluded that treatment with Chitosan agent, is better when treated at a concentration of Chitosan 1% v/v, and after that the treatment is completed to remove excess of Chitosan on the surface of the knit sample, it was washed with distilled water.



(a) **(b)**

Figure 31 – SEM - Fibres treated with Chitosan by Exhaustion (Magnification: 500) (a) Cotton fibre (b) Hemp fibre. (Source: Optic Center of UBI)

4.4 Thermal comfort of functional textiles

The thermal properties were evaluated in the apparatus Alambeta. The tests were performed according to the directions recommended by the manufacturer. The procedure used was:

The samples tested were conditioned by leaving samples 48 hours in an atmosphere of 20ºC (2ºC may vary more or less) and a relative humidity of 60% (ranging 5% more or less).

We tested the thermal properties of the knits in dry and wet state.For analysing the thermal properties in the wet state, we added a solution of distilled water with non-ionic detergent to 0.5 g/L.

It is very important that the tested samples are well centred and below the measuring point of the device. The tests were carried out on 30 specimens and then we made the global average to obtain the results.

Figure 32 - Alambeta equipment

4.5 Physiological comfort of functional textiles

For testing of the physicological properties of this investigation Permetest device was used. The tests were performed according to the recommendation given by the manufacturer. The samples tested were conditioned by leaving samples 48 hours in an atmosphere of 20ºC (2ºC may vary more or less) and a relative humidity of 60% (ranging 5% more or less).environment for a period of 24 hours. After this period of time, the test was performed with knits in dry state.

Afterwards, the knits were tested in the wet state, the samples were inoculated with solution of distilled water with non-ionic detergent at a concentration of 0.5 g/L. Waited until the samples absorb completely the solution. Continuous measurements were performed.

The tests were carried out on 30 samples and descriptive structure were made.

4.6 Antimicrobial textiles

After treatment of knits with antimicrobial agents, their characteristics were slightly modified as regards the absorptivity of water. It was noticed during the test that the amount of antimicrobial activity made necessary to make two different tests, one facing the knitting treated by Agiene® agent, which has hydrophilic characteristics, the method to verify the antimicrobial activity was carried out by absorption method. The knits that have been treated by Chitosan became hydrophobic after the treatment, so the inoculation of bacteria was done by transfer method. Both methods will be explained further in this topic.

The knitting treated by Bionyl® agent were not tested, due to the fact that, during handling, it was verified that most of the antimicrobial product comes out the knit surface, because he is not properly hyperlinked to the cotton and hemp fibres.

4.6.1 Objectives

This International Standard specifies quantitative test methods to determine the antibacterial activity of antibacterial finished textile products including nonwovens. ISO 20743:2007 is applicable to all textile products, including cloth, wadding, thread and material for clothing, home furnishings and miscellaneous goods regardless of the type of antibacterial agent used (organic, inorganic, natural or man-made) or the method of application (built-in, after-treatment or grafting).

4.6.2 Test Conditions

Test method: absorption method (an evaluation method in which test bacterial suspension is inoculated directly onto samples).

- Weight of the specimens:0.4 ± 0.05 grams
- Number of textile fabrics tested:
  - 6 negative control
  - 6 treated samples
- Bacteria for the test:
  - *Staphylococcus aureus* ATCC 6538P
- Bacterial concentration used: 1.5 - 3 x 105 cfu/ml
- Contact time with agitation: 24 hours

Due to the hydrophobicity of the fabrics, a test was made with the method of transfer plate which allows the inoculation of hydrophobic tissue.

Test method: transfer method (an evaluation method in which test bacteria are placed on an agar plate and transferred onto samples).

- Diameter of the specimens: 3.8 cm
- Number of textile fabrics tested:
  - ❖ 6 negative control
  - ❖ 6 treated samples
- Bacteria for the test:
  - ❖ *Staphylococcus aureus* ATCC 6538P
- Bacterial concentration used: 1.5 - 5 x 106 cfu/ml
- Contact time with agitation: 24 hours

4.6.3 Procedure

Procedure performed in absorption method:

1. The tissues were inoculated with 0.2 ml of *Staphylococcus aureus*.
2. Half of them (three negative controls and three treated samples) are analysed at zero contact time.
3. The other half of the fabrics is incubated for 24 hours at a temperature of 37oC. After this contact time are analysed.
4. For the analysis of fabrics (at 0 hours and 24 hours), each sample was added 20 ml of neutralizing (Dey-engley) and is subjected to mechanical agitation for about a minute with the vortex.
5. We performed bench dilutions and plated on Triptone soy agar (TSA). The plates are incubates for 24 – 48 hours at a temperature of 37ºC
6. Determination of the antimicrobial activity

Procedure performed in transfer method:

1. 12 agar plates were inoculated with 1 ml of the inoculum and covered all surface of the plate. Remove the excess liquid and the plate allowed to stand for 300 seconds
2. The fabrics specimens were placed on top of the agar plates and performing a transfer of bacteria from the plates to the fabrics.
3. 3 negative controls and 3 treated samples are analysed at zero contact time.
4. Other 3 negative controls and 3 treated sample are incubated for 24 hours at a temperature of 37oC. After this contact time are analysed.
5. For the analysis of fabrics (at 0 hours and 24 hours), each sample was added 20 ml of neutralizing (Dey-engley) and is subjected to mechanical agitation for about a minute with the vortex.
6. We performed bench dilutions and plated on Triptone soy agar (TSA). The plates are incubates for 24 – 48 hours at a temperature of 37ºC

7. Determination of the antimicrobial activity.

After the above procedure, the calculation has been done to evaluate the antimicrobial activity (vide formula in the topic *3.5.5.3 Test for specific antibacterial activity*).

CHAPTER 5

ANALYSIS AND INTERPRETATION OF RESULTS

5.1 Thermophysiological comfort

5.1.1 Evaluation of thermal properties

Follow the table 12:

Table 12 - Thermal Properties of Cotton and Hemp fibre

	DRY STATE			WET STATE		
	$\underline{b}\ [W.m^{-2}.K^{-1}.s^{1/2}]$	$\underline{\lambda}\ [W/m.K]$	$\underline{r}\ [m^2K/W]$	$\underline{b}\ [W.m^{-2}.K^{-1}.s^{1/2}]$	$\underline{\lambda}\ [W/m.K]$	$\underline{r}\ [m^2K/W]$
Natural Hemp	188	56,4	16,9	216	105,8	15,7
Hemp Chitosan Exhaustion	166	55,5	11,5	151	132	5,5
Hemp Agiene® Pad Batch	188	49,7	16,7	196	98,8	10,4
Hemp Agiene® Exhaustion	173	58,4	15,9	184	114	10,4
	DRY STATE			**WET STATE**		
	$\underline{b}\ [W.m^{-2}.K^{-1}.s^{1/2}]$	$\underline{\lambda}\ [W/m.K]$	$\underline{r}\ [m^2K/W]$	$\underline{b}\ [W.m^{-2}.K^{-1}.s^{1/2}]$	$\underline{\lambda}\ [W/m.K]$	$\underline{r}\ [m^2K/W]$
Natural Cotton	176	50,4	38,8	178	83,5	28,6
Cotton Chitosan Exhaustion	172	70	10,7	211	114	6,6
Cotton Agiene® Pad Batch	154	65,5	11,8	194	119	7,8
Cotton Agiene® Exhaustion	162	62,7	18,6	221	131,3	8,1

The results obtained will be far based on the wet state, as this represents the state that most closely matches the conditions of use of a particular piece of clothing, the dry state corresponding to time zero, which is the time when user dresses the cloth on.

The presented case of hemp, samples treated with chitosan applied by exhaustion had the best thermal due to its low thermal resistance (r) and a high conductivity (λ). Not with standing the absorptivity (b) is not the highest, but the differences are not significant.

Identical results were obtained for cotton samples, in which the best results were obtained by chitosan applied by exhaustion, this sample presented high thermal conductivity (λ) and the lowest thermal resistance (R). The absorptivity (b) is not the highest, but the difference between the attained results is not significant for the quantity in question.

According to the analysis of the thermal comfort properties, we can say, that hemp treated with chitosan applied by exhaustion had the lowest resistance and the highest thermal absorptivity although the thermal conductivity is not the highest. When analyzing cotton, we also point out that the sample treated with chitosan, applied by exhaustion had low thermal resistance and high thermal conductivity as intended. The absorptivity is not the highest, but the differences are not significant results.

5.1.2 Evaluation of physiological properties

5.1.2.1 Water vapour permeability (%)

According to the analysis results of water vapor permeability it is possible to conclude that the both fibers, cotton and hemp, without treatment, have the highest values for the water vapor permeability.

When analyzing finished samples, we can clearly observe tha hemp sample treated with chitosan applied by exhaustion, had the best permeability, which is of great importance for our prototype, because it means it has an excellent ability to promote physiological comfort, meaning that the natural transpiration of the body, more or less intense, it will evaporate easily to the environment. With cotton , we also observed that the sample with best permeability behavior is the sample that was treated with chitosan applied by exhaustion.

Tabela 13 - Water vapour permeability (%)

Standard textile

Initial Weight	Final Weight	Difference	Area	WVP=24M /At	Rate %
137,772	131,946	5,826	0,005408	1077,319	0

Reference sample	Initial Weight	Final Weight	Difference	Area	WVP=24M /At	Rate %
Hemp Natural	140,809	134,888	5,921	0,005408	1090,325	101,21
Hemp Chitosan Exhaustion	141,928	135,961	5,967	0,005408	1090,081	101,18
Hemp Agiene® Pad Batch	140,467	135,093	5,374	0,005408	1050,703	97,53
Hemp Agiene® Exhaustion	140,440	135,223	5,217	0,005408	964,706	89,55
Cotton Natural	139,899	134,068	5,831	0,005408	1078,244	100,09
Cotton Chitosan Exhaustion	140,085	134,098	5,987	0,005408	1076,433	99.92
Cotton Agiene® Pad Batch	139,879	134,111	5,768	0,005408	1066,595	99,00
Cotton Agiene® Exhaustion	140,663	135,038	5,625	0,005408	1040,152	96,55

5.2 Evaluation of antimicrobial activity

The antimicrobial testing aims to verify and quantify the antimicrobial activity.

Samples number 1 and 2 correspond to cotton and hemp knits treated with the antimicrobial agent Agiene®.

Samples number 3 and 4 correspond to cotton and hemp knits treated with the antimicrobial agent Chitosan.

1. Sample Nº 1 (COTTON):
    - Negative control
    - Treated sample

Table 13 – Result of antimicrobial activity for Cotton fibre treated by Agiene.

	Negative control	Sample 1
Concentration of inoculum	1.6×10^5 cfu/ml	1.6×10^5 cfu/ml
Average concentration of bacteria (t=0h)	6×10^3 cfu	6.2×10^3 cfu
Average concentration of bacteria (t=24h)	5.8×10^8 cfu	1.1×10^8 cfu
Determination of antimicrobial activity		
Value F	5	-
Value G	-	4.2
Antibacterial activity (A)	**0.8**	
Antimicrobial activity in percentage		
R (%)	**81%**	

2. Sample Nº 2 (HEMP):
    - Negative control
    - Treated sample

Table 14 – Result of antimicrobial activity for Hemp fibre treated by Agiene.

	Negative control	Sample 1
Concentration of inoculum	1.6×10^5 cfu/ml	1.6×10^5 cfu/ml
Average concentration of bacteria (t=0h)	4.6×10^3 cfu	5.4×10^3 cfu
Average concentration of bacteria (t=24h)	4.2×10^7 cfu	4.04×10^4 cfu
Determination of antimicrobial activity		
Value F	4	-
Value G	-	0.9
Antibacterial activity (A)	**3.1**	
Antimicrobial activity in percentage		
R (%)	**99.90 %**	

3. Sample N° 3 (COTTON)
    - Negative control
    - Treated sample

Table 15 – Result of antimicrobial activity for Cotton fibre treated by Chitosan.

	Negative control	Sample 1
Concentration of inoculum	3.6 x 106 cfu/ml	3.6 x 106 cfu/ml
Average concentration of bacteria (t=0h)	8.2 x 104 cfu	4.2 x 104 cfu
Average concentration of bacteria (t=24h)	3.4 x 108 cfu	1.5 x 107 cfu
Determination of antimicrobial activity		
Value F	3.6	-
Value G	-	2.5
Antibacterial activity (A)	**1.1**	
Antimicrobial activity in percentage		
R (%)	**95.5 %**	

4. Sample N° 4 (HEMP)
    - Negative control
    - Treated sample

Table 16 – Result of antimicrobial activity for Hemp fibre treated by Chitosan

	Negative control	Sample 1
Concentration of inoculum	3.6×10^6 cfu/ml	3.6×10^6 cfu/ml
Average concentration of bacteria (t=0h)	3.9×10^4 cfu	4.4×10^4 cfu
Average concentration of bacteria (t=24h)	3.2×10^8 cfu	2.7×10^7 cfu
Determination of antimicrobial activity		
Value F	3.9	-
Value G	-	2.8
Antibacterial activity (A)	**1.1**	
Antimicrobial activity in percentage		
R (%)	**91 %**	

The analysis of the antimicrobial activity denotes that the best result of all is obtained in Hemp with Agiene. This value is greater than the one we got with the same agent of cotton. Regardin te agent Chitosan the higest value is achieved with cotton while hemp decreases its performance when compared to the other agent. However the difference between those values is not as significant , due to the fact that antimicrobial activity above 90% is considered to be high.

5.3 Prototype of gown developed

At the conclusion of the experimental tests, it was possible ro certain the best optimized combination of the fiber and antimicrobial agent. In sequence, we developed a gown prototype that took into account the assumptions defined in section 2. The following imagens give us a visual description of the final outcome and underlines the best characteristcs that we sought toin part in our prototype.

On the next imagens, we can see the final visual outcome of the developed gown.

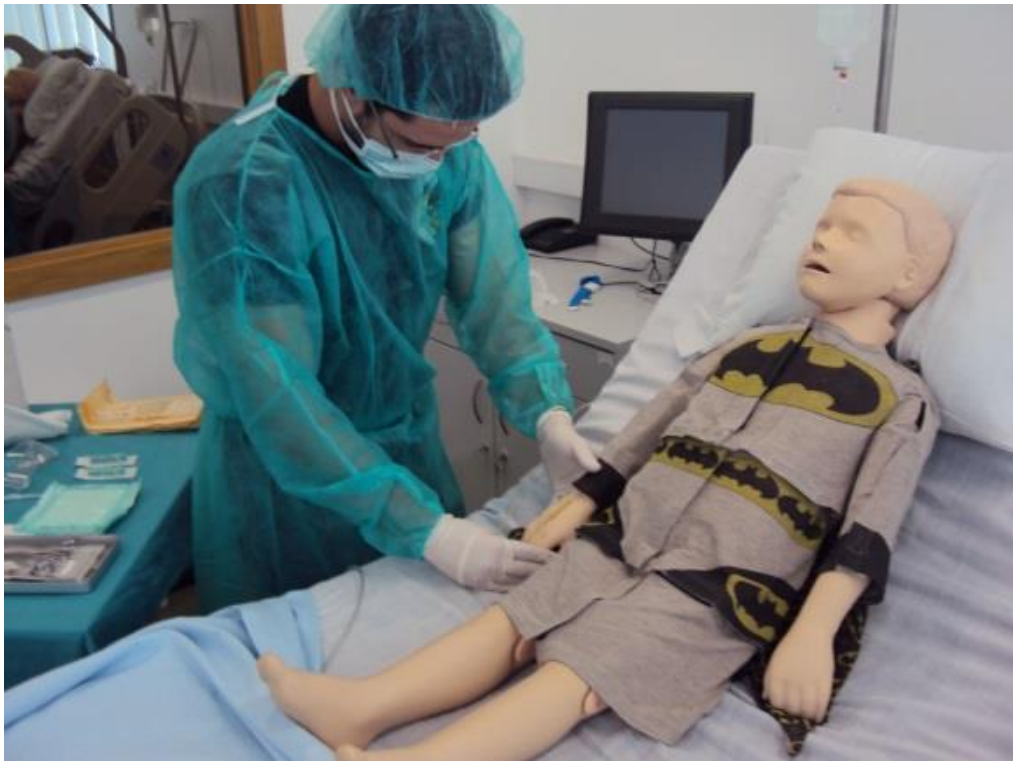


Figure 33 - Providing psychological comfort for the patient.

Figure 34 - Easiness in handling and application of catheters.

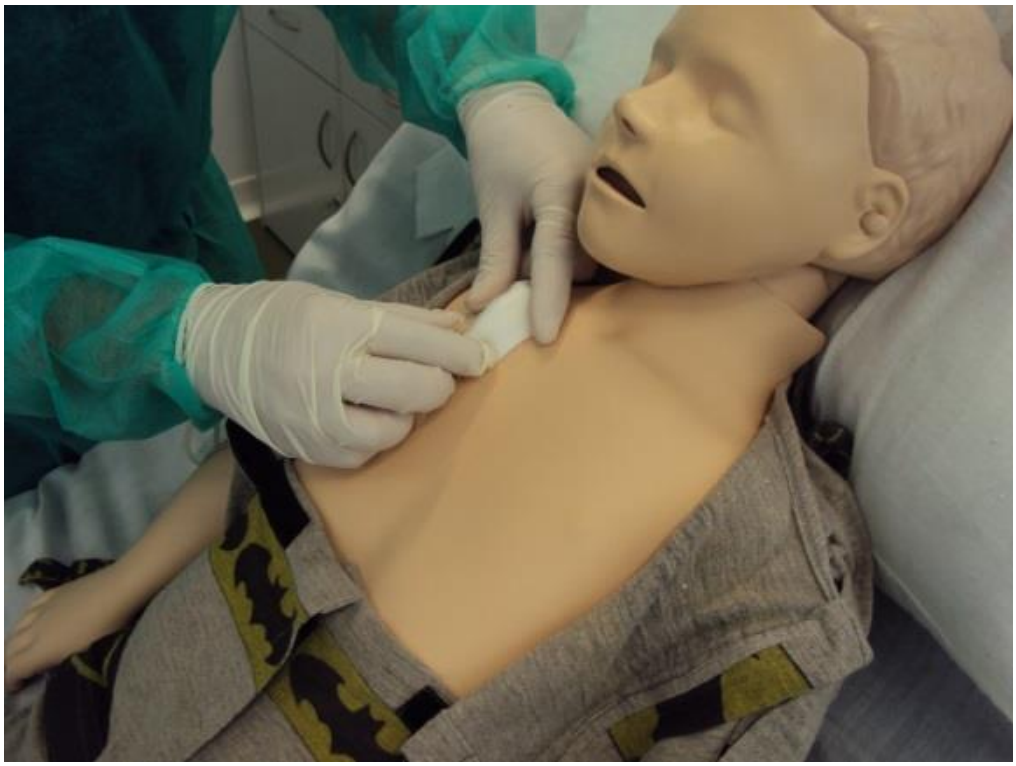


Figure 35 - Facility when handling the Implantofix (Implantable Drug Delivery System).

Figure 36 - The cover can be used as blanket.

Figure 37 - Facility in positioning of cardiac monitoring wires and auxiliaries tubes for drugs or serum delivery.

Figure 38 - Possibility of opening by modules.

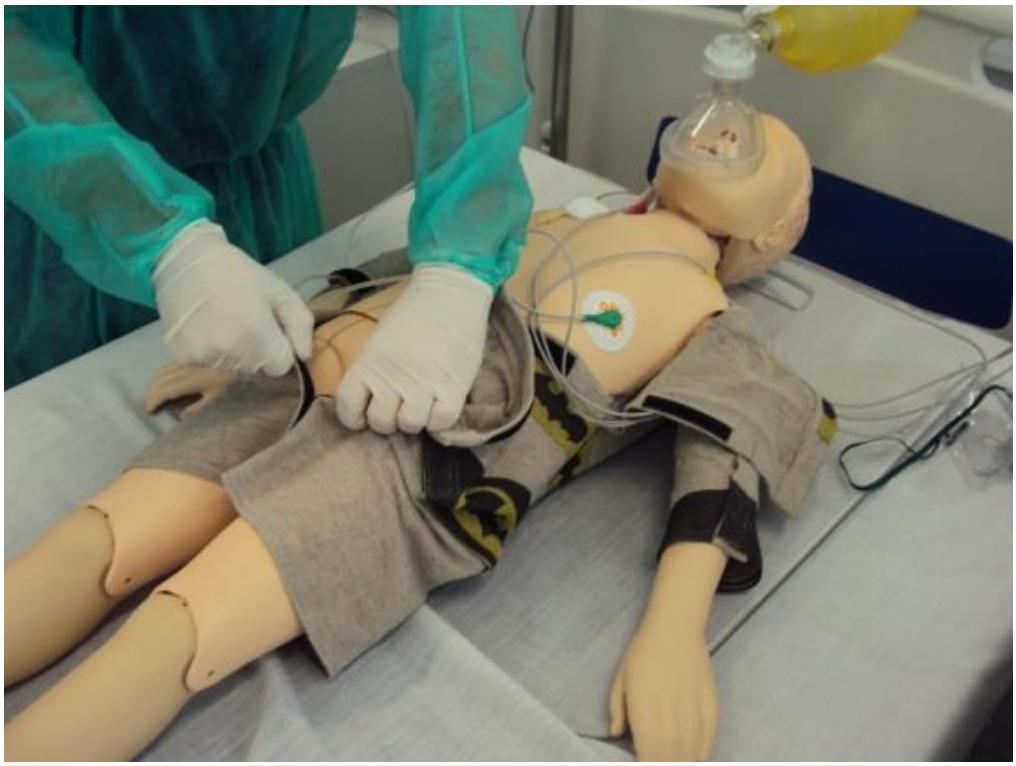


Figure 39 - Opening easily in case of urgency and emergency interventions.

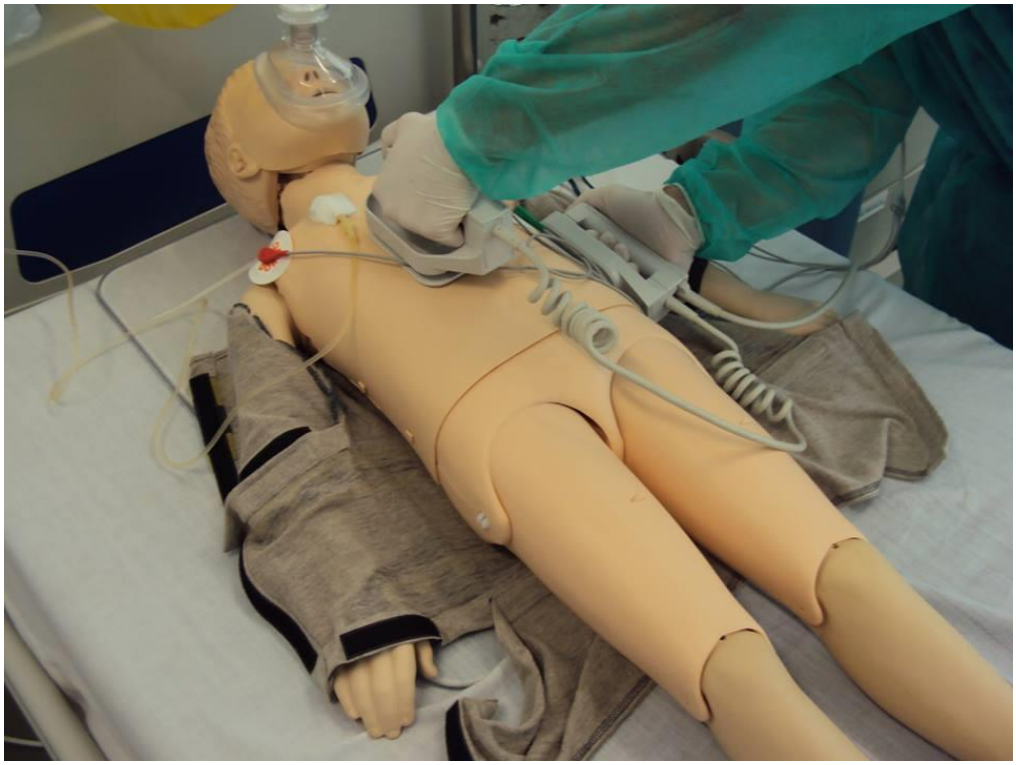


Figure 40 - Simulation of emergency intervention.

CHAPTER 6

CONCLUSIONS

a) Regarding the antimicrobial application process

After working with different processes such as Screen print, Powder Spray and Pad Bach, we come to the conclusion that the chemical Bionyl®, should only be applied to non-woven, because of the properties and behaviour that it possesses. We decided stopping further experiments with the Bionyl® product. The test in which were analysed were carried out with knit fibres of cotton and hemp. All the structured knit were jersey with yarn count between 24 Nm and 30 Nm. It was perceived that those knits have an open structure, are extremely malleable and are flexible which not contribute to the thin layer of Bionyl® applied.

An antibacterial knit was effectively obtained, but with difficult application for medical textile, because it is perceptible to the naked eye, that the Bionyl® product, when used in this quantity, cannot get a good fixation on the fibres which were investigated and it changes completely the knit touch.

When the knits were treated with the Powder Spray process, we obtained one of the most surprising results because even just applying a thin layer of resin before receiving treatment of Bionyl® powder we perceived that the product did not have adherence in the knit and it does not spread evenly across its surface this happens when the product is applied manually, as done in the essay. It's perceptible to the naked eye a thin layer of antibacterial product, which had to take greater care in its manipulation so that this layer does not break, which was inevitable, thus losing its functionality to the medical textile for those knits which were investigated in this research.

In the Pad Batch treatment we found that the product is more evenly spread across the surface of the knit, but when it was manipulated we realized that the product comes off the textile fibre, there is not a good adhesion for this concentration of Bionyl®. After the treatment the touch changed.

When dealing the Screen Print process, one of the best results was obtained. It was observed a thin layer of resin with Bionyl®, but also has been found difficult to apply the product in a uniform manner. This process is only applied to only one surface of the knit, and then it has just one surface with presence of antimicrobial product. As the structure was crafted Jersey, own knit more open due to the yarn count, which also hinders application in medical textile.

b) Overall Conclusions:

Accordingly to the aforementioned assumptions, we conceive and developed a gown prototype suitable to be used in healthcare facilities by male children aged 2-8 years old, when submitted to chemotherapy treatment.

For this purpose we sought to develop a gown with a set of characteristics that met the necessary requirements, namely, great antimicrobial effectiveness, maximized thermophysiological comfort and ergonomic shape combined with an appealing appearance, so as children may be led to interact with it, improving their psychological well being during treatments.

It was also our intention to develop a gown based upon sustainable fibres in order to attain a more eco-friendly piece of cloth. Moreover, we aim at the replacement of the usually used woven fabrics by knits.

In order to materialize the planned gown we produce knits with two different types of raw-materials: cotton and hemp, both of them in a single jersey structure.

Upon this knits three different types of antimicrobial agents - Bionyl, Agiene and Chitosan - were applied by different processes - Pad Batch, Exhaustion, Spray Powder and Screen Print respectively.

Several samples of finished knits were put to test in order to ascertain which one had the most optimized behaviour in terms of antimicrobial effectiveness and thermophysiological comfort. In the end, as proven, chitosan applied by exhaustion revealed to have the best optimized antimicrobial effect combined with maximized comfort.

Taking this into account this information and in order to be able to develop our prototype, we produced new knits in accordance to the previous conclusion. The drawings process, pattern making, sewing operations, etc. followed the technical details defined in section 2.9.6.

In conclusion, this research work proposed, conceived, developed and tested a new viable and, technically improved, alternative gown, to be used by small children undergoing chemotherapy.

CHAPTER 7

FUTURE RESEARCH GUIDELINES

Upon completion of a thesis it is likely to think that we add some contribution for the scientific area in question. Notwithstanding, it is also a very common feeling that the work carried out is not fully finished and has a lot of new possibilities to enrich and explore. Bearing this idea in mind, it is my true believe that the developed work can be thought as an initial matrix of a wider work that encompasses other technological solutions so as to develop sustainable and functional cloths for hospital and healthcare environments.

Thus, in order to enhance and complement the present investigation, we intend – in a near future - to develop a new experimental framework and develop a supplementary set of trials aiming at:

- Develop new knits structures incorporating localized patches with new fibres and functionalities to impart other properties, namely, self-cleaning.
- Despite given information by the antimicrobial agents producers we intend to carry out experimental tests to assess the washing fastness of the finished knits
- Widening the scope of antimicrobial tests in order to evaluate new bacterial strains, especially, Gram negative specimens, such as *Klebsiella pneumoniae* which is very commonly found in hospital environment.
- If possible, to develop a clinical trial (in hospital facilities) where our gown proposal will be put to test under real conditions, in order to ascertain its impact into the children's treatment quality and safety.

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