Chapter

How to Make Fabrics Talk Environment: The Scatol8 per la Sostenibilità Way

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Abstract

The mission of *Scatol8 per la Sostenibilità srl* (in English Scatol8 for Sustainability) is the realization of products and services to communicate the theme of sustainable development. The economic viability of the entrepreneurial initiative is ensured by three lines of activity: (1) the realization of personalized management systems, (2) carrying out environmental education activities, and (3) design and manufacture of products. Scatol8's products are unique design objects—therefore exclusive—crafted with materials and techniques derived from scientific research. Osmosis between new researches in the fields of business management, chemistry, environment, and the Scatol8 company leads to the manufacture of products that incorporate recent innovations and transfer the knowledge content to those who can afford them, meaning those who have culture enough to understand and appreciate them. It has been said: luxury is experiential. This is the concept we aim for with our products. The following chapter describes the qualities of some sustainable luxury products and deepens the ways of thinking, designing, and making a line of garments. These garments incorporate electronic devices with natural fabrics: cotton, hemp, and eco-leather. This is an example of upcycling as a result of technological innovation, which is then analyzed by the design thinking.

Keywords: fashion industry, product innovation, mass customization, smart textiles, interactive apparels, eco-fashion, natural fibers, natural dyeing, business models, fashion designers, wearable

1. The Scatol8

Scatol8 per la Sostenibilità srl (briefly, Scatol8 srl) is an academic spin-off of the University of Turin and an innovative start-up. The company, founded in 2016, is the natural consequence to extensive research programs at the national and international level on the relationship between the use and transformation of resources by economic organizations and the quality of the environment, conducted by the Commodity Science Area of the Department of Management, University of Torino. It works in the field of clean technologies and environmental monitoring. Its activity concerns the development, production, and marketing of innovative products and services with a high technological value and more specifically the development, production, and marketing of integrated electronic systems and networks for the collection of variables—in particular environmental—and analysis of data collected through intelligent dashboard, primarily intended for agricultural, commercial, and industrial activities. Product innovativeness is due to the development of specific algorithms that allow the application of methodologies (business intelligence and organizational intelligence) traditionally reserved for corporate information to environmental and energy data. These products have a high technological value because of the specifically developed software which makes them modular and highly customizable; in particular it allows both a simple connection to preexisting environmental management systems and complete technological integration with sensor and actuator networks (Internet of Things).[1]

1.1 Fundamental parts of Scatol8

Scatol8 is a sensor platform for environmental and management variable monitoring. The aim is to measure all those variables that are relevant for the interaction between an economical organization and the environment. Examples of these variables are electrical consumption, gas emission in air, waste production, etc. The data collected through the sensor platform are sent to a remote server (see **Figure 1**) that offers the opportunity to check the real-time values as well as to look at the historical series.

The data collected in the remote database are not only available from a web interface that is easy to use, but values can be elaborated, aggregated, and compared also among different networks. Scatol8 is mainly focused upon the environmental sustainability, and it's based on these criteria:

Accessibility: Hardware and software are fully based on open-source technologies and software in view of cost containment, openness, and ease of access, even for training and academic purposes.

Environmental compatibility: When possible, all electronic devices are placed in recycled containers, coming mainly from consumer goods and electronics industry, transformed and adapted to their new function, or in containers made of wood (a renewable resource) or even cardboard.

Modularity: The system is constituted from time to time, according to the requirements and specifications of each application.

Dissemination: Scatol8 is not only a product but also an initiative to spread knowledge, which aims to involve young people in the creation of technology (and not only in its use). Along with the hardware output of the company, there is a continuously updated line of information about observed variables, sustainability, and purposes.

We can logically divide the monitored variables in three main groups as shown in **Table 1**: the environmental, the managerial, and the biomedical parameters. The web application showing the measured values is called Crusc8 (dashboard). Many indicators, one per variable, compose it. **Figure 2** shows an example of Crusc8 with nine variables in the same network (on the left). For each indicator, it is possible to look at his past trend as shown on the right. These examples are taken from a monitored school; in particular the graph represents the measured temperature in a classroom where the data were collected every 15 minutes.

[1] *Scatol8 per la Sostenibilità srl*, established in 2016, draws back from various national and international research projects conducted within the Department of Management of the University of Turin. For any additional information, please visit http://scatol 8.net.

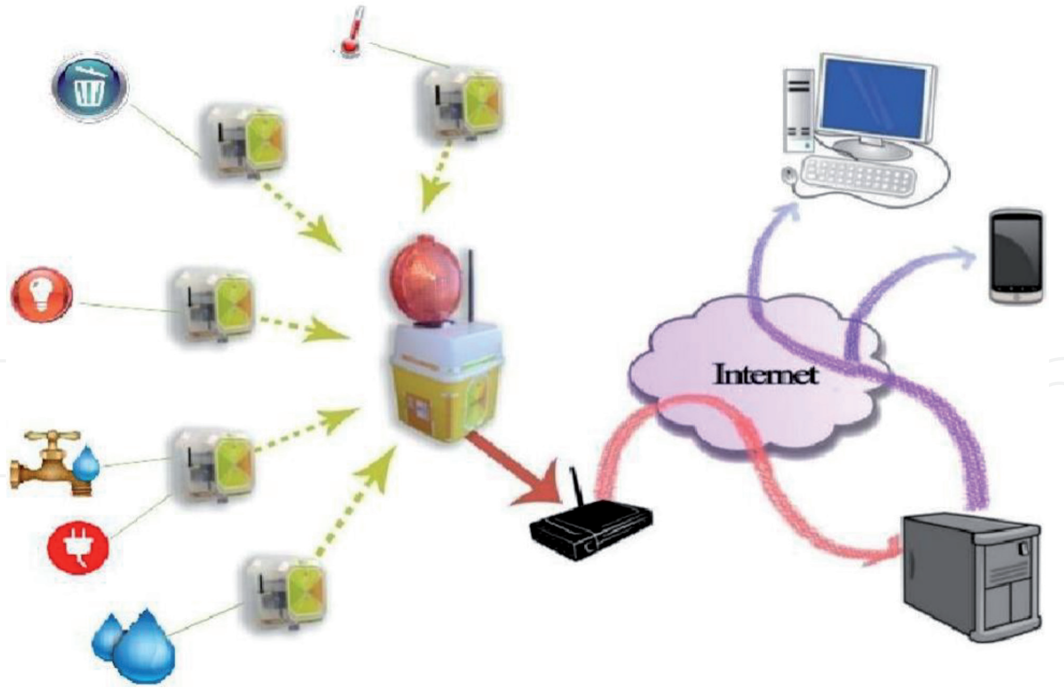

Figure 1.
An example of Scatol8 sensor network.

Environmental parameter
Acceleration
Power consumption
Wind direction
Distance (e.g., snow height, tank liquid quantities, etc.)
Liquid flow
Gas (presence of smoke, benzene, carbon dioxide, LPG, propane, hydrogen, oxygen, methane, carbon monoxide)
Illuminance
Mass (e.g., waste production)
Movement (e.g., intrusion, number of pieces, etc.)
Oxidation-reduction potential
pH
Rain
Atmospheric pressure
Radioactivity (decays α β γ)
Noise
Liquid temperature
Soil temperature
Air temperature
Soil humidity
Air humidity
Wind speed
Vibration
Biometric parameters

ECG
Electromyography
Frequency of breathing
Glucose and blood pressure
Heartbeat
Galvanic skin response
Body temperature

Table 1.
Variables actually measured by Scatol8.

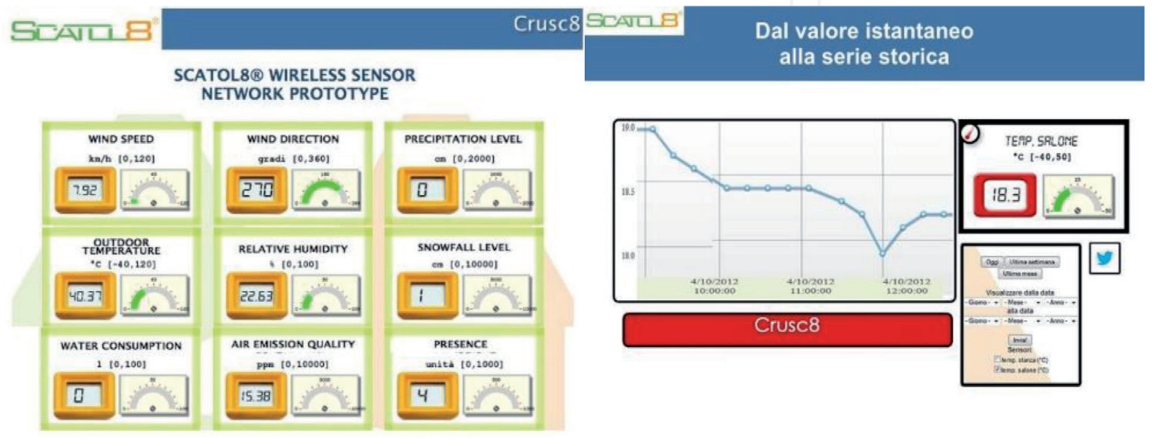

Figure 2.
Examples of Crusc8 and the temperature historical series.

1.2 Sustainable luxury products

Scatol8 srl products and services are manufactured according to the customer's specific requirements. Whether it is the planning and implementing of a remote sensing network, a training project, or a product, the answer to customer needs makes it a unique object. Everyone has the central idea to prove sustainability through materials and constructive methods. Therefore, materials are natural (various Italian woody species, natural fibers, and dyes) and the construction method crafts. From the union of these, unique and exclusive objects are created, whose sustainability is defined by scientific methods and processes. Features are tailored to the customer's needs, both in terms of sensors and actuators: A custom-made approach to sustainability.

The process shown in **Figure 3** highlights the steps that, from an idea, lead to the definition of product requirements after identifying and evaluating the conditions of economic, environmental, and social sustainability.

Being Scatol8 made of hardware, software, and containers, the definition of requisites analyzes, in a systemic way, the relations among these elements, to ascertain the feasibility of a product. The refinement work is carried out through the organized interaction of subjects with various training backgrounds, in a design thinking logic, which allows to explore various options for defining product requisites. Whenever a variation is suggested on one of the three elements to better respond to customer needs, the impact on other items is checked. This way of proceeding allows the definition of feasible product requirements. As far as the environmental sustainability test is concerned, life cycle assessment is the most commonly used methodology, while economic sustainability is examined with the business model

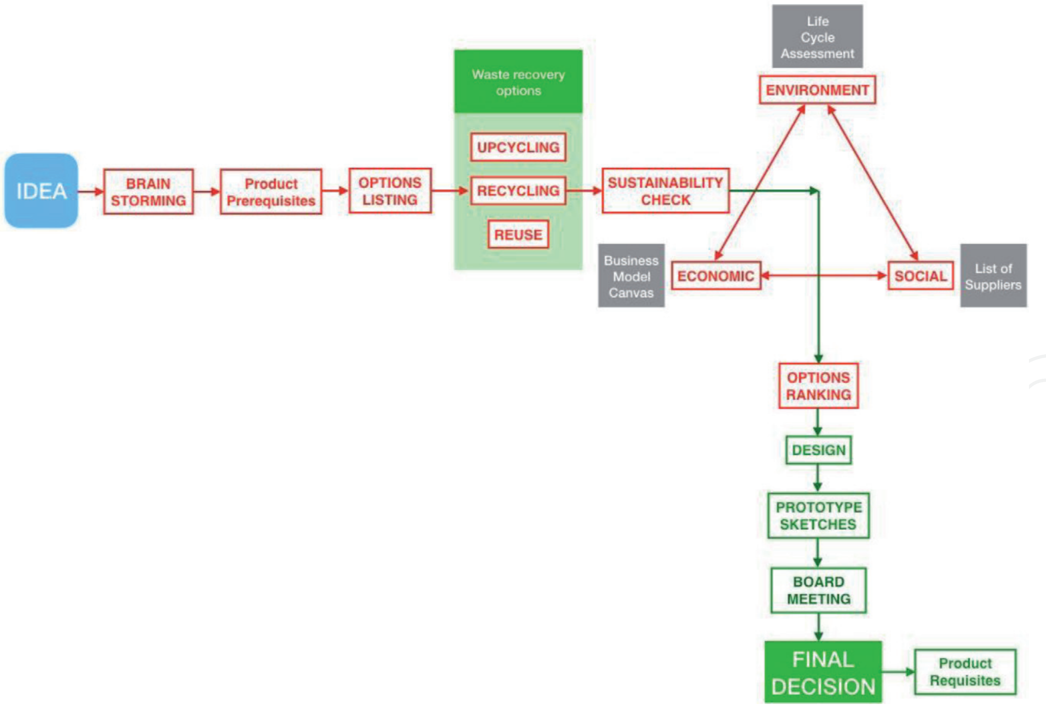

Figure 3.
The design planning from the initial idea to the definition of the product requisites.

Figure 4.
The first Scatol8 lamp produced by Caneschi Ltd.: S8-LIL, Scatol8 Long Interactive Lamp.

canvas [1]. Social sustainability is sought through collaboration with companies located in Italy. Among the products that have been recently made, we present two data-knots, camouflaged by lamps.

Figure 5.
S8-SIL, Scatol8 Short Interactive Lamp.

Figure 6.
S8-vela.

Scatol8 revealed itself through prototypes, designed and produced in a green supply chain, in accordance with the strategic lines that guide our achievements. S8-LIL (**Figure 4**) and S8-SIL (**Figure 5**), Scatol8 Short and Long Interactive Lamp: lighting systems, in two sizes, to determine sequences bright, are dynamic interior design objects that contribute to well-being. Built of wood and natural fabrics, they interact with the environment, changing the appearance and promptly conquering the senses of the living space. Distributed in an apartment, S8-LIL and S8-SIL are a peripheral nodes of a Scatol8 network; the values of the environmental variables are conveyed to a router, published on the Internet, and displayed via smartphone and tablet. Lamps themselves (or any other object) can not only illuminate but also spread aromas, sounds, etc. It belongs to the same stream S8-Vela (**Figure 6**), consisting of a lamp, made of essence of chestnut, naturally dyed based on chestnut tannins, with medium-density fiberboard base, featuring three types of environmental monitoring sensors, in particular monitoring of temperature, humidity, and carbon monoxide parameters, also equipped with LED light actuators.

In the presentation of the Scatol8 system, detailed information on the hardware has been provided. The countless combinations and architectures of sensors, peripheral nodes, and coordinator node are not ends in themselves; indeed they are oriented to the collection and disclosure of information.

2. Wearable technologies

Wearable applications are possible thanks to the development of smart textiles, also known as electronic textiles, and thanks to the miniaturization of electronics that has allowed to integrate small circuits into the textile products [2]. This kind of textiles, introduced in the early 1990s, strongly influenced by military research and wearable technology in general [14], enables electronic components to be embedded in the fabric itself. The research behind these fabrics involves different topics like materials science, chemistry, design, and others. The multidisciplinary approach is also relevant because of the coexistence of design and usability of requirements. Another significant aspect in wearable technologies (also called wearable devices or wearables) is the optimization of power consumption in electronics that allowed to project smart applications whose batteries last enough for the specific usage. For example, the battery on a sport band must (at minimum) last the time of an average running session. New wireless technologies with low power consumption allow smart textile products to eventually communicate with other devices such as computer or mobile phones. In the case using these devices, the wearable application communicates on the Internet; we can say this product is also an IOT[2] application.

Wearable technologies can include many features. The smart textiles can be connected to sensors and react to external changes called stimuli. In response to these stimuli, the material can change some properties like its shape, color stiffness, etc. The wearable technologies can also include some actuators as some LEDs, displays, or speakers [3].

Virtually, in all the human cultures, people use garments not just for protecting themselves but also for distinguishing their sex, their social status, or their belonging to a specific subculture. Smart garments now extend their social function

[2] We can say that an object is IOT if it can be used without Internet connection, but within the net it extends its capabilities. For example, a server is not an IOT device because it is useless without a working net. On the other hand, a car can exist also without the use of the Internet to extend its capabilities, but the Internet would impact its nature or behavior, for example, giving real-time traffic information.

working as transmitters, sensors, actuator, or energy-harvesting entities. If these garments include a microcontroller, they can implement some logic like interacting with the cloud or with other devices [4].

Wearable technologies have been the subject of scientific studies since the mid-1990s [3]. The impulse, in terms of funding for research and product development, has been initially given by warfare applications. Immediately afterward, the potential of products in the biomedical sector and, subsequently, in sportswear area was understood. Lastly, with less resources, proposals have appeared in the fashion industry. The connections between these four sectors feed an increasingly rapid introduction of new products.

Presently, in the military sector, wearable technologies are identified as electronic technologies or computers that are incorporated into items of clothing and accessories which can comfortably be worn on the body. These wearable devices can perform many of the computing tasks as mobile phones and laptop computers; however, in some cases, wearable technology can outperform these handheld devices. Wearable technology tends to be more sophisticated than handheld technology available in the market today because it can provide sensory and scanning features not typically seen in mobile and laptop devices, such as biofeedback and tracking of physiological function [5].

Wearable technologies are now an important part in the process of developing military uniforms. New features can be monitoring the health of the soldiers as well as providing overall battlefield insights [6]. The military uses the data collected during engagement to improve the planning phase of future missions reducing causalities. One of the most important consequences using this kind of smart clothing is the reduction of injuries and consequentially the reduction of lifetime treatment borne by the whole country. The data collected from many soldiers and processed can help to dynamically change tactic as well as to improve the communication in the group [6].

Wearable military objects share many needs and requirements with some civilian applications. For example, in some sport or medical contexts, it would be useful to monitor some biometric parameter directly on the clothes. Devices like smart bands are already available on the market at cheap prices. New features are currently under development like monitoring athletes' oxygen saturation and heart rate and sending those data on a server where the coach and medics can analyze them [7]. Zhou et al. [8] explain a textile application where a matrix of sensors measures the muscle activities during the sport activities. In this way, it's possible not just to measure if there is a muscle contraction but also if the movement is done correctly. Another example in the sport context is a wearable system composed of a GPS connected with a breath sensor and an electrocardiogram to trace athletes' body performances [9]. Wearable sensors can be used not only for athletes; Mascia and others show an application where inertial sensors are used to evaluate people's movement, and in particular it is possible to check if a child can run properly [10]. Medicine can also take advantage from wearable technologies. Tuba and others explain how it is possible to detect vital signs with a sort of watch [11]. Dehydration can also be detected to evaluate the health status of elderly, diabetic, and sporting people in real time throughout the day [12]. Another interesting example of wearable medical application is a spine posture monitoring system based on inertial sensor. The data collected are elaborated with a mathematical and geometrical model; in this way it is possible to monitor rehabilitation sessions as well as to help patients to correct bad postures [13]. The sector of fashion has been the last one, in order of time and compared to the sectors cited before, to be involved in the IoT diffusion.

Lena Berlin, from the Swedish School of Textiles [14], did an in-depth analysis about smart textile in fashion. One first interesting point is that if medical and workwear application researches are mainly developed in public projects (e.g., EU projects) or universities, on the other hand sport applications and fashion textile projects are developed by universities and companies. After the literature analysis, the author said: An overall impression of the analysis and speculations is the strong belief that the potential of using smart textiles lies in application such as medical, workwear, and other technical applications rather than fashion. This can be true if we consider the potential of the research development, which is the main focus of scientific articles, but it is not so obvious if we consider the potential economic revenue in a huge market like the fashion one is. It's difficult to analyze that impact now because there are not still a lot of big companies working in fashion that have invested significantly in wearable. An example of a big company investigating in wearable fashion devices is Adidas that bought Textronics in 2008 [15]. There are also some technical barriers that are limiting the diffusion of smart textile applications. Sensors and radio can be quite expensive; for this reason many applications are just LEDs integrated in clothing. There is not a standard for interconnections between textiles and electronics, and it is difficult to make all the components robust enough. Because of the typical high costs and small production, we can say that wearable fashion products are not yet a mass product and mainly concern the luxury.

The wearable technology sector is, peculiarly, multidisciplinary. Considering innovations in tissues, research is a priority of materials engineering or bioengineering, with regard to hardware and software, electronic engineering, information technology, and telecommunications and with regard to shapes, architecture, design, etc. (see other references in the bibliography). If, then, it comes to assessing demand and defining production and commercialization strategies, we can see the involvement of product engineering, logistics, business economics, strategic marketing, etc.

The growth prospects of the wearable technology sector appear to be very promising, although there are substantial differences between sources. Recently, the "wearable technology market—global for 2022" report has predicted a growth rate of 15.51% between 2016 and 2022, moving from 15.74$ billion in 2015 to 51.60$ billion in 2022. However, it is a very wide sector, which includes also, but not only, textile products. Products that could have the highest growth rate are augmented reality glasses or virtual reality glasses. Hanuska and others show that the smart textile market for military uses is expected to significantly grow becoming a 500 M$ market in 2018 because this is now a common need shared among almost all the countries in the world.

The EU has supported research in the wearable sector since 2002, allocating 3.984 million with the FP6 program. Subsequently founding continued with FP7 program. The main projects are [16]:

1. "My Heart," 16 million/allocated from 2003 to 2009

2. "Dephotex," funding of 3.131.482 Euros

3. "Stella Project," funding of 7 million Euros

The biomedical sector was the most funded one by the EU. Despite an extensive research effort in several projects for over 10 years, there are only few smart textile clothing products on the market, and the volume of business, if declared, seems to be modest in the context of fashion and clothing. However, there are some newly established companies focused on the development and commercialization of smart textile clothing. An interesting aspect in these efforts to commercialize smart textiles is the interdisciplinary collaboration between companies in fashion and electronics, respectively. Besides pure fashion companies, there are some companies established that sell know-how on how to integrate electronics into textiles and clothing. A number of EU projects in smart textiles have been supported over the last decades. Most of the supported projects are within the health monitoring area. Another type of projects at the EU level is developed enabling technologies for smart textiles, for example, stretchable electronics, integration of electronics in textiles, technologies that are necessary for the development of smart textile applications, health monitoring for medical assistance, health monitoring integrated in work wear, projects developing enabling technologies, fashion, and clothing companies.

Consultancy partners specialized in textile and electronics. The combination of textiles and electronics in smart textiles has opened up for a new type of consultancies who are specialized in the combination of textiles and electronics. These consultancies concentrate their business in supporting other companies in their manufacturing of smart textiles and clothing rather than manufacturing and selling their own collections. However, some of them combine their consultancy with the manufacturing and marketing of their own technologies or materials [14].

2.1 Wearable technologies and fashion

The Swedish school of textile has thoroughly investigated the field of wearable technologies. The report on smart textiles and wearable technologies [6] presents an overview as a basis of further discussion of how smart textiles could be introduced in fashion. As shown there are already some commercial initiatives around Europe who specifically target fashion. What is also obvious is that there has been an extensive research activity both at the European and national levels in the area of smart textiles and clothing. The total funding of the presented EU projects, for example, is around 70 million Euros, which could be seen as a high financial contribution. It should though be noted that the money is shared between researchers in different areas such as textiles, electronics, wireless technology, battery research, and system engineering. These research efforts are therefore not only a concern in smart textiles since the results also contribute to developments in other areas. Despite a rather extensive research effort, the industrial and commercial activities are still in its infancy.[3]

The report "a roadmap on smart textile" [17] focuses on the potential of the smart textile; it divides the market into three areas: healthcare, workwear, and sports. The fashion industry is not studied and neither considered as a field of interest for the future. In another market survey, carried out by Ohmatex [18], fashion is considered as one of the areas but assessed as irrelevant initiatives, because of the size of the impact. The analysis reveals the barriers between the research and the commercial outlets which have been overtaken by several emerging designers, among which, for the originality of the proposals, Cutecircuit [19, 20], Pankaj and Nidhi [21], Anouk Wipprecht [22], Becca McCharen [23], Pauline van Dongen [24], and Akll Giysiler [25]. Some products result in an effective connection between healthcare and workwear, mediated by innovative stylistic elements: Clothing+, HVDING [26], MOON Berlin [27], Myontec, No-contact [28], Philips Lightning Lumialive [29], Stealth Wear anti-drone garments [30], Textronics [31], Utope [32], and WARMx [33].

The difference between implementations for healthcare and workwear, and implementations in the fashion field, is that in the first case, they are oriented to health monitoring or facilitating the wearer's communication, whereas in fashion applications, they are more oriented to a visual or a tactile feedback.

Looking at the latest high-fashion brand collections, which include smart clothing or accessories, we can find encouraging signals about the business perspectives. Ralph Lauren, Opening Ceremony, Rebecca Minkoff [34, 35], Karl Lagerfeld, and Hussein Chalayan [36] are just some of the great brands that have integrated various types of wearable technologies into their products. Chanel [37] launched a line of LED-powered handbags in the Spring-Summer 2017 collection, and it appears to be

[3] Lena Berglin, op. cit.

Figure 7.
One "ready to wear" kimono.

determined to integrate new technologies into its brand. Chanel has been trying to sort out its relationship with technology, looking for the ways in which technology tucked into clothes can improve our lives or at least make fashion become more interesting.

The contemporary presence of emerging designers and "approaches to wearable technologies," made by big brand, Andrew Bolton, the Costume Institute's chief curator, states that "Technology is eroding the difference between haute couture and ready-to-wear" [38].

The most common market entry barriers are current technology limits and the lack of standardization. Encumbrance, energy consumption, interconnection between textile materials and electronics, lack of standardization and quality systems, and training are examples of technical barriers. Low production rates and costs are barriers which are additional aspects related to the constraints imposed by safety and health. These factors affect both emerging designers, oriented to design and produce exclusive outfit and prototypes, and high fashion, oriented to realize one-of-a-kind outfit (**Figure 7**). It is likely that collaborations between these worlds, distant from economic capacity but convergent on technologies and the scale of production, can be considered. The adoption of wearable technologies by the industry, as well as it is for the society, is just at its first steps. Mesut [39] lists some of the possible applications: ease the life for the people with impairments; enable companies to interact with theater business people easier, to conduct market research more effectively and to apply sales and service strategies more efficiently; enable policemen, firemen, and military members to provide public and personal safety; enhance the virtual reality in games; and enable the doctors to monitor health indicators for the people continuously. These examples demonstrate how wearable technologies will make life easier and safer and how they can help to improve the entertainment market with new features.

3. The Scatol8 srl in the computational clothing

Scatol8 srl has a branch in the textile industry, called *Indigo Laboratories*. The emphasis on laboratory activity refers to the performance of the garment creation; in particular they are carefully designed to achieve both esthetic and functional performances. In the textile field, new technologies allow to extend the functions of garment. Indigo Laboratories, with its products, operates on the integration between electronics and textiles. The business is the *creation of prototypes* that incorporate the Scatol8 guidelines (accessibility, modularity, eco-compatibility, dissemination of knowledge) and their application to the production of *garments integrated with* *hardware and software*, components belonging to the *wearable technologies*, or, more specifically, *computational clothing*. The commitment in this area is functional to the achievement of Scatol8's goal, which is to ultimately disseminate the culture of sustainability, through modular and environmentally friendly products and projects, which promote relationship awareness between the individual and the environment where he lives. Therefore, our proposal combines a scientific application—related to the monitoring of environmental quality parameters—with fashion.

"Computational clothing" is a concept which emphasizes efforts to integrate computers and clothing. The manufactory aims to make garments which have the ability to process, store, retrieve, and send information. This capability will allow clothing and accessories to work as a stand-alone computer, to "react" according to environmental conditions and/or to connect to the Internet or other networks. Also, computational clothing will be able to change its appearance; it will allow users to access on specific apps "loaded" on modern smart devices (smartphones, tablets, etc.) [40].

In the field of textiles and clothing, *Scatol8 srl works in a network with some close relatives*:

- With the *QUMAP Laboratory* (QUMAP is the Italian acronym for quality of goods and product reliability), located at the PIN—University of Citta di Prato.

- With the *Phytolab-DiSIA Laboratory* of the University of Florence, to study and applicate new plant fibers (e.g., nettle and hemp) and natural dyes obtained from waste of the agro-industry such as oenological, fruit and vegetable, olive oil sector, and/or by officinal dyeing species.

- With two Italian SME that produce eco-leather from vegetable source, that is, the scraps of vine-wineries and olive tree pruning activities.

3.1 Interactive denim kimonos

The capsule collection we made, interactive denim kimonos (**Figure 8**), is made up of five short kimono models (Hanten), which respect the traditional proportions of this type of garment, winking to a more European fit, so it can be easily worn all days, in casual circumstances. The choice of a garment that belongs to the millennial Japanese tradition, but realized with the renowned Italian craftsmanship, has been carried out with the specific aim of demonstrating how the integration with wearable technologies is more than ever flexible and can be adapted and modulated according to the context, even if this means merging two apparently distant worlds.

Kimonos are packed in an environmentally friendly way: each garment is made from three vintage high-quality jeans (100% cotton) that, dismantled and reassembled, create a new item of clothing with completely different use of the starting materials, even though it has their distinctive patterns in a patch of blue or black tones.

We used special natural fabric ribbon, dyed with natural dyes for the integration of LEDs and patches in eco-leather, it has harmoniously conversed with the jeans patchwork, and it allowed us to achieve a unique and original result. Natural dyes, obtained from aqueous extraction or by green technologies, may be yellow obtainable from *Carthamus* or *Curcuma*; yellow-orange from golden onion and red onion; red from species rubia red beet, and myrtle or from scraps of the wine sector such as vinegar and grapevine; brown obtainable from chestnut extract; blue from spirulina algae; or by extraction from the Guado species.

Alternatives of hardware, software, and fabrics have been routinely verified in their reciprocal relations, to reach the present proposal by a network of Italian companies that worked together for the execution of the capsule collection.

Figure 8.
One example of interactive kimono.

3.2 Hardware and software components

Kimonos are equipped with a Scatol8 system, made up of hw and sw. The hardware consists of the following elements:

- Microcontroller Arduino-Arduino Micro
- Bluetooth module DSD TECH HM-10 Bluetooth 4.0 BLE IBeacon UART with 4PIN Basic card for ONU R3 of Arduino 2560 mega nano-sensors
- NooElec 1m actuators 60-Pixel Addressable 24-Bit RGB LED Strip, 5V, Waterproof IP68, WS2812B (WS2811), 4-Pin JST-SM

The *software* runs the Scatol8 system:

- Allows dialog between microcontroller, sensors, and actuators
- Realizes the smartphone app in Android and iOS
- Manages communication, via Bluetooth, to the smartphone, allowing colors changing schemes and sequences of the LEDs
- Manages communication between Scatol8 and the server
- Draws and makes the dashboard Crusc8 working
- Processes data to draw environmental quality maps

Table 2 shows the programming languages used for carrying out the activities.

Project part	Adopted language
Microcontroller	C++
App mobile	C#, sql
Database	Sql
Backend	HTML, PHP, JavaScript, SQL

Table 2.
The adopted programming languages.

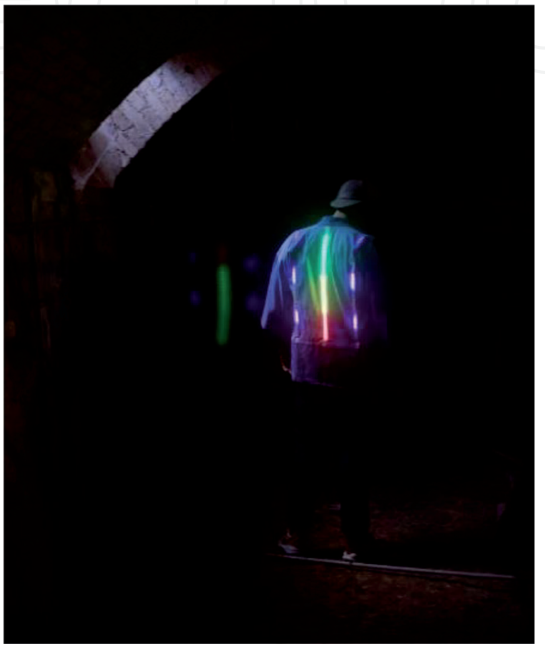

Figure 9.
A running kimono. It detects one environmental variable and change the LED's light proportionally to the acquired value.

Features can be set based on the user's needs both with sensors and actuators. The prototypes presented change their appearance depending on the sound intensity or the temperature or the brightness; dozens of sensors are available, and most of them are currently being tested to customize kimonos. The LEDs, driven by the open-source microcontrollers, take on a bright intensity and different colors to reflect the trend of the variables and to adapt to the color of the fabric (**Figure 9**). In addition to the LEDs, there are other actuators used in computational clothing: for example, it is possible to use heating systems that intervene when the temperature drops below a certain threshold, interaction systems with smartphones, for the collection and transmission of data, buzzers, etc. Also, through a smartphone application (**Figure 10**), you can *set the color and LED sequences* as you liked, depending on the style of your cloth, circumstance, or mood. In this way, the system continues to collect data through the sensors, but the chromatic effect is not determined by the intensity of the monitored variables. Kimono holders can log and make available the date, time, place, and intensity of the variable measured by their clothing (**Figure 11**). This allows the drawing of environmental thematic maps.

3.3 Environmental review

Kimonos have sprung out from the design planning of **Figure 3**. Alternatives of hardware, software, and fabrics have been routinely verified in their reciprocal

DOI: http://dx.doi.org/10.5772/intechopen.88120

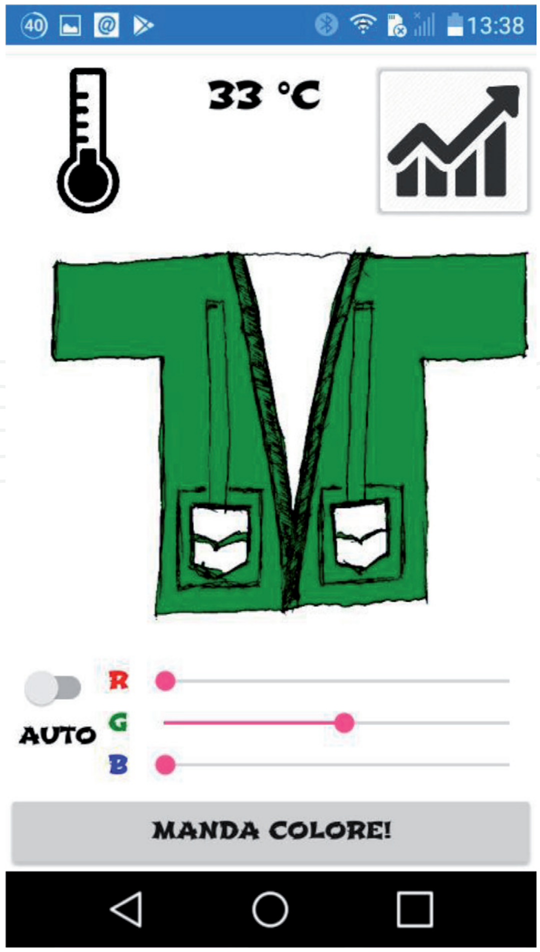

Figure 10.
The mail page of the application. The user can set the color of the kimono and read the detected environmental variable.

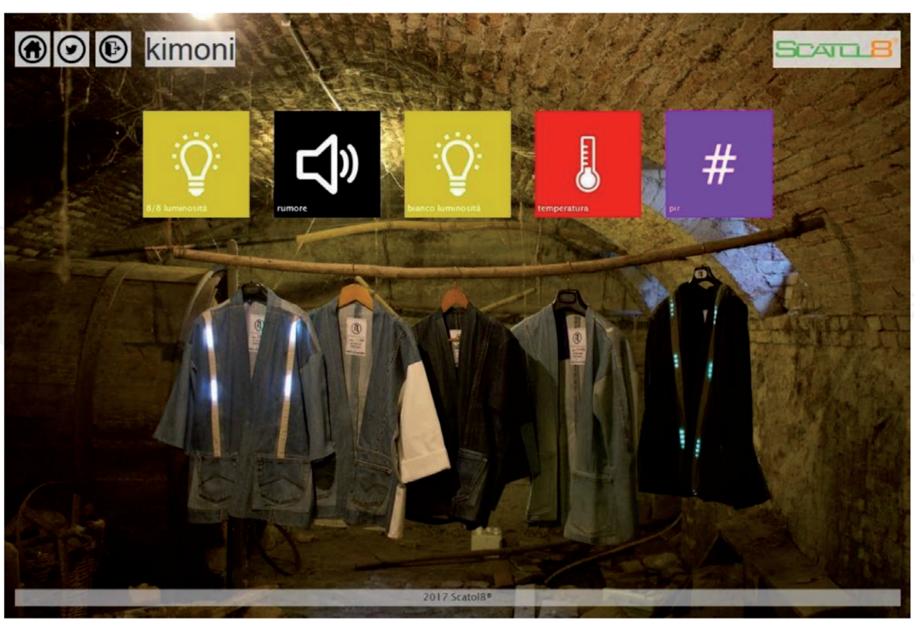

Figure 11.
The smartphone app forwards the collected data to a server. In this way it's possible to check the values everywhere using a browser, not just if you are near the kimono.

relations, to reach the present proposal. **Figure 12** describes the workflow of an interactive kimono. If we consider the process for the production of kimono from a gate-to-gate perspective, the input factors are:

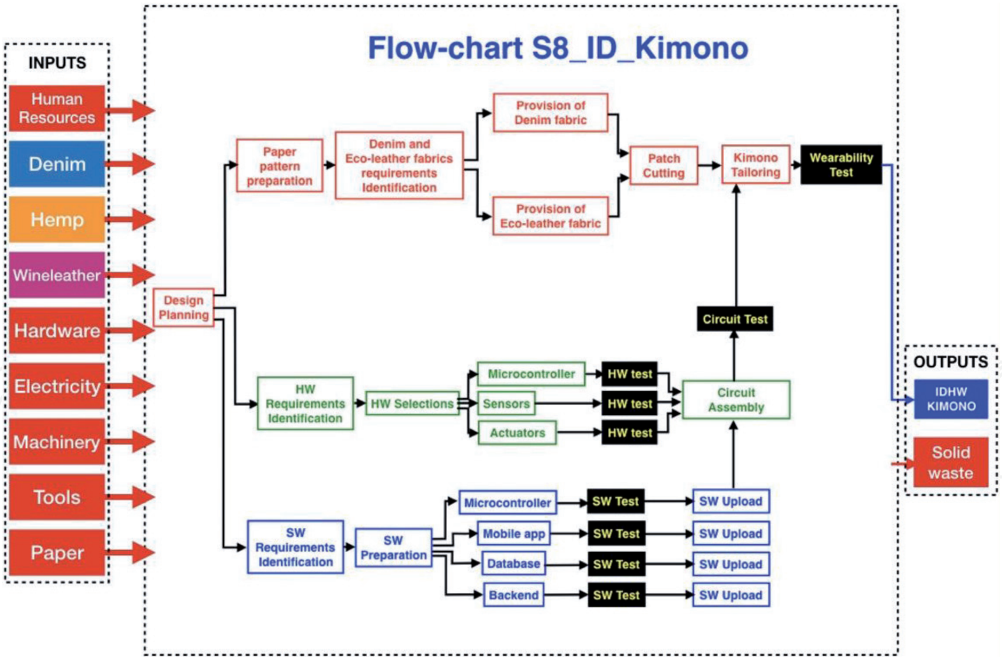

Figure 12.
The workflow of an interactive kimono.

- Fabrics (denim, hemp, eco-leather)
- Various materials (sewing thread of various diameters, model paper, writing instruments, tailor-made meter)
- Equipment (sewing machines, computers, microcontrollers, sensors, LEDs)
- Tools (tailor's scissors, needles)
- Various software
- Electric energy
- Human resources of multiple professionalism

The operations carried out are exclusively of a physical nature (drawing, cutting, and sewing), and the wastes (wastes of fabric) are reused in other artifacts.

Noting the low environmental impact of the operations carried out in the production of kimono, the improvement of environmental performance has been sought through a critical analysis and evaluation of kimono components, considering the type of raw materials and components and the susceptibility to substitution, in relation to the available environmental information. **Table 3** describes the situation.

Following the implementation of this decision-making scheme, in the framework of an environmental review, attention was focused on the type of fabric and on the identification of an alternative to cotton use.

With regard to the opportunity of denim replacement, this has emerged with reference to the environmental impacts that take place upstream within the Indigo Laboratories production process.

From a broader point of view, from cradle to grave, the life cycle assessment (LCA) would take into account the environmental impacts of denim.

Parts of kimono	Need for replacement	Susceptibility to substitution
Denim (cotton)	Appropriate	Possible
Ribbon (natural fibers dyed with natural dyes)	Not necessary	—
Patch of eco-leather	Not necessary	—
Electronics	To be verified	Not possible in the short term
Batteries	To be verified	Partial

Table 3.
Parts of a kimono and opportunities for ad environmental improvement.

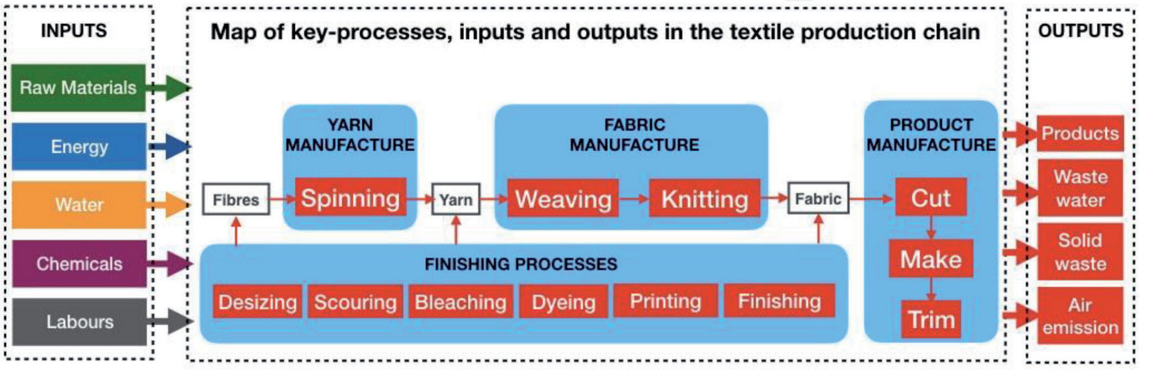

Figure 13.
The map of key processes.

Figure 13 shows the map of key processes in the textile production chain, no matter the type of fiber, being it synthetic, artificial, or natural.

Fibers, yarns, fabrics, and garments are the elements that mark the evolution stages. Each of them is a product, i.e., the output of transformation activities that generate a burden of an environmental impact, in terms of waste water, solid waste, and air emission.

If you want to evaluate the complete environmental impact, applying the LCA methodology, upstream the manufacturing process, there is the stage of fiber production; downstream there are the stages of distribution, use, and disposal [42].

Figure 14 drops the general scheme to the case of the production of cotton clothing. Each phase can be considered in itself a from-gate-to-gate form, or the whole cycle of transformations can be evaluated, in a from-cradle-to-grave form. *Scott Camp*, *Gordon Clark*, *Laura Duane*, and *Aaron Haight* have studied the life cycle of jeans from cradle to grave as a collection of seven independent systems. These systems in their respective order are (1) cotton production; (2) fabric production; (3) garment manufacturing; (4) transportation and distribution; (5) consumer use; (6) recycling, which then goes back to step (2); or (7) waste stream in a landfill [41]. Each phase is linked to the subsequent by a transportation activity. If we consider that cotton cultivation is restricted to subtropical areas and that garment manufacturing involves companies located in various countries, from Far East to South and Central America and the USA, it's easy to have an idea about the environmental burdens of transports.

Figure 15 deepens the disposal phase and includes recycling processes. After the use phase, discarded garments can be incinerated (with the generation of energy) or dumped into a landfill. But they can be recycled, after collection and sorting. Depending on their conditions, they can be reused as secondhand products; their

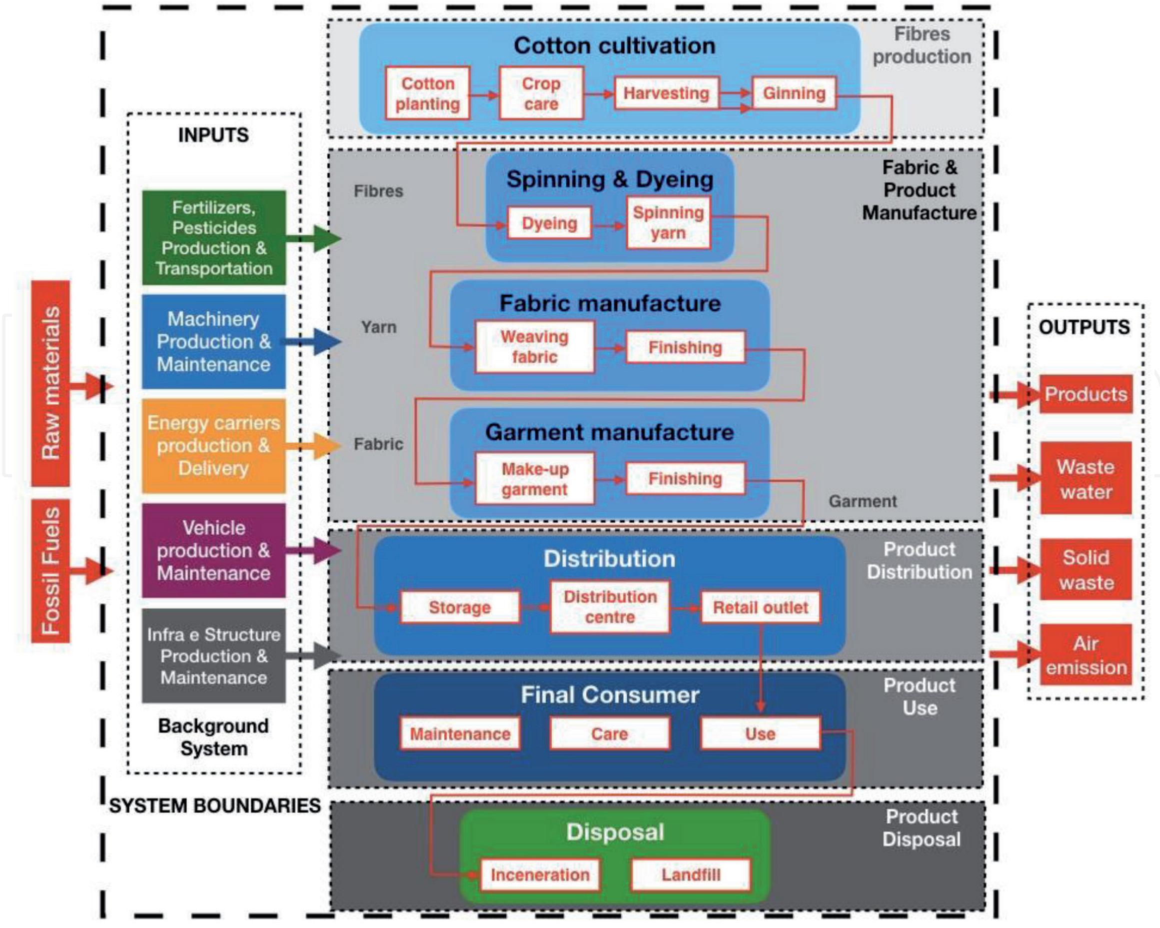

Figure 14.
Life cycle stages of a cotton clothing.

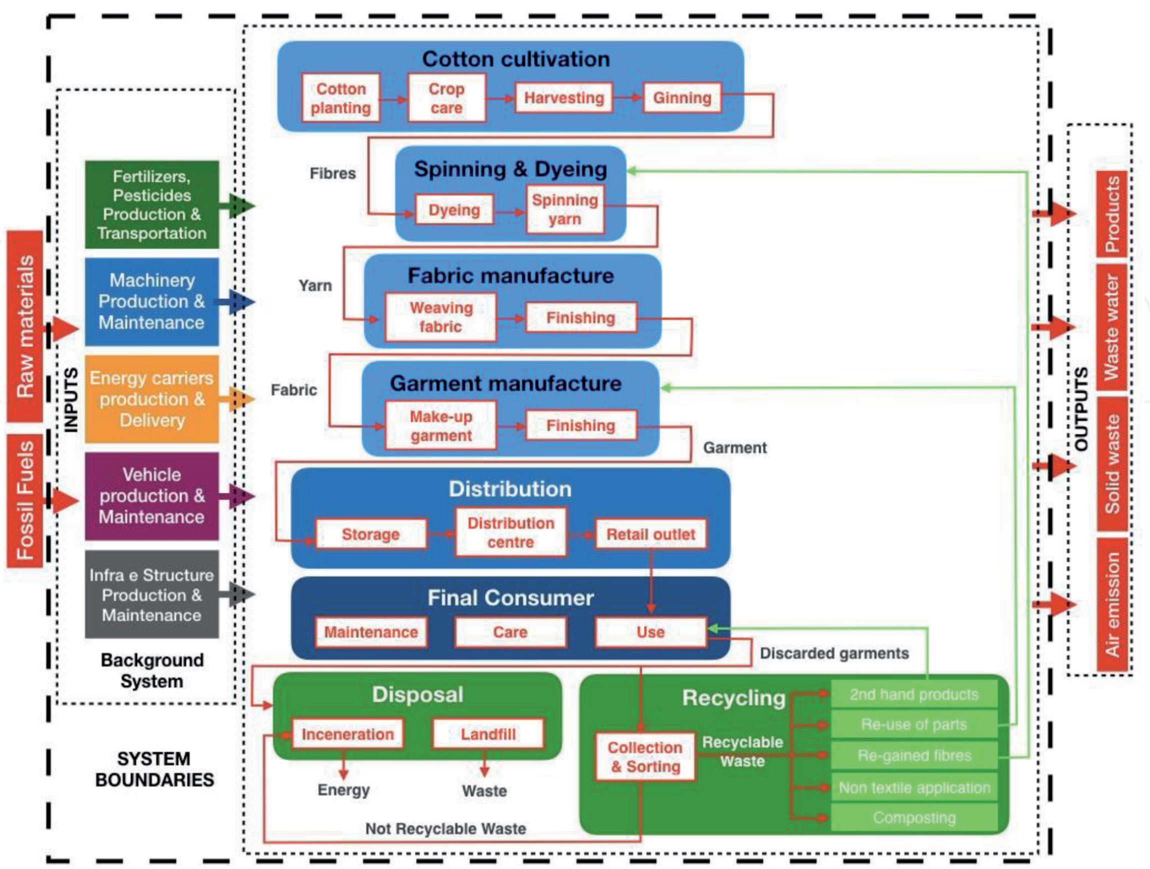

Figure 15.
Life cycle stages of a cotton clothing, with a focus on end-of-life options.

fibers can be recycled in the production of a new fabric; parts of them can be used for the production of new garments; and, in this case, we use the term *upcycling*.[4] The valorization of discarded garments is made up of the circular economy and extends the life cycle of a product, promoting material and energy recovery.

With regard to denim (cotton), the recovery of a material results in an environmental gain as disposal has been avoided; the same can be said for the eco-leather fabrics, being produced with waste of agriculture.

Numerous bibliographic references on the application of LCA to cotton fiber, denim fabrication, jeans packaging, use, and disposal emphasize critical aspects in various phases, especially in relation to water use and use of pesticides.[5]

Cotton is the world's most pesticide- and chemical-intensive crop. Of all the insecticides sprayed worldwide, cotton spraying accounts for roughly of them, also consuming 10% of the world's pesticides on an annual basis with an estimated cost of the pesticides totaling $2.6 billion [43].

These factors have been highlighted and discussed in the framework of a review by the Indigo Laboratories team with the aim of identifying improvement margins and assessing their feasibility.

The research of an alternative fiber was based on scientific contributions that evaluated, with LCA methodology, the environmental impact over the entire life cycle of other fibers.

Considering the whole textile chain, from spinning to finishing, it cannot be ignored that the use of chemicals may have carcinogenic and neurological effects, may cause allergies, and may affect fertility. During these processes, large amounts of water and energy are used, and, in general, non-biodegradable wastes are produced [55].

What are the alternatives to cotton? Emily Kenny-Troughton [46] examines all the available options to avoid or limit the environmental and social impact of the denim production process (**Figure 16**). These alternatives include, but are not limited to, recycled cotton, in-conversion cotton, organic cotton, organic flax, bamboo fiber, BCI cotton, hemp and nettle fibers, TENCEL TM as apex Modal, and recycled polyester. Conventional hemp is very different from cotton; as the plant requires little to no pesticides, fungicides, or herbicides and as it grows so

[4] With the term upcycling, the transformation of a waste into a new fashion object using creativity is indicated. Coined for the first time in 1994 by journalist Reiner Pilz and officially cleared in 1997 in the same book by Gunter Pauli, the concept of upcycling is well defined and largely distinct from the most consolidated recycle term, which describes an industrial process of transformation of waste. The "end of life" of products in the fashion system Rome, October 2013, edited by Clemente Tartaglione and Sara Corradini with research contributions of Gianmarco Guazzo, Mauro Di Giacomo.

[5] A large part of the sustainable solutions currently offered focus on the fibers used to create the garments and the ethical and environmental impact that they have. Aside from the petroleum-based obvious bad guys like polyester, cotton is one of the least sustainable fibers currently in use by the clothing industry. Issues with the fiber range from enormous water usage to the controversy of GMO crops and from exploitation of farmers to the widespread use of harmful chemicals. Around 20 million tonnes (USA) (18.14 billion kg) of cotton are grown every year (wwf.panda.org, 2016), and these fibers are present in over 50% of all clothing and other textiles (cottoninc.com, 2016). An example of how inefficient growing cotton is takes around 1514 liters of water for a simple cotton t-shirt (including all processes) and around a staggering 6814 liters of water (Tree- Hugger.com, 2016) to fully process a pair of jeans. The amount of cotton needed for one t-shirt and one pair of jeans is 1 kg (wwf.panda.org, 2016), and just over 1 billion pairs of jeans are sold annually on a global scale (statisticbrain.com, 2016), which gives a rough total of around 1 billion kilos of cotton being affected by the denim industry a year. This shows that steps taken to reduce denim's impact can have large-scale consequences. Research Report, Emily Kenny-Troughton, 500668689, International Fashion & Management, Ligia Hera & Jacqui Haker, page 5, 13/06/2016.

Figure 16.
One kimono made of hemp.

fast, it leaves all other weeds in the shade. In order to make threads from hemp, it is necessary to use the best fibers that are found in the stalk of the plant. This process does not require any chemicals at all, only using the enzymes naturally found in the plant itself meaning that it does little to no harm to the environment, workers, or end users of the product [45]. Lea Turunen states that comparison between hemp and cotton is difficult, due to lack of comparable data, but for the crop production stage, hemp performs clearly better than cotton with respect to pesticide use and water use. To improve hemp performance, she recommends to concentrate on fiber processing and yarn production stages, where hemp requires more energy [47].

There are studies which provide rankings of textile fibers according to their environmental impacts, as shown in **Table 4** and **Figure 17** [44, 45].

Hemp conventionally grown performs very well. In addition, its evaluation would be even better in our reality, as hemp has been cultivated for centuries in

Ranking	Fibers
Class A	Recycled cotton, recycled nylon, recycled polyester, *organic hemp*, organic flax (linen)
Class B	TENCEL, organic cotton, in-conversion cotton
Class C	*Conventional hemp*, ramie, PLA, conventional flax (linen)
Class D	Virgin polyester, polyacrylic, Lenzing Modal
Class E	Conventional cotton, virgin nylon, rayon (cuprammonium), bamboo viscose, wool, generic viscose
Unclassified	Silk, organic wool, leather, elastane, acetate, cashmere, alpaca

Table 4.
Environmental impact of textile fibers.

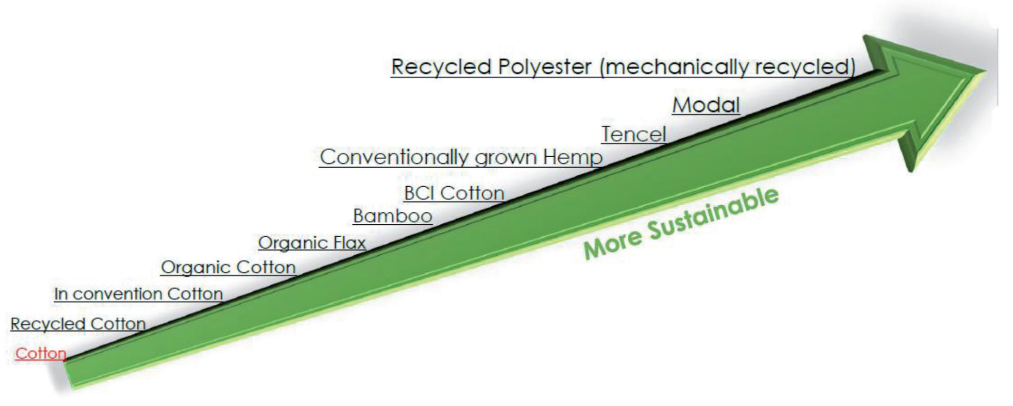

Figure 17.
Degree of sustainability of various fibers compared to cotton.

Piedmont. The fabric supply market is very close to our company, minimizing economic and environmental impacts.

Figure 18 shows the production of hemp fibers. Spinning and dyeing, fabric manufacturing being the same as cotton, and differences in terms of environmental impacts can be found at the agricultural production, straw processing, and transport stages. The best alternative is raw hemp or dyed with natural pigments.[6]

In literature, many studies highlight the benefits of hemp, also due to its use in many economic sectors, leading to the integral use of its parts [47–51].

It is a fiber that can be used for the production of a variety of commercial items such as textiles, clothing, thermal insulation, paint, paper, biofuel, biodegradable plastics, food, and animal feed [52, 53].

Ribbons and patch of eco-leather—The ribbons and the patch in eco-leather are made of natural fibers and dyed with natural pigments; they do not need to be replaced.

Electronics—Electronic devices, consisting of microcontrollers, sensors, and LEDs, evolve rapidly: it is likely to presume that the market will produce even more miniaturized products, available, so constructed with less material, as a concrete example of dematerialization strategies.

To get an environmental impact assessment of electronic components, we started an LCA study of the electronic devices we use. As far as LEDs are concerned, there are studies that unequivocally determine environmental benefits of LEDs compared to other forms of lighting (which would not be usable in

[6] Conventional hemp is very different from cotton; as the plant requires little to no pesticides, fungicides, or herbicides and as it grows so fast, it leaves all other weeds in the shade.

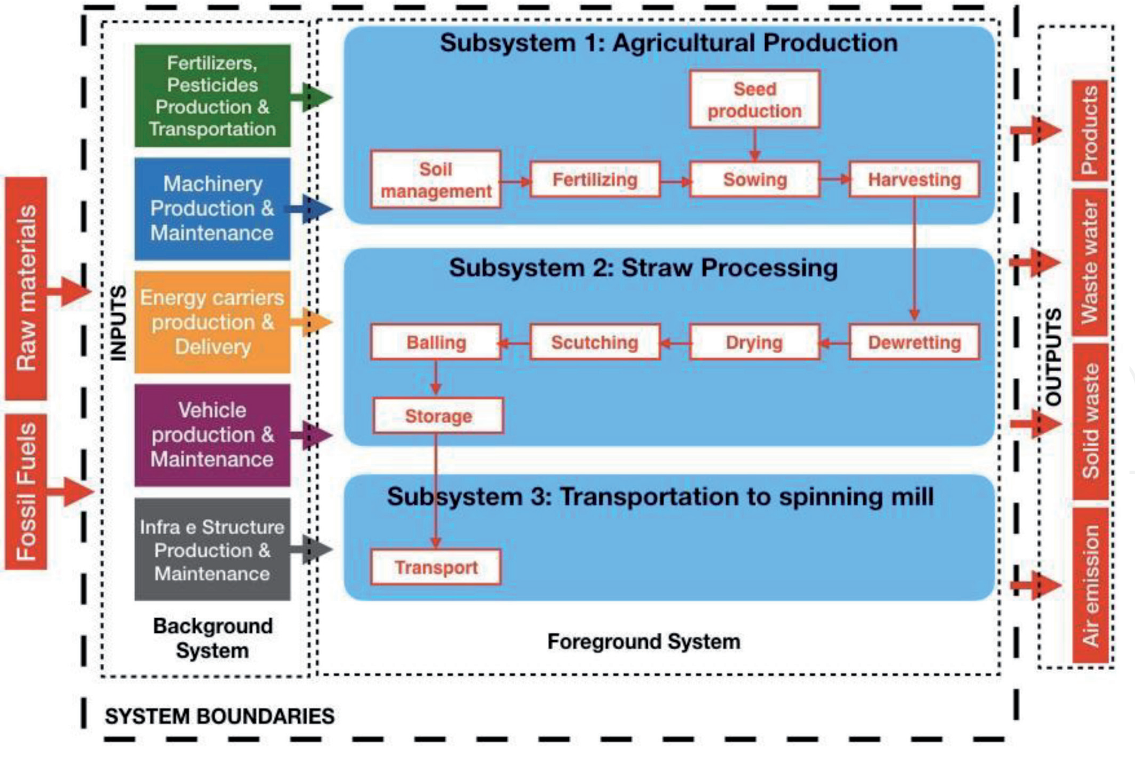

Figure 18.
Production of hemp fibers.

garments); the literature does not provide estimates for microprocessors and sensors that we used.

Batteries—The batteries currently used have a weight of about 250 g and a variable lifetime depending on the type of usage but can also reach 3 h of autonomy before being recharged.

The ability to integrate into the garment photovoltaic cells would reduce the size and weight of the batteries but would require an LCA verification of the cells themselves. It is something on which we are currently working with a special prototype.

As a final decision, at the end of the review on environmental performance of kimono, it has been decided to plan the manufacture of a line of hemp made of kimono which is significant not only for the environmental point of view but also for the recovery of cultural values associated with the cultivation and use of hemp.

4. Conclusions

Scatol8 for Sustainability is an entrepreneurial initiative that raises the theme of sustainability by incorporating it into luxury goods. Buying a Scatol8 product means belonging to an elite who appreciates handicraft products, an expression of Made in Italy, and acting to be aware of the environment in which one moves. Then, culture becomes a matter of luxury. In a magmatic market of consumer goods, it is not the price to decree the exclusive connotation. The price limits the boundary between who has and who does not have. Luxury, in the Scatol8 vision, delimits the boundary between who is and who is not.

The concept of Scatol8 has been presented through various luxury products (**Figure 19**) that testify the creativity of our innovative start-up. Multidisciplinary know-how, creativity, innovation, short lead time, and outcomes that exceed expectations are the critical success factors we are working on to improve ourselves continually.

Figure 19.
The capsule collection S8-ID-kimono, presented during the exhibition "Y Kimono Now," in Caraglio (CN), Piedmont, Italy.

The *S8_ID_KIMONO* has been analyzed in detail; it fulfills the requirements of portability, modularity, and awareness-raising through continuous monitoring of environmental conditions. Hardware and software have been optimized to reduce size and energy consumption. *Indigo Laboratories' proposal incorporates functional and fashion aspects. The functional side is taken from the various electronic devices and consists in monitoring environmental variables; the fashion part is represented by the colors, their variation, and intensity, which transform the garment*. The transmission and processing of data add a scientific aspect. Regarding the monitoring of parameters related to the quality of life, the introduction of new sensors on air quality and the biomedical field will broaden the capability of the garments and, consequently, the business opportunities.

Indigo Laboratories intends to expand the number of corporate network members, to increase the effectiveness of joint ventures. Starting with the design of garments, developed together with fashion institutes, thanks to a diversification of production cycles, Scatol8 will be able to develop products whose degree of customization will increase. In view of continuous improvement, we plan to introduce patches of natural fabrics, dyed with natural dyes, to enhance cultivation and environmentally virtuous practices, carried out in Italy.

In addition, a current work in progress is the expected adoption of design for environment techniques to develop garments that, from design, propose to integrate hardware not to simply add it. The transition from application to electronic integration is important, in our opinion, to give birth to really new cloth in shapes and style.

In addition to kimono, the electronic system miniaturization and the versatility of the LEDs allow Scatol8 to be integrated in other garments, suitable for every occasion; for example, the cotton t-shirt collections, which supported Scatol8's message from 2013 onward, made with strictly certified sustainability fabrics [54], will be renewed and revolutionized by the interaction made possible by the patented device.

Cost reduction that could be achieved by standardizing the models would lead to the spread of garments that, from the point of view of environmental quality research, would potentially allow thousands of surveys, georeferenced, useful to undertake health policies and to evaluate their effectiveness. Monitoring of environmental conditions and biomedical parameters will provide guidance to improve the quality of life by enabling, in emergencies, the sending of warning signals or the pilotage of systems designed to improve conditions.

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References

[1] Beople. The business model Canvas. 2017. Available from: http://www.businessmodelcanvas.it/

[2] Berglin L. Smart Textiles and Wearable Technology—A Study of Smart Textile in Fashion and Clothing. Swedish School of Textiles, University of Borås; 2013. p. 7

[3] Henock HD. Literature over view of smart textiles [Thesis for the Master of Textile Technology]. Boras, Sweden; 2010

[4] Foroughi J, Mitew TE, Ogunbona PO, Raad R, Safei F. Smart fabrics and networked clothing: Recent development in CNT-base fibers and their continual refinement. IEEE Consumer Electronics Magazine. 2016;**5**(4):105-111

[5] National Institute of Advanced Studies. International Strategic and Security Studies Program (ISSSP), Wearable Military Technologies, ISSSP Reflections No. 30, Bangalore, India; 2015

[6] Hanuska A, Chandramohan B, Bellamy L, Burke P, Ramanathan R, Balakrishan V. Smart Clothing Market Analysis. Berkley: Berkley University of California; 2016

[7] Fua Y, Liub J. System design for wearable blood oxygen saturation and pulse measurement device. Procedia Manufacturing. 2015;**3**:1187-1194

[8] Zhou B, Sundholm M, Cheng J, Cruz H, Lukowicz P. Measuring muscle activities during gym exercises with textile pressure mapping sensors. Pervasive and Mobile Computing. Sep 2016. DOI: 10.1016/j.pmcj.2016.08.015

[9] Li RT, Kling SR, Salata MJ, Cupp SA, Sheehan J, Voos JE. Wearable performance devices in sports medicine. Sports Health. 2016;**8**(1):74-78

[10] Mascia I, Vannozzia G, Bergaminia E, Pescea C, Getchellb N, Cappozzoa A. Assessing locomotor skills development in childhood using wearable inertial sensor devices: The running paradigm. Gait and Posture. 2013

[11] Yilmaz T et al. Detecting vital signs with wearable wireless sensors. Sensors (Basel, Switzerland). 2010;**10**(12):10837-10862. DOI: 10.3390/s101210837

[12] Zak J, Solovei D, Sedlacek J, Hubalek J. Development of wearable medical system for dehydration detection. 2012 4th Electronic System-Integration Technology Conference, ESTC. 2012. pp. 1-6. DOI: 10.1109/ESTC.2012.6542216

[13] Voinea G-D, Butnariu S, Mogan G. Measurement and geometric modelling of human spine posture for medical rehabilitation purposes using a wearable monitoring system based on inertial sensors. Sensors. 2017;**17**(1):1-19. Article No: 3

[14] Berglin L. Smart Textiles and Wearable Technology. The Swedish School of Textiles, University of Borås; 2013

[15] Rutherford JJ. Wearable technology. IEEE Engineering in Medicine and Biology Magazine. 2010;**3**:19-24

[16] Community Research and Development Information Service—Project and Results Site. 2017. Available from: http://cordis.europa.eu/projects/home

[17] Anne S, van Langenhove L, Guermonprez P, Deguillemont D. A roadmap on smart textiles. Textile Progress. 2010;**42**(2):99-180

[18] Ohmatex project. 2006. Available from: http://www.ofseth.org

[19] Wearable technology. Vision and history. 2017. Available from: https://cutecircuit.com/wearable-technology/

[20] Twitter Dress: Social…fashion. 2017. Available from: http://www.bigodino.it/tecnologia/twitter-dress.html

[21] Pankaj, Nidhi. 2017. Available from: http://www.pankajnidhi.com/ss12-Geometrica.html

[22] Synapse dress, l'abito smart che veste il modo in cui ti senti. 2014. Available from: http://www.medaarch.com/2014/09/synapse-dress-labito-intelligente-che-veste-il-modo-incui-ti-senti/

[23] Codame Fashion+Tech. Behance. 2017. Available from: https://www.behance.net/gallery/16246789/Codame-FashionTech

[24] Werable Technology. From Fitbit to Solar Cells. 2014. Available from: http://www.dressed.so/blog/2014/08/08/wearable-technology-from-fitbit-to-solar-cells/

[25] Giyilebilir teknomoda: Akilli Giysiler. 2014. Available from: https://www.youtube.com/watch?v=ordT391jXeY

[26] Hovding. 2017. Available from: https://hovding.com/

[27] Moon Berlin. 2017. Available from: http://www.moonberlin.com/

[28] No-contact. 2017. Available from:http://www.no-contact.com/

[29] Philips showcases production-ready Lumalive textile garments. 2006. Available from: https://phys.org/news/2006-08-philips-showcases-production-ready-lumalive-textile.html

[30] Ahproject. 2017. Available from: https://ahprojects.com/projects/stealth-wear/

[31] Textronics. 2017. Available from: http://www.textronicsinc.com/

[32] Utope. 2017. Available from: http://www.utope.eu/sporty-supaheroe jacket01.html

[33] Smart textiles—product development around textile current circuits. 2017. Available from: http://www.warmx.de/index.php/industry-and-research.html

[34] Rebecca Minkoff. 2017. Available from: https://www.rebeccaminkoff.com/

[35] The rise of wearable technology. 2015. Available from: https://dispatchist.com/the-rise-of-wearable-technology-interlaced/

[36] Paris Fashion Week, sfilano occhiali e cinte smart di intel. 2016. Available from: http://www.corrierecomunicazioni.it/it-world/43735paris-fashion-week-sfilano-occhiali-ecinte-smart-di-intel.htm

[37] Weeables on the Runway. 2016. Available from: https://www.wearable-technologies.com/2016/11/wearables-on-the-runway/

[38] Brooklin's Wearable Revolution. 2016. Available from: https://www.nytimes.com/2016/05/01/fashion/brooklyn-wearables-revolution.html?

[39] Mesut C. Wearable technologies and its future applications. In: Proceedings of ISER. Science Plus International Conference; Bangkok, Thailand. 2015. ISBN: 978-93-84209-99-5

[40] Barfield W, Mann S, Baird K, Gemperle F, Kasabach C, Stivoric J, et al. Computational Clothing and Accessories. 2001

[41] Camp S, Clark G, Duane L, Haight A. Life Cycle Analysis and Sustainability Report—Levi Strauss & Co.—ENVS 195: Sustainability Science, Dr. Saleem Ali. 2010

[42] Tartaglione C, Corradini S, Guazzo G, Di Giacomo M. The "End of Life" of Products in the Fashion System. Rome: Fondimpresa; 2013. pp. 17

[43] Snyder RL. Fugiive Denim: A Moving Story of People and Pants in a Borderless World. 1st ed. New York: W.W. Norton & Company; 2008

[44] Luiken A. The life cycle of jeans, NVRD-project, chain management jeans. In: ISWA Beacon Conference on Waste Minimisation and Recycling; Wien. 2015

[45] Kenny-Troughton E, Hera L, Haker J. Research report "To what extent is it possible for a denim company or denim department within a company to implement a fully sustainable denim development process?". International Fashion & Management. 2016

[46] Kenny-Troughton E, Hera L, Haker J. Research Report, 500668689. International Fashion & Management. 2016. p. 19

[47] Turunen L, Hayo van der Wert. Life Cycle Analysis of Hemp Textile Yarn—Comparison of Three Hemp Fiber Processing Scenarios and a Flax Scenario. 2016

[48] Addlesperger E. Commodity of the Quarter, Hemp, DePaul University Library, Chicago, Illinois, USA. Journal of Agricultural & Food information. 2015;**16**:196-202. DOI: 10.1080/10496505.2015.1050323

[49] Hayo MG v d W. Life cycle analysis of field production of fibre hemp, the effect of production practices on environmental impacts. Euphytica. 2004;**140**:13-23

[50] She L, Patel MK. Life cycle assessment of polysaccharide materials: A review. Journal of Polymers and Environment. 2008;**16**:154-167. DOI: 10.1007/s10924-008-0092-9

[51] Hayo MG v d W, Turunen L. The environmental impacts of the production of hemp and flax textile yarn. Industrial Crops and Products. 2008;**27**:1-10

[52] Kymalainen H-R, Sioberg A-M. Flax and hemp fibres as raw materials for thermal insulations. Building and Environment. 2008;**43**:1261-1269

[53] Clarke RC. Traditional fiber hemp (cannabis) production, processing, yarn making, and weaving strategies—Functional constraints and regional responses. Part 1. Journal of Natural Fibers. 2010;**7**(2):118-153. DOI: 10.1080/15440478.2010.482324

[54] Scatol8 official website. Available from: http://scatol8.net/?p=3014

[55] Torres Ana L, Angel GM. Sustainability in Fashion and Textiles: Values, Design, Production and Consumption. Sheffield: Routledge; 2013