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Industrial textile recycling and reuse in Brazil: case study and considerations concerning the circular economy

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Reciclagem industrial e reuso têxtil no Brasil: estudo de caso e considerações referentes à economia circular

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Abstract: Textile products are present in all aspects of our lives and drive a significant part of the world economy. Issues related to enterprise competitiveness, sustainability, limitation of natural resources, environmental and social impacts are increasingly considered. In this context, the recovery and recycling of textile materials are essential. This study aimed to present an overview of the Brazilian textile and clothing industry, highlighting the mechanical and chemical recycling processes and reuse. We also discuss the reasons for importing textile waste, and considerations about circular economy concepts, correlating them to the key factors and obstacles involving industrial operation of textile recycling. The authors conducted technical visits to textile recycling industries in order to observe the production processes and identify their main challenges. Nevertheless, the initiatives show that Brazil is on track for industrial sustainability, following a global production trend.

Keywords: Textile; Recycling; Reuse; Circular economy; Sustainability.

Resumo: *Os produtos têxteis estão presentes em todos os aspectos de nossas vidas e movimentam uma parte significativa da economia mundial. Questões relacionadas com competitividade empresarial, sustentabilidade, limitação dos recursos naturais, impactos ambientais e sociais, são cada vez mais consideradas. Neste contexto, a recuperação e a reciclagem de materiais têxteis são extremamente necessárias. Este estudo teve como objetivo apresentar uma visão geral da indústria de vestuário têxtil brasileira, com destaque para os processos mecânicos e químicos de reciclagem e reutilização. Também foram relacionados os motivos da importação brasileira de resíduos têxteis com os conceitos da economia circular, relacionando-os como os principais fatores e obstáculos na operação que envolve a reciclagem de produtos têxteis. Os autores realizaram visitas técnicas em indústrias de reciclagem têxteis, a fim de observar os processos de produção e identificar os seus principais desafios. Ademais, as iniciativas brasileiras mostram que o Brasil está no caminho certo para atingir a sustentabilidade industrial, seguindo uma tendência global de produção.*

Palavras-chave: *Têxtil; Reciclagem; Reutilização; Economia circular; Sustentabilidade.*

1 Introduction

Textile products are present in our homes, hospitals, workplaces and vehicles in different formats and features, and, along with the garment industry, it moves a significant share of economies worldwide, determining habits and behaviors of consumption in society (Caldas, 2004). Such behaviors of consumption are supplied by an economic model of linear production based on "extract, transform,

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discard" which depends on large amounts of low-cost materials, and easy access to water and energy in abundance (Ghisellini et al., 2016).

Brazil is among the top ten textile industry markets, positioned as the second major supplier of indigo and the third fabric producer, according to data from Brazilian Textile and Apparel Association (ABIT, 2015). An industry worth US$ 797 billion on global value according to estimates of the World Trade Organization (WTO, 2015).

In the current economic environment, competition for new markets is increasingly fierce, and the perception of consumers for sustainable and affordable products is increasing rapidly. That causes producers to invest in the quality of their products and in responsible waste management, not only aiming company sustainability, but also for a myriad of businesses opportunities, until the end of the product life cycle (Cobra, 2015).

In this context, the recovery and recycling of textiles, become more and more necessary, not only environmentally, but also economically: reducing the need for landfill space, water and energy consumption, pressure on natural resources and, consequently, reducing the costs of industrial operation (Wang, 2006).

The ideal production model would incorporate the idea of circular economy to the heart of global value chains that exerts strategic influence on the design of the products, their consumption and the recovery of used materials, a proposal of economic planning from the private sector that established goals to use material resources that depends of social reproduction (Abramovay, 2014).

This study aimed to present an overview of the Brazilian textile and clothing industry, highlighting the mechanical and chemical recycling processes and reuse, with case study of companies operating in these areas. Data related to imports of textile waste is indicated (silk, wool, cotton, synthetic and artificial fibers), pointing out the reasons that lead the country – one of the major producers of textiles products and clothing, and consequently a large textile waste generator – to import textile waste rather than use domestic waste. Finally, considerations about the circular economy concepts was made relating them to the main factors and obstacles involving the industrial textile recycling operation, a necessary activity for the economy and the environment, but still little spread in Brazil.

The methodology analyzed the Sectorial Report for Brazilian Textile Industry carried out by the Institute of Studies and Industrial Marketing (IEMI); the analysis system of the information on foreign trade (ALICEWEB), the use of scientific literature, patents and laws concerning the textile recycling market and the circular economy. Through research on the internet, twenty-one companies of different sizes were located in the Brazil, which carry out the industrial process of recycling through the mechanical process by breakdown the fabric into fiber through cutting and, shredding, and the chemical process of regeneration textile fibers. The authors visited five textile-recycling industries in order to observe the different production processes and identify its major bottlenecks, as well as in a hospital at the city of São Paulo, which disposes large amount of textile waste in the form of professional uniforms.

2 Textile fibers

Textile fiber is the raw material submitted to manufacturing processes that can be transform into yarn used in textiles or industrial products. Textile fibers can be divided into those ones found in nature (for example: cotton plant, wool and animal asbestos mineral origin); and chemically made, which are still subdivide in artificially-obtained through processes that use natural polymer (cellulose), and whose production processes using synthetic polymers synthesized from first generation petrochemicals (ethylene, propylene, benzene and xylene) (Barbosa et al., 2004 ; TEXTINFO, 2011). Figure 1 provides a non-exhaustive overview of all the fibers.

In Brazil, cotton and polyester are the most common fibers used in fabrics as seen in Table 1, which lists the production of fabrics according to the fiber origin during the period from 2012 to 2014.

3 Textile and apparel market

Brazil is the fourth major producers of textiles products in the world and the fifth in the apparel production. It is self-sufficient in cotton production and regarded as a global reference in swimwear, jeans and home textiles, producing 9.8 billion pieces by year, and about R$ 5.5 billion in garments. The value of textile industry and manufacturing production in 2014 was R$ 164.9 billion, according to data presented in

Table 1. Production of fabrics in Brazil by nature of the fiber (in tons).

	2012	2013	2014
Cotton	752,879	772,213	752,908
Polyester	296,009	308,015	310,384
Viscose	14,189	12,703	11,832
Polyamide	7,376	7,489	7,023

Source: IEMI (2015).

Table 2. Textile Industry Production Value in 2014 (R$ billion).

	(R$ billion)
Fibers and filaments	2.6
Fabrics	39.4
Apparel	122.9

Source: IEMI (2015).

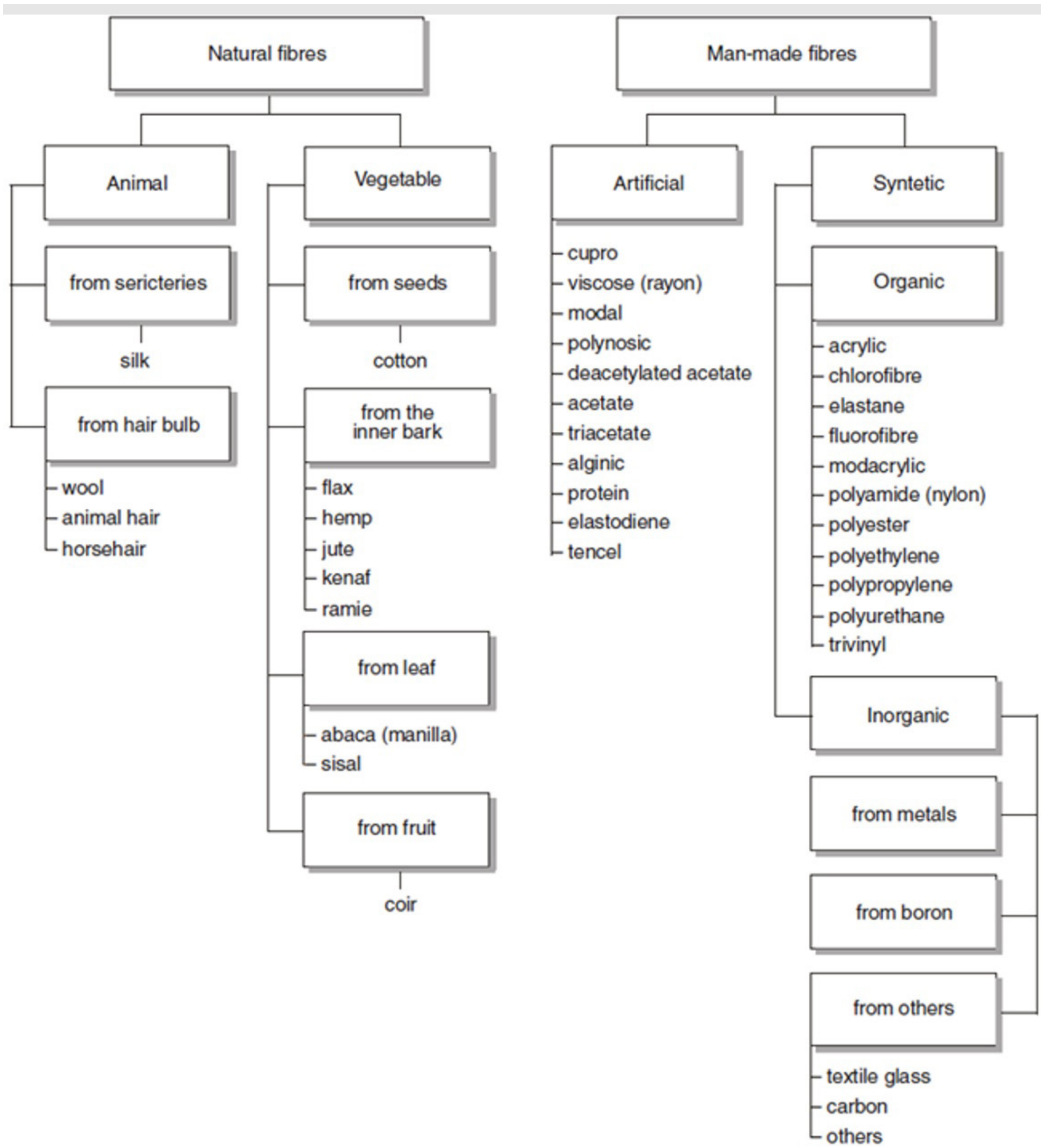

Figure 1. Classification of textile fibers. Source: Adapted from Barbosa et al. (2004) & TEXTINFO (2011).

Table 2, which represents 5.6% of the GDP generated by the manufacturing industry, demonstrating the relevance of this sector to the Brazilian economy (ABIT, 2015; IEMI, 2015).

The textile and clothing production chain is present in all 27 Brazilian States, with more than 32,000 companies, located mainly in the South and Southeast regions of Brazil, especially in the State of São Paulo, which concentrates 27% of production units (Brasil, 2014).

The textile and clothing sector is the second largest employer in the Brazilian manufacturing industry, behind the food industry. There are approximately 1.585.6 million direct jobs, representing 17% of the total of workers engaged in the manufacturing industry, distributed in all segments of the production chain, from the natural and synthetic fibers production, spinning, weaving, knitting, finishing and sewing (ABIT, 2015). Figure 2 represents the structure of vertical chain of textile and clothing distribution in Brazil, including the P&D centers, technical schools and universities as intellectual support in all segments of the production process.

Analyzing the relation between Brazilian textile production and the population of Brazil in 2014 – approximately 204 million people (IBGE, 2014), the

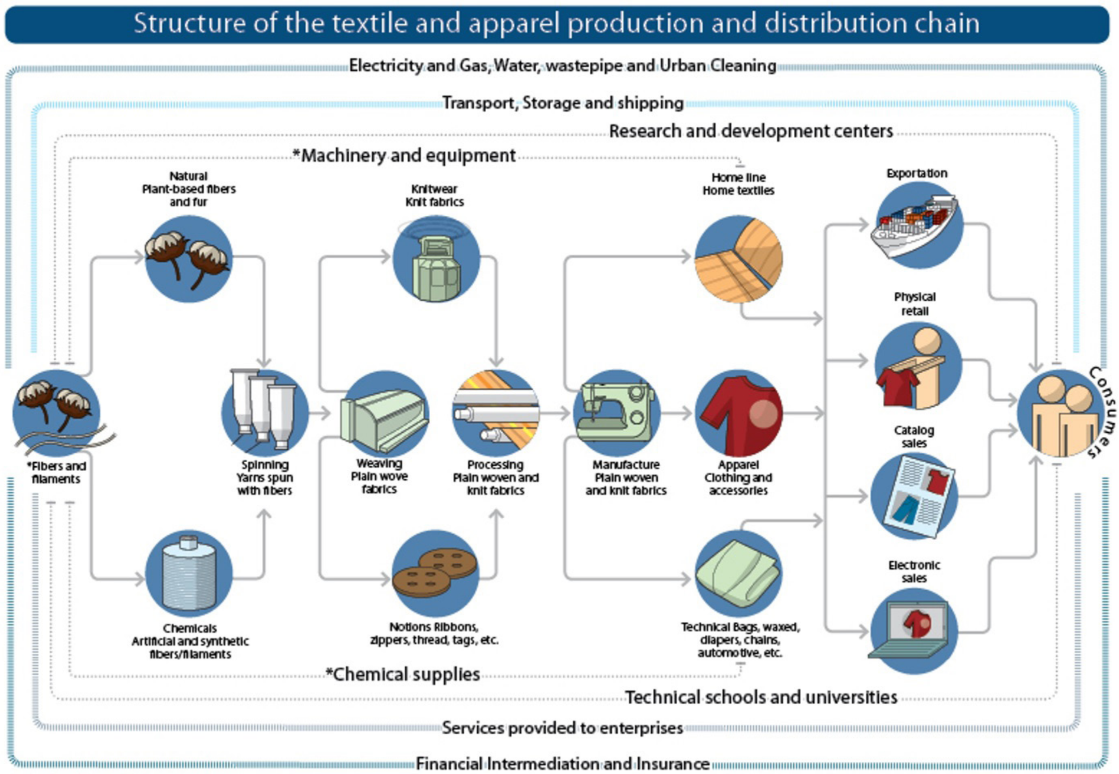

Figure 2. Structure of the production chain and textile and clothing distribution. (*) Segments of suppliers. Source: ABIT (2015).

consumption of textile products per individual was 10.3 kilograms. The Table 3 shows that the annual consumption of textile fibers per inhabitant was 13.3 kilograms, indicating that imports products supplied the difference between production and consumption per capita (approximately 23%) (IEMI, 2015).

The consumption of cotton fiber is predominant in Brazil, about 84% of the total fiber consumption, or 1.042 million tons, followed by artificial and synthetic textiles fibers compounds (13%) and other natural fibers (3%) (IEMI, 2015). Brazil is the third largest exporter of cotton, the fifth largest consumer and the first in productivity in non-irrigated land (land cultivation at low rainfall) with a medium volume around 1.7 million tons of cotton plume per harvest, which puts Brazil among the five largest producers, alongside countries like China, India, USA and Pakistan (ABRAPA, 2016).

4 Textile recycling processes

Recycling is the process in which a product or its components are used to create something new, it represents the technical form of reuse, but specifically refers to discarded items, minimizing the use of virgin raw materials and the amount of waste disposal in landfills or sent to incineration. However, reuse is a general term that combines materials or items that have reusable qualities, regardless of whether the product would have the same function or not (Wang, 2006).

Table 3. Annual consumption of textile fibers (in kilograms per inhabitant).

	***Per capita* consumption (kg)**
2012	13.0
2013	13.2
2014	13.3

Source: IBGE (2014) and IEMI (2015).

Recycling and reuse processes contributes to the management and conservation of raw materials that would otherwise be discarded, decreasing the need for new exploitation of natural resources that would be needed for the production of new goods and products (Abramovay et al., 2013; Castro & Amato-Neto, 2012).

4.1 Mechanical process of textile recycling

The most common textile recycling process is the mechanical recycling by cutting and shredding fabric scraps, according to the capacity of the machine and the final product (Wang, 2006). Figure 3a shows the beginning of the process of cutting and shredding, with the machine loaded with *jeans* scraps.

The machine that performs the process is called Textile-Shredder, and can be composed of

(a) (b) (c)

Figure 3. (a) Initiation of *jeans* shredder; (b) Shredder designed for recycling scraps of spinning, weaving, knitting and nonwoven; (c) Fiber from shredded jeans. Sources: (a) (c) Adami Têxtil (2014); (b) Laroche (2015).

2, 4, 6 or 8 rolls, the more rollers, greater the quality of the recycled fiber. The rollers have different diameter with numerous needles on its surface, as shown in Figure 3b, responsible to rip and shred the rags. They rotate at high speed, and the number of needles increases in with each roll, in order to shred completely the textile materials as shown in Figure 3c (Laroche, 2015).

The design of the shredders machines works in accordance with the textile waste composition used and are capable to shred from 50 to 3,000 kilograms per hour (Laroche, 2015). According to the textile scraps composition, the shredded fibers can turn to the industry by blankets, stuffing, geotextiles and fillers or can return to the textile spinning process (Wang, 2006).

4.2 Chemical process of textile recycling-synthetic fibers

Chemical fibers were developed to copy and improve natural fibers characteristics and properties. As their applications grew, they became indispensable in the day by day life, due mainly to the increase of the world population that demands garments at low cost and fast production, while reducing the vulnerability of the textile industry to potential difficulties in agricultural production (Aguiar, 1996).

Synthetic fibers were made from petroleum-derived resins and its use is widespread in all segments of the textile and clothing industry. Among many, the most common are polyester, acrylic, polyamide/nylon, polypropylene and elastane (Araújo & Castro, 1986). Only polyester, polyamide and elastane can be recycled through the chemical regeneration process (Wang, 2006).

Three different patents of synthetic fibers chemical regeneration were available in public domain on the Brazilian National Institute of Industrial Property website. The oldest patent found – code PI/9202682-A dates from 1992, concerning the recovery of solid polyester (such as found in PET bottles and other products manufactured with this plastic). This process consists of grinding, drying, cleaning and reusing the solid polyester (plastic) as a raw material in fusion and extrusion processes at temperature of 295°Celsius to obtain yarns and textile filaments (Siebje & Siebje, 1992).

The second patent refers to the separation of polyamide and elastane, and date from 1994, with the code PI/9301022-2-A. Initially the fiber separation take place according to the color and quality of the yarn. The textile waste is placed inside a stainless-steel tank with formic acid. The contents of the tank pass through a filter that retains the solid part in form of a lightweight foam spandex. The foam is washed to remove any residue of polyamide. The remaining liquid is heated in a condenser at 50° Celsius, causing the separation of the formic acid, which passes to the gaseous phase. Finally, the polyamide deposited in the condenser in form of a thick mass that can be reused in the textile industry or in the chemical industry of plastics (Wolft, 1994).

In 2013, the patent PI/1104317-2-A2 published in Brazil details the process of recycling of polyamide 6 and 6.6 in order to obtain a state of purity that can allow the residue to be reused in the way it was designed for and chemically generated. In this process, the dissolution of the fiber occurs without modifying the molecular structure of the polyamide pure or as raw material for the production of engineering plastics (Heilberg, 2013).

The difference between polyamide 6 and polyamide 6.6 is the synthesis and quantities of amides radicals that feature different characteristics to the materials. Among the distinct feature, lightness, low friction coefficient, great power of electrical insulation, wear and, especially, chemical agent's resistance should be highlighted (Aguiar, 1996).

5 Textile recycling in Brazil

Like any industrial activity, the textile and apparel production chain generate solid waste, such as containers, plastic cones, lubricating oil, sweeping residues, unprocessed fibers, paper, cardboard, mud, scrap and rags, among others (CNI & ABIT, 2014).

In order to develop textile products, the template pieces that compose the garment are drawn on top of several layers of fabric, which is distributed in a way to maximize the use of the fabric. The template can be done manually or with the aid of software's, that helps minimize fabric waste, which in some cases can reach 20% (Audaces, 2014). The Figure 4 illustrates the cutting operation, in which the fabric is layered (spread) and cut to develop a particular garment.

According to estimates from SEBRAE (2014), Brazil produces 170 tons of textile waste per year, great part generated in the State of São Paulo. SEBRAE estimates that 80% of the material is destined to dumps and landfills, a wasted that could generate income and promote the establishment of sustainable business if used as raw material for other purposed.

5.1 Textile recycling industries in Brazil

Through online research, twenty-one companies of different sizes were located in Brazil. All of them perform the recycling process through the mechanical process of shredding or chemical fibers regeneration process (Table 4).

The authors visited five industries presented in Table 4, specified here as companies A, B, C, D and E (Table 5). The visits occurred in the São Paulo State between September 2014 and August 2015. Although the companies permitted the disclosure of the following information, they requested to remain unidentified.

The companies were classified in accordance with the classification criteria of IBGE (Brazilian Institute of Geography and Statistics), by the number of employees. According to these criteria, is considered micro-industry those companies with 19 employees or less; small industry, from 20 to 99 employees; medium industry from 100 to 499 employees and with over 500 employees a large industry (IBGE, 2014).

The industries 'A' and 'B' consume as raw material both textile waste from disposal, also called post-industrial scraps from the production of yarns or fabrics, and waste from post-consumption textile. Companies 'C', 'D' and 'E' use only post-industrial waste.

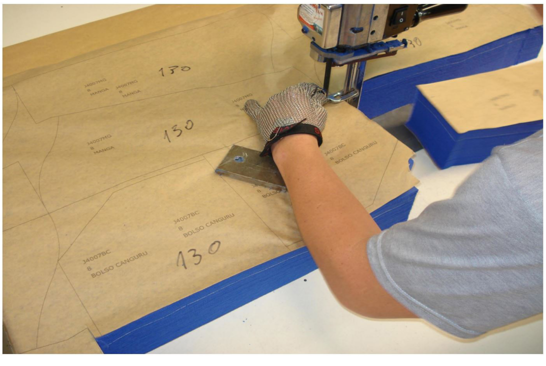

Figure 4. Fabric cutting in clothing industry. The spreading fabric in layers not covered by the templates (chips) are the textile waste. Source: Audaces (2014).

Even so, all five industries visited claimed that they could use post-consumption waste from domestic and industrial (clothing, professional uniforms, bedding, rugs and carpets, etc.), if there were controlled conditions of cleanliness and the absence of any metal or plastic trimmings, which could cause damage to the machinery. Any problems and/or limitations regarding the eventual use of shredded fibers obtained through the textile post-consumption waste, can present great variability in their physical and chemical properties depending on the material composition and the detrition suffered during the end of the article's life cycle.

Company 'A' is the only one that collects directly from the streets that concentrates large number of clothing factories. The separation of the textile waste happens inside the company, and part of the waste collected is discarded again for being too dirty. Companies 'B', 'C', 'D' and 'E' either buy or collect textile waste from other companies without charge. The acquisition prices between those companies are similar (Table 6).

According to information provided by companies 'A', 'B', 'C' and 'D', the costs of logistics and transport could be reduced if there were warehouses close to the main sorting centers of textile waste.

The expenses with logistics and transport, along with the absence of any tax incentives, make, in some cases, the cost of recycled textile fibers equal to the cost of virgin raw materials, leading some industries to purchase imported textile waste, for being cheaper and also have the advantage of coming apart by color and composition.

5.2 Textile waste importation in Brazil

Brazil officially imported more than 223 thousand tons of discarded waste since January 2008, at a cost of US$257.9 million. In the same period, the country failed to earn about US$12 billion for not recycling 78% of the solid waste generated internally, due to the lack of selective waste collection. The national industry that reuse recycled product as raw material for clothing, automobiles, packages and other, absorbs more than the country collects and recycles. Generating the need to import. The allocation of urban waste is a constitutional role of districts, but only 7% of all 5,564 Brazilian municipalities have recycled waste collection. Thus, in the year of 2008, at least 175.5 thousand tons of residues in the form of plastic, paper, wood, glass, aluminum, copper, batteries and other electrical components and even the ashes from the incineration of municipal waste

Table 4. Brazilian textile recycling companies.

Company	State	Raw material	Final product	Website
Adami Textil	SC	Residue natural and chemical fibers post-industrial	Fiber	http://www.adamitextil.com.br/site/index.php
Benefibras	MG	Post-industrial waste of natural fibers	Fiber	http://www.benefibras.com.br/
Benefios	SC	Post-industrial waste of natural fibers	Wires and strings	www.benefios.com.br
Cotan	PR	Post-industrial waste of natural fibers	Wires	http://www.cotan.com.br/index.php?pg=2&tp=5
Ecofios	SP	Post-industrial waste of natural fibers	Wires	http://www.ecofios.com.br/?pagina&menu=000001
Ecosimple	SP	Post-industrial waste of natural fibers and chemical properties	Fabric	http://www.ecosimple.com.br/
Eurofios	SC	Post-industrial waste of natural fibers	Wires and strings	eurofios.com.br
Fiação Patamuté	PB	Post-industrial waste of natural fibers	Wires	www.fiacaopatamute.com.br
Flocos Fibra	SP	Post-consumption waste of ballistic vests	Fiber	http://www.flocosfibra.com.br/index.php/produtos
Grupo Wolf	SP	Post-industrial waste of chemical fibers and synthetic	Fiber	http://www.grupowolf.com.br/
H3 Polímeros	SP	Post-industrial waste of chemical fibers and synthetic	Flake of polyamide and PET	http://www.h3polimeros.com.br/index.html
JF Fibras	SP	Post-industrial and post-consumer waste fibers chemical and natural	Fiber	www.jffibras.com.br
Korea Têxtil	SP	Post-industrial waste of natural fibers	Wires	http://www.koreatextil.com.br/produtos.html
Lonatex	MG	Post-industrial waste of natural fibers	Fabric	http://www.lonatex.com.br/
Maxitex	RS	Post-industrial waste of natural and chemical fibers	Yarns, fabrics and clothing	http://www.maxitex.com.br/site/content/home/
Multicolor	EC	Post-industrial waste of natural fibers	Wires	multicor.ind.br
Ober	SP	Post-industrial waste of natural fibers and chemical properties	Nonwoven	http://www.ober.com.br/
PG Fios	SC	Post-industrial waste of natural fibers	Wires	http://www.pgfios.com.br/ficha.htm
Sempre Verde	SP	Post-consumer carpet waste	Nonwoven	http://www.sempreverdeambiental.com.br/?portfolio=new-project
Superfios	PE	Post-industrial waste of natural fibers	Fiber	http://www.superfios.com.br/index.html
Virgeflex	SP	Post-industrial and post-consumer waste	Fiber	Company No website, available at http://www.oficiallistas.com/

Source: Prepared by the authors.

Table 5. Textile recycling companies visited in São Paulo State.

Company	Size	Recycling process	Raw material*	Final Product
A	Micro	mechanics	PC/PI	textiles; furniture
B	Small	mechanics	PC/PI	automaker; furniture; textiles
C	Small	Chemistry	PI	plastic; textiles
D	Small	Chemistry	PI	plastic; textiles
E	Great	mechanics	PI	automaker; furniture; nonwoven

*PC = post-consumption and PI = post-industrial. Source: Prepared by the authors.

had to be imported. Between January and June of the later year, 47.7 thousand tons were imported. Even so, 780 Brazilian recycling companies operate nowadays with 30% of idle capacity for lack of raw materials, according to the *Instituto Socioambiental Plastivida* (O Estado de São Paulo, 2009).

In this context, the Brazilian imports of rags and waste (silk, wool, cotton and other synthetic and artificial fibers) – by State and by Country, indicate that there is a textile waste market to be understood and exploited internally. In 2015, Brazil imported 8,941,986 kilograms of textile shreds and rags at a cost of US$ 5,848,422.00, price free on board (FOB) – value of the product without the freight, as noted in Tables 7 and 8, showing a decrease in imports in comparison with 2014 data (ALICEWEB, 2016). The imported volume, however, is still quite significant given the availability and production of textile waste in the country.

According to the data presented in Table 7, in 2015 the state of Ceará was the biggest importer of textile waste by bulk, and the state of São Paulo, the biggest importer in commercial value, with volume three times lower compared to the State of Ceará, which suggests the selection of waste with greater value. The major exporting countries by volume are Honduras, Turkey and others, such as Bangladesh (Table 8), countries with tradition in textiles and clothing, however, with industrial production lower than Brazil.

In 2014, Brazil was responsible for 2.6% of the textile global production in the world, while Turkey and Bangladesh produced 2.5% and 1% respectively (IEMI, 2015).

According to Zonatti et al. (2015), Brazilian market involved with textile reuse and recycling prefers to import rather to use the national textile waste, available in abundance, because of a series of problems related to poor management of this material. The major problems indicated are: waste discarded with dirt and mixture of different raw materials, high labor cost to accomplish the separation, lack of fiscal and tax incentives for commercialization of the products, transport and logistics costs, among others. His study emphasizes that Brazilian market also disregards the potential of clothing articles discarded by individuals after consumption, due to the lack of studies on the possibilities of recycling.

Table 6. Purchase price of textile waste by recycling companies.

Composition of textile waste	Value per kilogram
Mixed waste	R$ 0.05 to R$ 0.10
Cotton waste (jeans)	R$ 0.10 to R$ 0.15
Acrylic fiber or polyamide	R$ 0.70 to R$ 1.00
White 100% cotton fabric	R$ 1.20 to R$ 1.70
Colorful fabric 100% cotton	R$ 0.70 to R$ 1.00

Source: Prepared by the authors.

Table 7. Brazilian imports of rags and waste (silk, wool, cotton and other synthetic and artificial fibers) by State.

STATE	2013		2014		2015	
	US$ FOB	Kg Net.	US$ FOB	Kg Net.	US$ FOB	Kg Net.
Grand Total	**9,919,327**	**8,698,668**	**8,339,768**	**13,103,621**	**5,848,422**	**8,941,986**
São Paulo	3,446,076	1,484,588	2,539,233	1,102,271	2,354,682	1,033,178
Santa Catarina	2,605,200	1,293,513	2,104,563	3,107,923	1,256,864	1,032,509
Ceará	1,321,001	3,095,161	1,837,748	4,620,585	1,251,605	3,856,019
Paraíba	1,625,109	2,369,885	1,419,152	3,401,516	579,123	2,032,567
Pernambuco	597,620	365,002	264,758	284,555	143,105	195,284
Other	323,360	90,504	170,434	586,660	256,910	774,960

Source: Adapted from ALICEWEB (2016).

Table 8. Brazilian imports of rags and waste (silk, wool, cotton and other synthetic and artificial fibers) by country.

COUNTRY	2013		2014		2015	
	US$ FOB	Kg Net.	US$ FOB	Kg Net.	US$ FOB	Kg Net.
Grand Total	**9,919,327**	**8,698,668**	**8,339,768**	**13,103,621**	**5,848,422**	**8,941,986**
USA	2,377,109	1,051,184	1,530,781	505,356	1,530,833	520,134
Honduras	1,086,137	2,699,672	1,479,258	4,966,102	1,109,226	4,516,581
Argentina	1,874,882	794,696	1,101,738	605,720	939,634	428,646
Pakistan	710,657	306,394	610,397	297,208	609,421	369,612
Turkey	1,722,898	2,425,789	1,744,086	3,557,219	562,362	1,570,477
Other countries	2,146,683	1,420,918	1,869,628	3,171,905	1,090,813	1,519,067

Source: Adapted from ALICEWEB (2016).

5.3 Reuse and recycling post-consumption - professional uniforms case

As mentioned before, the textile waste is classified as post-industrial, the waste from the production of yarns, fabrics and clothing and post-consumption (industrial and domestic), textile and garment discarded after use because they are worn, damaged or outdated.

Considering only the disposal of apparel, between 9.8 billion pieces of clothing where produced in a year and estimates that over 150 million have no destination defined. On average, the collections have 50% to 75% of sales when exposed in retail. The leftovers go to settlement or bazars. In the end, the loss could reach 7%. Which was not sold can be donated, milled, deposited in landfills or incinerated (Frias, 2012; Castro & Amato-Neto, 2012).

The present research did not find specific information about post-consumption disposal of domestic textile and apparel at national or regional level. However, the Brazilian Association of Public Cleaning and Special Waste Companies (ABRELPE) made and estimate. In General, each Brazilian produces on average 383 pounds of trash per year, over one kilogram of waste per day (Barbosa, 2013). Which grasps 63 million tons in 12 months. The amount of garbage grew 21% in the last decade, but the proper treatment given to such waste has not increased.

According to ABRELPE, only 3% of the solid waste produced in Brazilian cities are recycled, although 1/3 of all the urban waste is potentially recyclable, composed by 7% leftovers of food; 17% plastic; 13% paper; 2,5% glass; 2% metal; 0,5% inert residues; and 8% other (ABRELPE, 2014; O Povo, 2014).

Currently, in academic research and reports on urban waste developed by public or private bodies, textiles are classified in the sub-category “other” (when – and if – it is cited), hindering its quantification and subsequent studies about their impacts on the environment (Zonatti, 2016). Thus, the amount of textile waste in post-domestic disposal would be within the “other” category, i.e. under 8% overall, implying in a first estimate of about 5 million tons a year at the national level of post-consumption household disposal of textiles and clothing.

In this context, the post-consumption waste of professional uniforms represents another market for the recycling industry. The standardization of professional uniforms provides good communication and identification for the employees, and brings benefits like safety, comfort, self-esteem and good impression on external public in relation to the company’s image. It also shows that the company has trained his employee for a specific function, adding to the professional the identification of an expert on a subject (Zonatti et al., 2015).

In an interview held on the hospital chain in São Paulo city, showed that the replacement of uniforms of its 12,000 employees occurs, on average, every 18 months. Each employee receives three units of each piece that makes up the uniform, depending on the function; the employee can have up to four different parts, such as pants, shirt, jacket, apron, coat, etc. The disposal procedure of the uniforms consists in manually remove any identification or logo, either embroidered or printed. Then the uniforms partially destroyed are send to landfills, which creates additional costs for the company.

According to a survey from 2011 carried out by the IEMI, Brazil had up to 1.200 industrial companies that manufacture exclusively professional clothes, generating 52.000 jobs, producing 267 million uniforms per year and US$ 3.6 billion in production values. In the same year, consumption reached 283 million pieces; only 6% of this total supplied by imported items, highlighting the possibilities for textile recycling in the context of circular economy (IEMI, 2011).

Aside the chemical and mechanical recycling of textile waste already addressed is it possible to reuse uniforms to manufacture other pieces. Several groups and NGOs already worked with the reuse of textile waste, as an example, the Ecotece Institute (ECOTECE, 2016) and the social enterprise Retalhar (2016), which work exclusively with the reuse of professional uniforms discarded by workers of several industrial segments. This groups and NGOs transformed the uniforms into corporate gifts, such as cases and bags, produced by an inclusive workforce. Usually the company that provide the uniforms buy those corporate gifts to distribute for their employees in internal campaigns about sustainability (Ferreira, 2014).

The corporate gifts have the intention to take the brand or company known for all the society, in order to generate affinity, loyalty, promote sales and awareness, always seeking brand promotion and strengthening business relationships. In 2013, the business gifts sector grossed R$ 5.5 billion according to Brazilian Association of Business Gifts (ABRINDE), emphasizing the growth for those companies that add sustainability and cultural values to their products (SEBRAE, 2015).

6 Circular economy and the textile and clothing industry

6.1 Concepts of circular economy

The decline of natural resources led many countries to seek ways to increase their resilience to a deficit in supply of industrial raw materials (Lovins, 2008). Thus, recycling waste and leftovers from manufacturing processes to make new products is a cheap and effective solution (Stahel, 2010; Zonatti et al., 2015).

Recently, the term called "Circular Economy", popularized by the Ellen McArthur Foundation in 2010, and presents a model able to decouple economic growth from generating waste. Recently, the term gained popularity among global companies thanks to its environmental benefits, transforming waste into useful resources for the manufacture of new products and the possibility to increase profits and competitiveness of companies, being a generic definition for business models and processes that do not generate industrial wastes, but instead reuse natural resources repeatedly. As conceived by its creators, circular economy consists of a cycle of continuous positive development that preserves and enhances natural capital, optimizing the production of resources and minimizing risks, through finite inventory management and renewable fluxes, at any industrial scale (Stahel, 2010).

According to the Ellen MacArthur Foundation (2013), circular economy has the ambition to keep products, components and materials on its highest level of usefulness and value all the time, not just recycling, but also revaluing throughout the productive processes, whether these are biological or technical cycles. This concept has deeply rooted origins with other theories and authors, and has been refined and developed by several schools since the 1970's, among them:

- **Regenerative Design**: Concept developed by John t. Lyle in the United States, whose approach was based on the theory of design oriented process, describing processes to restore, renew and revitalize its own sources of energy and materials, creating sustainable systems that incorporate the society needs with nature integrity;
- **Performance Economy**: Vision of an economy in cycles (or circular economy) and its impact on job creation, economic competitiveness, reduction of resources and waste prevention, a term created by Walter Stahel, architect and economist, in 1976, credited by the term "*Cradle to Cradle*" at the end of 1970;
- **Cradle to Cradle**: The German chemist, Michael Braungart, in conjunction with the American architect Bill McDonough, continued to develop the concept created by Stahel, besides working on the certification process, considered a design philosophy that involved all materials in industrial and commercial processes;
- **Industrial Ecology**: Study of the materials and energy flows in industrial systems, focusing on connections between operators within the "industrial ecosystem". This approach aims to create closed-loop processes in which the waste serve as input, thus eliminating the notion of an unwanted byproduct. Industrial Ecology adopts a systemic point of view, designing production processes according to the local ecological constraints, while observing its global impact since the beginning, as it seeks to mold them to work as close as possible to the living systems;
- **Bio mimetics**: An approach that studies the best ideas observed in nature, mimicking its designs and processes to solve human problems. Term created by scientist Janine Benuys;
- **Blue Economy**: Open movement initiated by Belgian entrepreneur Gunter Pauli that brings together studies case, initially compiled into the eponymous report delivered to the Club of Rome. Based on 21 principles, Blue Economy insists on determined solutions according to their local environment, its physical and ecological characteristics, placing emphasis on gravity as the primary source of energy.

The development and implementation of a strategy that adopts the transition of a linear economy to a circular economy, based on a model of sustainable development, represents an opportunity with multiple benefits related. From the environmental impact, through the reduction use of raw materials, and the social impact, fostering jobs and economic growth where it is applied (Stahel, 2010).

6.2 Application of circular economy concepts in the textile and apparel industry

Management waste responsibly is important not only for the sustainable goals of the companies, but also creates a platform of economy opportunities and competitiveness through productive processes that minimize waste focusing on resource recovery (Stahel, 2010). Particularly in the textile sector, as shown in Figure 5, the vast majority of textile waste could be recycled.

Synthetic and artificial textile waste takes a long time to decompose in nature. Polyamide, for example, takes about 30 years to decompose, while polyester takes more than 100 years (Loga Logística Ambiental de São Paulo, 2013). There are technologies available for chemical and artificial fibers, which can be recycled repeatedly with little degradation of its main features. However, during the process of recycling cotton scraps fabrics (post-industrial waste), the size of the fibers reduces and the mechanical features

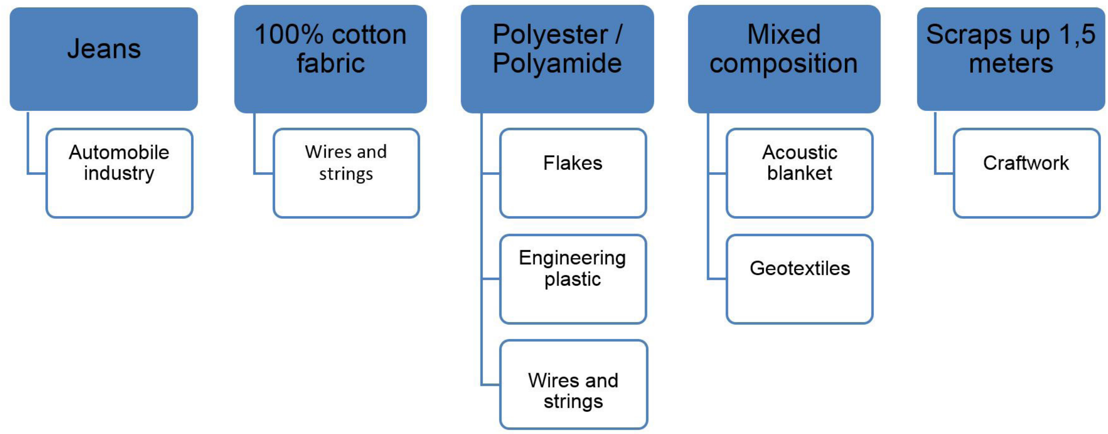

Figure 5. Recycling Possibilities for Textile Waste. Source: SinditêxtilSP (2013).

change significantly. Therefore, other fibers, virgin or recycled, should be mixed to improve the quality in recycled fabrics (Halimi et al., 2008).

Turn waste into new products and materials with maximum efficiency is the way adopted by different sectors of the industry, forced by the increasing demand for finite natural resources. The goal is to reach an economic model with zero waste, making the society able to reduce their disposal, increasing the product life, reusing and recycling raw materials after they are consumed (Stahel, 2010; Zonatti et al., 2015).

The Figure 6 illustrates a template related to circular economy, constituting an ideal application in textile industry chain. This format summarized in two circles prolongs the materials life, as it passes from collection to reuse or repair (WRAP, 2016b).

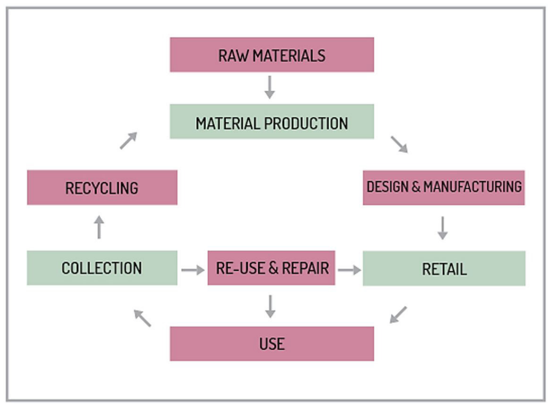

Figure 6. Circular Economy in Textile and Apparel Industry. Source: Adapted from WRAP (2016b).

The model presented in Figure 6 was presented by WRAP (The Waste and Resources Action Program*)*, which is a non-profit organization located in the United Kingdom, who heads the sustainable Clothing Action Plan, a group of major retailers, brands, recycling industries and NGOs. The goal of WRAP is bringing together the efforts of industry, government, consumers and third sector to reduce the use of resources and ensure the recognition of business performance through the development of sectoral goals, through actions focused on improving the waste collection and separation systems and development of markets for reuse and recycling products (WRAP, 2016a).

In so-called developed countries (European Union and United States), there are companies working specifically on collecting and recycling textile waste. These companies usually perform a screening of all material collected: If the textiles are in good condition, they sent to underdeveloped countries as “second-hand parts”, for example. If the article is in bad shape, but still has value because of the fiber material, it is send to recycling. If the material does not have any condition of use or recycling, it is incinerated (Zonatti, 2016; Muhammad, 2013). Note that these countries do not need to deal strongly with environmental problems arising from the industrial textile production, only with problems related to disposal of garments by individuals after it is used. The approach of developed countries for circular economy in the textile industry need a greater awareness of what occurs on other countries involved in the global textile chain (Zonatti, 2016).

On the other hand, the current situation of many textile producers in developing countries, including Brazil, is still far from the ideal circular economy-related, and there are still serious additional problems related to chemical and biological safety of textile waste disposal. In addition, academic and scientific literature related to development of textile recycling are rare, since this problem is related to developing or underdeveloped countries, where the largest textile industries are situated, in which, due to lack of environmental awareness, social inequality and economic limitation research on this theme are not performed (Zonatti, 2016).

7 Final considerations

The reuse and recycling of textile waste go far beyond the environmental and social benefits, as a factor of differentiation in the market, competitiveness, increased efficiency, economy, and above all, to avoid liens for the textile and clothing industry, through a compulsory regulation. Brazil is one of the major suppliers of raw materials, such as water, minerals, wood and non-renewable fuels, resources whose use in the circular economy has as ideal to reduce dramatically.

The circular economy wave to a promising technological development, innovation and competitiveness gains, through increasingly contemporary innovation aims to improve the use of resources and reduce dependence on primary products of the economic system.

Meanwhile, virgin natural's resources will become more and more expensive and burdensome to obtain due to various rules about its origin and the environmental problems caused by climate change. By reusing existing materials, companies can avoid the costs problems of acquisition of raw materials. In the textile industry case, the circular economy brings opportunities that involved the whole production chain, i.e. same product and/or their constituents have the potential to return to production chain numerous times, multiplying the generation of revenue.

To achieve the circular economy production model, the textile industry needs innovative strategies to strengthen the relationship between client-manufacturer and perpetuate positive experiences with the consumers to overcome the challenge of creating returning systems for post-industrial and post-consumption textile waste, taking in account the geographical specificities, tax and the logistics of the Brazilian reality.

To persuade a systemic change in the current model of textile production it is necessary to generate solid connections, educate, and involve the society to build a joint vision of sustainable and creative economy with financial, social and environmental purpose.

The processes and methodologies of recovery and recycling of textile waste are consolidated and in constant technological evolution. Many companies seize the opportunity to competitive advantage in this segment despite any tax incentives granted, and although shy, the Brazilian initiatives, shows that, the country is on the right path of industrial sustainability, following a beneficial and essential trend for society as a whole.

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