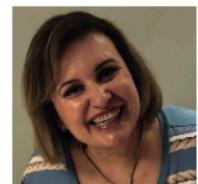


# CIRCULAR ECONOMY: PROPOSAL FOR SUSTAINABLE SNEAKER PRODUCTION IN A SMALL FOOTWEAR COMPANY

*Economia Circular: proposta para a produção de tênis sustentável em empresa calçadista de pequeno porte*



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## ABSTRACT

A solution for the destination of discarded textile scraps from clothing companies is textile shoddy. The process is known as textile recycling. The shoddy fibers are obtained from the processing of residual materials and reinserted into the textile chain to produce new fabrics through circular economy strategies. In this context, the main objective of this article is to present a proposal to produce sustainable sneakers for small footwear companies. To produce the yarns, shoddy fibers originating from garment scraps discarded by industries in the city of Ibitinga (SP, Brazil) were used. Textile materials discarded by the clothing manufacturers with a 100% polyester composition were selected; the fabric scraps were shredded and mixed with recycled polyester fibers (PET) to produce the yarns: 50% shoddy fibers / 50% recycled polyester from PET bottles. The yarns were produced on ring spinning frames and the uppers on rectilinear knitting machines. The produced articles showed that there is technical viability to produce seamless knitted uppers using shoddy fibers as raw materials.

## KEYWORDS

Seamless knitted uppers; Sustainability; Textile recycling; Sneakers; Circular economy.

## RESUMO

Uma solução para a destinação das aparas de tecidos descartadas pelas empresas de confecção são os desfibrados têxteis. O processo é conhecido como reciclagem de tecidos. As fibras desfibradas são obtidas a partir do processamento dos materiais residuais e reinseridas na cadeia têxtil para a produção de novos tecidos através das estratégias da economia circular. Nesse contexto, o principal objetivo deste artigo é apresentar uma proposta para a produção de tênis sustentável para empresas calçadistas de pequeno porte. Para a produção dos fios foram utilizadas fibras desfibradas oriundas de aparas de confecções descartadas pelas indústrias da cidade de Ibitinga (SP). Foram selecionados materiais têxteis descartados pelas confecções com composição 100% poliéster, as aparas de tecidos foram desfibradas e misturadas com fibras de poliéster reciclado (PET), para a produção dos fios: 50% fibras desfibradas/ 50% poliéster reciclado de garrafas PET. Os fios foram produzidos em fiação de anéis e os cabedais em máquinas retilíneas de malharia. Os artigos produzidos mostraram que existe viabilidade técnica para a confecção cabedais de malha sem costura utilizando como matérias-primas as fibras desfibradas.

## PALAVRAS-CHAVE

Cabedais de malha sem costura; Sustentabilidade; Reciclagem têxtil; Tênis; Economia circular.

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## 1. INTRODUCTION

The first sports shoes were produced in the mid-19th century, using cotton canvas and rubber soles as raw materials. The use of textile materials in sports footwear provided greater functionality or added benefits to consumers.

More recently, in 2012, Nike and Adidas launched sneakers with seamless knitted uppers on the market, using weft flat knitting technology. The sneakers are produced using various structures, making the upper seamless, comfortable, ultralight, durable, and with an adjustment to the user's foot (Power, 2018). Currently, there are other technologies for the production of seamless knitted uppers, such as raschel machines (warp knitting) and large and small diameter circular machines (weft knitting).

According to ABICALÇADOS (2024), footwear production can be divided by predominant material and by type of use. The main raw materials used in the production of Brazilian footwear are: plastic, rubber, synthetic laminate, textile, leather, and other materials. By type of use, they are classified as: flip-flops, casual, formal, sports, safety, and orthopedic. Sneakers can be classified as casual, inspired by sneakers, or sports, inspired by existing sports modalities (Marcondes Silva & Sanches, 2025).

The Brazilian footwear chain operates in a linear production. According to Schuch *et al.* (2020), this scenario needs to be remodelled because the extensive exploitation and degradation of the natural ecosystem will lead to a scarcity of raw materials. Large quantities of solid waste are discarded by textile companies at all stages of the production process. In the footwear sector alone, about 25% of the raw materials used are discarded as material scraps, like garbage.

Thus, the main objective of this article is to present a proposal to produce sustainable sneakers for small footwear companies. Regarding the methodology, according to Gil (2010), scientific methodology is characterized by the nature of the research, its methodological approach, its objectives and approach to the research problem, and the technical procedures adopted. From the point of view of its nature, the present research is classified as applied, with an inductive method of approach; it is an exploratory research study with a qualitative approach, and the technical procedure adopted was the case study.

## 2. RESEARCH SCENARIO

### 2.1. Brief History of Footwear Evolution

Prehistoric man used materials such as raw leather, wood, straw, and fabrics in the production of his rudimentary footwear. The assembly was quite simple: the leather, usually thin, from goats or dogs, was cut to a size close to the foot and braided with strips usually made of fibers or papyrus. The leather used to make the soles were thick, such as those from horses or oxen, and in some cases, the soles were made of wood (Ferreira, 2010).

Primitive shoes remained unchanged for many years; only in the fourth century was there a change in concept, introducing decorative variations in footwear. From this point on, footwear became, in addition to a protective artifact, an object symbolizing power and wealth among ancient civilizations. The period of the Middle Ages in Europe was, for footwear artisans, one of the best times to unleash their creativity. The most used material was cowhide, but the highest quality boots were made of goatskin. In the Renaissance the shoes began to be made to measure to fit the wearer's foot perfectly. Luxurious materials such as silk, velvet, and fine leather were widely used, and shoemakers began to experiment with heels and ornaments (Ferreira, 2010).

Before the Industrial Revolution, shoemaking was a meticulous art. Artisan shoemakers used techniques passed down through generations to produce custom-made shoes

that were comfortable and stylish. Shoe production was predominantly a manual craft, practiced by artisans who personalized shoes for each client. The process was, by nature, time-consuming and limited the number of shoes produced. However, customers could choose the specific design, materials, and adjustments to meet their needs and preferences.

The First Industrial Revolution marked the transition from artisanal shoemaking to mass production. According to Cardoso (2008), instead of hiring many skilled artisans, companies hired a good designer to create the project, a good manager to oversee production, and many unskilled workers to perform small tasks as machine operators. The high remuneration of the former two was offset by the lower wages paid to the latter. Thus, mass production came to represent a saving of time and money for the manufacturer.

With the 1st Industrial Revolution came innovations such as the sewing machine and the rubber vulcanization process, which revolutionized shoe manufacturing. The introduction of sewing machines and assembly lines completely changed the way shoes were made. The main advantage of mass production is the ability to manufacture large quantities of shoes in a short period, aiming to meet the growing demand for products while reducing production costs. Reduced costs allowed more people to buy quality shoes at lower prices. However, mass production also brought challenges. Standardization can lead to a loss of quality and exclusivity, in addition to environmental issues related to the use of synthetic materials and large-scale manufacturing processes.

After World War II until the late 1960s, footwear industries were concentrated in the wealthiest countries that had developed high-performance production models. However, after the beginning of the 1970s, these production models proved unviable due to the need for abundant labor and high labor costs, forcing the footwear industry to undertake a permanent migration in search of countries or regions with abundant labor and lower wages.

A first migration of the footwear industry was observed towards the so-called Asian Tigers (South Korea, Taiwan, and Hong Kong), and another migratory movement of footwear production took place in Asia towards less developed countries such as China, Indonesia, and Vietnam. Currently, about 80% of footwear production is concentrated in the following countries: China, India, Vietnam, Indonesia, and Brazil, with China alone accounting for 54.6% of global footwear production (ABICALÇADOS, 2024).

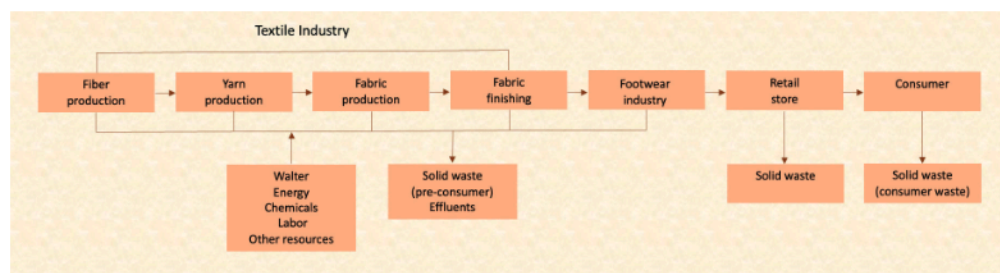
## 2.2. Brief History of Footwear Evolution

The Brazilian footwear chain operates in a linear production, where significant quantities of fossil resources are extracted from nature and used as raw materials to produce footwear. At the end of their useful life, these products are discarded by consumers and sent to landfills. This production model is based on the extraction, production, use, and disposal of resources and materials (Sanchez *et al.*, 2022). A traditional sneaker is composed of more than 50 parts, as shown in Fig 1, which illustrates the main components of a sneaker.



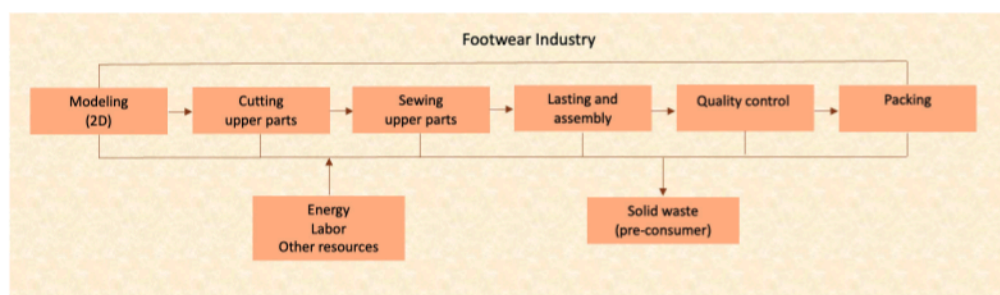
**Fig. 1** - Main parts of a sneaker. Source: (Dos Santos& Silva, 2009).

The upper, which is the upper component attached to the sole, has the function of protection and safety, providing comfort and convenience to the feet. The upper can be produced from a single material or it can be produced with several materials, the main materials are leather, woven or knitting, synthetic laminates, etc. According to Duarte & Sanches (2022), the production of conventional fabric sneakers begins in the textile chain: with the production of textile fiber, yarn, woven fabric, knit fabric, and non-woven fabric, textile processing. The finished fabric is sent to the footwear industry to produce sneakers. Fig 2 shows the main stages of the production process of conventional fabric sneakers.



**Fig. 2** - Conventional process of fabric sneakers: productive chain from the textile industry to the final consumer. Source: Adapted from Sanches *et al.*, (2022).

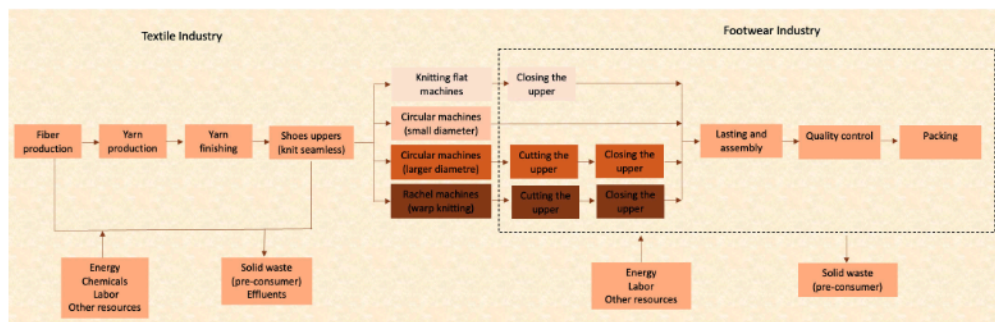
In footwear companies, the production process is carried out through the following activities: modelling preparation (shoe creation), cutting of the upper parts, upper assembly (sewing of the parts), upper assembly on the sole, finishing, quality control, and packaging (Sanches *et al.*, 2024), as illustrated in Fig. 3.



**Fig. 3** - Conventional production process of sneakers in the footwear industry. Source: Adapted from Duarte & Sanches (2022).

Brazilian footwear industries are known as traditional industries, have existed for many years, and are labor-intensive, as the vast majority are small and family-owned, use artisanal production methods, and make little investment in technology. According to ABICALÇADOS, (2024), approximately 50.0% of companies consist of up to four employees, and only 6% of companies in the sector have more than 100 employees.

In addition to the conventional process, knit uppers can be produced by new seamless technologies: knitted on flat knitting machines, large diameter circular knitting machines, small diameter circular knitting machines, or raschel machines (Cuden, 2022; Sanches *et al.*, 2021). These new technologies function as outsourced companies, meaning they deliver ready-made seamless knit uppers to the footwear industry, in the size and shape to be assembled onto the sole. Fig. 4 illustrates the main stages of the production processes for seamless knitted uppers.



**Fig 4** - New technologies used in the production of seamless knit uppers. Source: Sanches *et al.*, (2025).

In the textile industry, knitting receives dyed yarns to produce seamless uppers. In the footwear industry, the preparation of seamless uppers produced using different technologies follows different flows, as illustrated in Fig 4. The steps of assembling the upper onto the sole, quality control, and packaging of the sneakers are carried out, following the same production flow described for sneakers produced by the traditional process (Sanches *et al.*, 2024).

### 2.2.1 Flat Knit Upvers

The production of seamless upper knit using flat knitting is carried out without generating waste, with the uppers produced in the size and shape requested by the footwear industry. This technology reduces the production time of sneakers in the footwear industry, generates no waste, and reduces the costs of the final product (Basu & Gupta, 2019). According to Krinner (2023), flat knitting machines produce one upper every 10 minutes and can knit three uppers simultaneously. The uppers produced on straight machines are open. The machines can produce closed uppers, but this operation is not normally carried out by the knitting because it reduces the production capacity of the machines.

### 2.2.2 Small Diameter Circular Knit Upvers (Sock-shoe)

According to Sandonini (2017), the 3D knit uppers produced have the shape of a sock (3D) and are produced in three minutes. The upper is delivered to the footwear industry ready to be assembled onto any type of sole, reducing waste generation, production time, and the cost of the final product for this industry.

### 2.2.3 Large Diameter Circular Knit Upvers

Large diameter circular knitting machines have a productivity that, depending on the type of structure used, can be twenty times greater than the productivity of a flat knitting machine. According to Cunha (2018), the energy consumption for the production of one upper is about five times lower than the same upper produced on a flat knitting

machine. The uppers produced by this technology are knitted side by side. The fabrics produced between the uppers need to be cut, and the footwear sector discards 10% of the raw materials used in the form of material scraps when this technology is used.

#### 2.2.4 Double-bar Raschel Machine

The productivity of this technology is much higher than the productivity of large diameter circular knitting machines. However, to produce uppers using a raschel machine, it is necessary to prepare the warp beam, making the technology viable only for large quantities of uppers (Krinner, 2023). The knit uppers are knitted in the fabric side by side, and, just like the uppers from large diameter circular knitting machines, the knitted fabric between the uppers, about 10% of the produced knit, needs to be cut by the footwear industry.

### 2.3. Main raw materials and their impacts on the production process

The selection of raw materials and the production process will define the impact that footwear will have on the environment. The materials commonly used in the manufacture of sneakers are: polyester, polyamide, polypropylene, elastane, cotton, and wool are the textile materials most used by the footwear industry. The synthetic materials make sneakers lighter and more comfortable, improve the performance of athletes, and reduce the cost of the final product, but these raw materials are derived from fossil fuels. According to McLoughlin (2020), the footwear industry is responsible for 1.4% of global greenhouse gas emissions. Sneaker producing companies generate 313 million tons of CO<sub>2</sub> per year. According to, the upper, normally produced with polyester threads, a material that uses a lot of energy during processing, is responsible for 41% of total carbon emissions.

The production of a standard pair of sneakers generates 14 kilograms of carbon emissions, MIT (Massachusetts Institute of Technology) researchers conducted a study that determined the production process stage is the most polluting, generating 9.5 kilograms of carbon emissions, representing 64% of the total carbon emissions of a pair of sneakers. The raw material extraction/production stage generates 4 kg of carbon emissions, which represents 29% of the carbon footprint of a pair of sneakers. Within the production process stage, Granskog *et al.* (2020) stated that textile processing is responsible for 25% of industrial water pollution and point to the use of chemicals, liquid waste, and intensive water use as the main contributors to the loss of biodiversity.

#### 2.4. Circular Model and Textile Recycling

According to the Ellen MacArthur Foundation (2020), in the circular model, products are designed with a view to their reuse, recycling, and recovery. The circular economy has as its principle the implementation of a new production model that does not cause negative impacts on the environment.

Recycling is an alternative to incineration and landfill disposal of waste. It allows the production of new products from discarded raw materials, with lower production costs and a reduction in the consumption of energy and other resources (Sanchez *et al.*, 2022). The recycling of textile materials can be carried out through four routes: fiberizing, mechanical recycling, chemical recycling, and energy recycling. The choice of recycling route is made based on the composition of the material to be recycled. Recycling is carried out in three main stages: collection and sorting of materials, selection of the recycling process, and choice of a manufacturing process to transform it into a new product.

### 2.4.1 Textile Recycling: Fiberized Fibers

Polyester fiber is obtained from synthetic polymers. Many types of polyester can be synthesized; however, they are all produced by a condensation reaction and all contain an ester functional group. The most used type of polyester for fabric production is polyethylene terephthalate (PET). The production of virgin PET emits volatile organic compounds, releases toxic pollutants into groundwater, and, when compared to the production of natural fibers, consumes a large amount of energy and a low amount of water (Stone *et al.*, 2019). Manufacturing scraps (pre-consumer) can be fiberized and reinserted into the textile chain to be used as raw materials in the production of a new product. The fiberizing process consists of cutting the fabrics and defibrating them to transform them into fiberized fibers, which will then be transformed into yarns and then into new fabrics. Fabric scraps (pre-consumer) must be separated by material type and color so that the recycling result is as satisfactory as possible and there is no damage throughout the process.

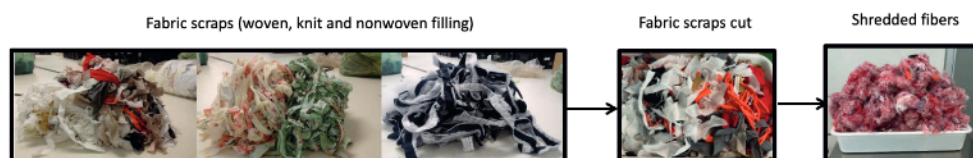
De Souza Pereira *et al.* (2016, pp. 10-11) mention in their research that the reuse or recycling of one ton of cotton clothing “uses only 2.6% of the energy needed to manufacture these products from virgin material.” [...] “Another positive factor is the absence of dyeing, [...], and with this, pollutant emissions are lower [...]”.

When comparing fiberized fibers from polyester fabrics with fiberized fibers from cotton, polyester fibers have an additional technical advantage: the length of the fibers, as it is possible during the process to cut the fibers to the necessary length to produce yarns, with 100% fiberized fibers or to be mixed with other materials (Sanches *et al.*, 2022). In the production of fiberized polyester fibers, volatile organic compounds are not emitted, there is no release of toxic pollutants into groundwater, it consumes a smaller amount of energy when compared to the production of virgin polyester, and there is no dyeing, as it uses dyed raw materials.

## 3. MATERIALS AND METHODS

### 3.1. Materials

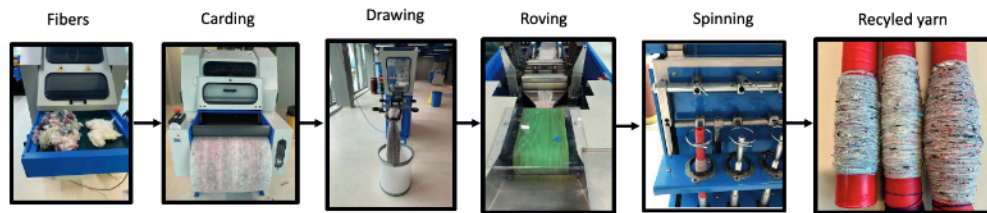
Fabric scraps with 100% polyester composition, discarded by garment factories in Ibitinga (SP), Brazil, were selected. The material was cut with an average length of 30mm and fiberized by a fiberizing machine, which transformed the material into fiberized fibers. Recycled polyester fibers from PET bottles were acquired on the market. Fig 5 shows the selected material.



**Fig. 5** - Manufacturing scraps (pre-consumer). Source: Sanches *et al.*, (2022).

### 3.2.1 Production of Recycled Yarns

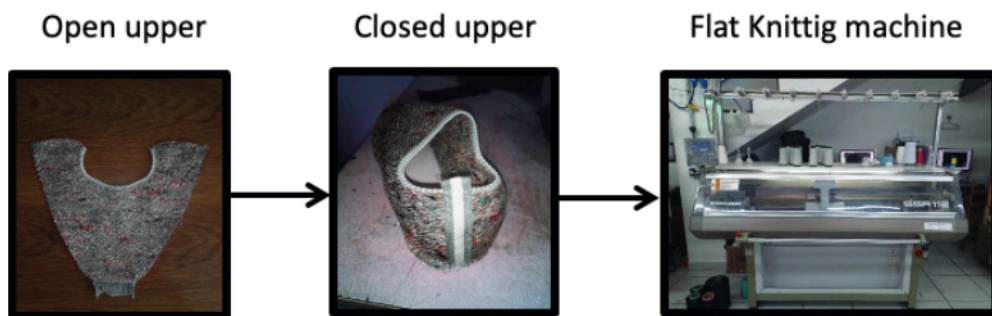
The selected spinning process was conventional short-staple spinning. The fiberized fibers were mixed with recycled polyester fibers from PET bottles in a carding machine to produce the blended yarn with 50% fiberized fibers/50% recycled fibers from PET bottles. Then, the fiber web formed in the carding machine was processed in a drawing frame/roving frame and transformed into yarn by a ring spinning frame. Fig 6 illustrates the blended yarn production process.



**Fig. 6** - Blended yarn production process. Source: Adapted from Sanches *et al.*, (2022).

### 3.2.2 Production of Seamless Knit Uppers

Fig 7a, 7b, and 7c illustrate, respectively, an open upper produced by flat knitting machines, the closed upper after the sewing stage carried out by the footwear industry, and a Shima Seiki brand flat knitting machine used for knitting seamless uppers.



**Fig. 7a, 7b, 7c** - Stages of the production process. Source: Sanches *et al.*, (2024).

### 3.2.3 Final Product

A three-dimensional model was created so that the product could be better visualized even before it was actually manufactured. Fig 8a and 8b shows the 3D sneaker.



**Fig. 8** - Simulation of the final product. Source: Faustino, (2023).

## 4. RESULTS AND DISCUSSION

When comparing the production process of conventional fabric sneakers with new technologies to produce seamless knit uppers, it can be stated that the production process of conventional sneakers is longer and has a greater number of steps to be carried out by the industries in the textile chain. The number of operations is also greater in the footwear industry, and it uses a large amount of labor, mainly in the cutting and sewing sectors of the upper and discards a large amount of fabric scraps from the cutting sector into the environment. Higher energy consumption, due to the process having a greater number of steps, and the disposal of fabric scraps into the environment are the main contributors to the environmental impact caused by this sector.

The different technologies used in the production of knitted uppers produce different textile products, but there are also products that can be made by more than one technology, as is the case with uppers for sports shoes. Knitting mills typically select the technology based on the needs of their customers.

Sneakers produced with seamless knitted uppers, compared to those produced by the traditional process, are lightweight, durable, breathable, flexible, have a comfortable fit, and all the necessary functionalities, defined based on the activities that will be performed by users. At the same time, they reduce working hours in the industry and environmental impact, improve inventory management, speed up time to market, and allow ultimate customization of sneakers.

In addition to the quantity of uppers produced by each technology, the raw materials that can be used in each technology must also be analyzed. In weft knitting, the variety of materials is wider; the technology allows selecting yarns from natural, artificial, and synthetic fibers. In warp knitting, the raw materials used are synthetic fibers (filaments), with polyamide and polyester being the most common.

## 5. CONCLUSIONS

Replacing virgin polyester with recycled polyester in the production of uppers will reduce the amount of carbon emissions, as the production of raw materials will not be necessary, and the process of transforming fibers into yarns will have fewer steps. Since garment scraps are colored, the yarns produced will be colored, meaning that the dyeing operation of the recycled yarns is eliminated during textile processing. In addition to reducing the consumption of virgin raw materials, it reduces the consumption of energy and water, and the emission of effluents, thus reducing the environmental impact caused by the production process.

For the production of knit uppers in a small footwear industry, the ideal is to use flat knitting machines. The technology for producing seamless uppers using flat knitting will contribute to the reduction of the environmental impact caused by the conventional footwear industry, the reduction of textile solid waste disposal in the environment and will reduce the number of steps in the production process, aiming to increase the competitiveness of companies, reduce their costs with taxes and fees, increase production, and decrease human errors. Flat knitting technology also allows for the production of small batches of uppers, increasing the possibility of product diversification when compared to uppers produced on small diameter circular knitting machines.

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She has been a professor at the School of Arts, Sciences and Humanities since 2006 and has been an associate professor at the University of São Paulo since 2011. She is a visiting professor at the University of Lisbon (Portugal), at the Polytechnic Institute of Castelo Branco (Portugal) and at the University of Campania “Luigi Vanvitelli” (Italy) and researcher at the School of Arts, Sciences and Humanities, at the Center for Research in Architecture, Urbanism and Design (CIAUD) at the University of Lisbon (Portugal) and at the Fashion Research Lab (FA.RE Lab) at the University of Campania “Luigi Vanvitelli”.

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Professor in the Department of Design at São Paulo State University (UNESP, Brazil) and in the Design Graduate Program at São Paulo State University (UNESP, Brazil). I hold a bachelor's degree in Textiles and Fashion from the University of São Paulo (USP), and a master's and doctorate in Mechanical Engineering from the State University of Campinas (Unicamp, Brazil). I completed a Sandwich Doctoral Internship

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Dr. Francisca Dantas Mendes is President of the SUSTEXMODA Institute, Coordinator of NAPI-SUSTEXMODA (USP), and Associate Professor at USP-EACH. With a PhD and postdoctoral degree from USP, she researches sustainability in fashion, focusing on textile waste and socio-environmental impacts. Author of three books and numerous articles, she leads the “Fashion in the Textile Chain” Research Group (CNPq). She is a member of the scientific committee of the Responsible Fashion Series (Antwerp) and coordinates the Textile Working Group of the São Paulo City Council. Since 2000, she has collaborated with UNESCO on initiatives for a culture of peace.

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