3D Printing Technology: an overview of the textile industry

Walakis Vieira Bataglini
Ana Julia Dal Forno
Fernanda Steffens
Antônio Augusto Ulson de Souza
Textile Engineering Department, Master Program in Textile Engineering
Santa Catarina Federal University – UFSC Blumenau
Rua João Pessoa, 2514 – Velha – Blumenau/SC, Brazil, CEP 89036-004
ana.forno@ufsc.br

Liane Mählmann Kipper
Industrial and Process Systems Master Program
Santa Cruz do Sul University - UNISC
Av. Independência, 2293 - Universitário, Santa Cruz do Sul - RS, Brazil, 96815-900
liane@unisc.br

Abstract

This paper is part of a research that involves the nine technologies of industry 4.0 applied to the textile sector. Here the focus is the literature review made with the SciMAT (Science Mapping Analysis Tool) software. The tool analyzed was the Additive Manufacturing, but the papers showed the term most used is the synonym three-dimensional printing. The first time the term appeared in publications was in 2016. This paper will present the steps for implementing additive manufacturing, textile industry applications, as well as advantages and challenges. The results showed that machine adaptations are relatively easy with the introduction of accessories and examples include smart textiles such as electronic parts, seamless or cut fabrics, and even entire parades with all parts made on the 3D printer. However, it is still necessary to develop models that adapt to different bodies, adjusting with greater flexibility, improving the production process through an automatic selection of needles.

Keywords
Industry 4.0, textile, review, 3D Printing, Additive Manufacturing.

1. Introduction

Additive Manufacturing is the formal term for what is popularly defined as three-dimensional printing (3D) (Straub 2017, Gibson et al. 2014, Matthews 2017). The technology has been known to the industry since the 1970s, but initially it was only used in prototyping and simulation. From the 2000s onwards, it was also used in the production of finished products. According Gibson et al. (2014), from then on, the first applications of technology specifically in the textile area emerged.

Second Borgianni et al. (2017), initially, the technology was used in the industry to rapidly prototype developing products, serving as a basis for analysis, adjustment and approval. In short, this technology consists of creating physical models by printing data from a virtual model where complete products or parts of them are manufactured directly by printing (Straub 2017, Borgianni et al. 2017).

Thus, it can be stated that Additive Manufacturing is a process where a variety of Technologies convert data from virtual models into physical models quickly and easily (Sabantina 2015). The data is transformed into a series of two-dimensional (2D) cross-sections of determined thickness, which will be sequentially deposited by a printer on top of each other, forming a 3D physical model, making sequential manufacturing processes unnecessary to obtain the product (Gibson et al. 2014, Sabantina 2015).

Several methods allow the additive production of 3D shapes, such as stereography, lithography, laser sintering modeling, or fused deposition modeling (FDM) (Leist 2017, Borgianni et al. 2017, Gibson et al. 2014, Sabantina 2015).

The manufacture of articles by 3D printing has gained increasing popularity, something that can be explained by the flexibility and personalized service that it provides. According Straub (2017), the consumers can obtain products tailored to their needs, and suppliers can create parts that can be customized or produced on a unit scale.

The use of 3D printing finds application in many areas, including artificial limb manufacturing, tissue engineering, sensors, clothing, footwear, among others (Straub 2017, Matthews 2017, Leist 2017 Gibson et al 2014, Sabantina 2015, Simonis et al. 2017). Numerous materials can be printed, such as plastics, nanocomposites, micro-fluids, pharmaceuticals, biodegradable materials, metals, wood, carbon fibers, basalt and concrete (Straub 2017, Sabantina 2015, Celaschi 2017, Nascimento 2019).

The authors Gibson et al. (2014) summarized the 3D Printing process in eight steps, presented in the diagram belowd (Figure 1).

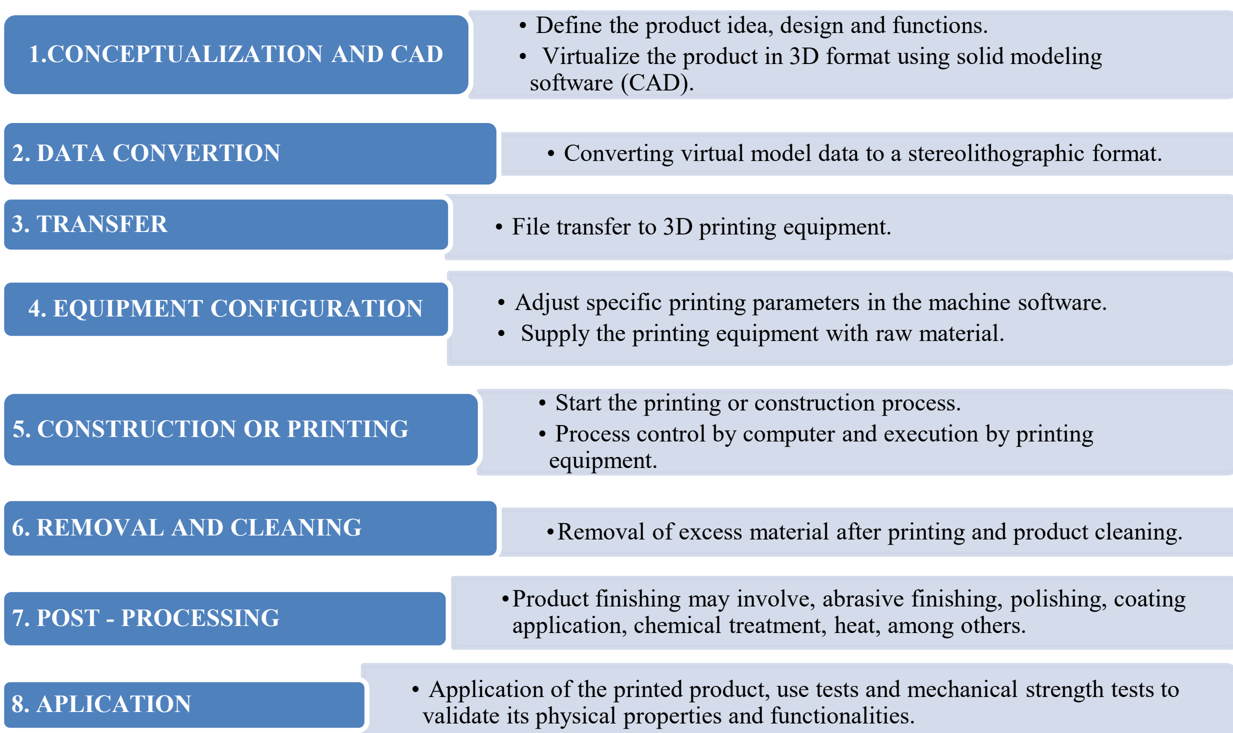

Figure 1. 3D Printing Process eight steps (Gibson et al. 2014).

The paper is structured as follows. First, it was introduced the concept of Additive Manufacturing, its synonyms and history. Afterwards, it was presented the eight steps to implement it. Section 2 presents the methodological procedure for literature review, realized with SciMAT software. After, there are state of the art analyzes of that industry 4.0 technology applied to the textile sector. Section 3 shows some advantages and challenges, final considerations, and future works. Finally, the references are listed.

2. Methodological Procedure

The Figure 2 shows the database searches, starting with keywords, “Textile” and “Industry 4.0” or “Industrie 4.0”. After, was selected the platforms as Web of Science and Scopus. At first moment, 278 papers were found, but it was applied the focus of this paper: 3D Printing or Additive Manufacturing. To carry out this mapping, the SciMAT software was used. This software was proposed by Cobo et al. (2012) that developed the free downloadable SciMAT with bibliometric process and arrangements to incorporate methods, algorithms and measurements for all stages of scientific mapping, from preprocessing to visualization of results (Guitiérrez-Salcedo et al. 2018, Montero-Diaz et al. 2018, Kipper et al. 2019).

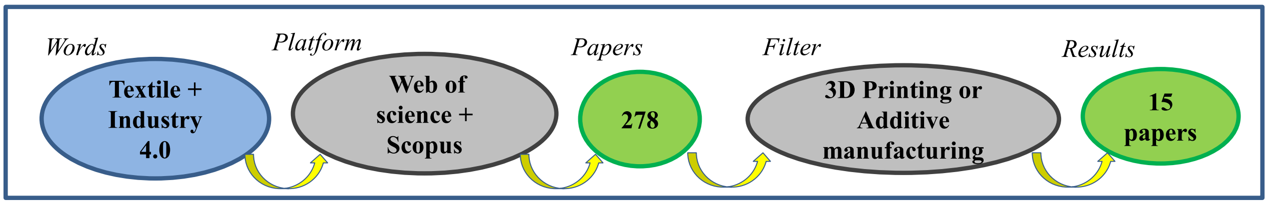

Figure 2. Steps of literature review.

In addition, Figures 3 and Table 1 are taken from the same software that shows related words. The density was 157.95 (density range = 1) and centrality of 42.94 (centrality range = 0.43).

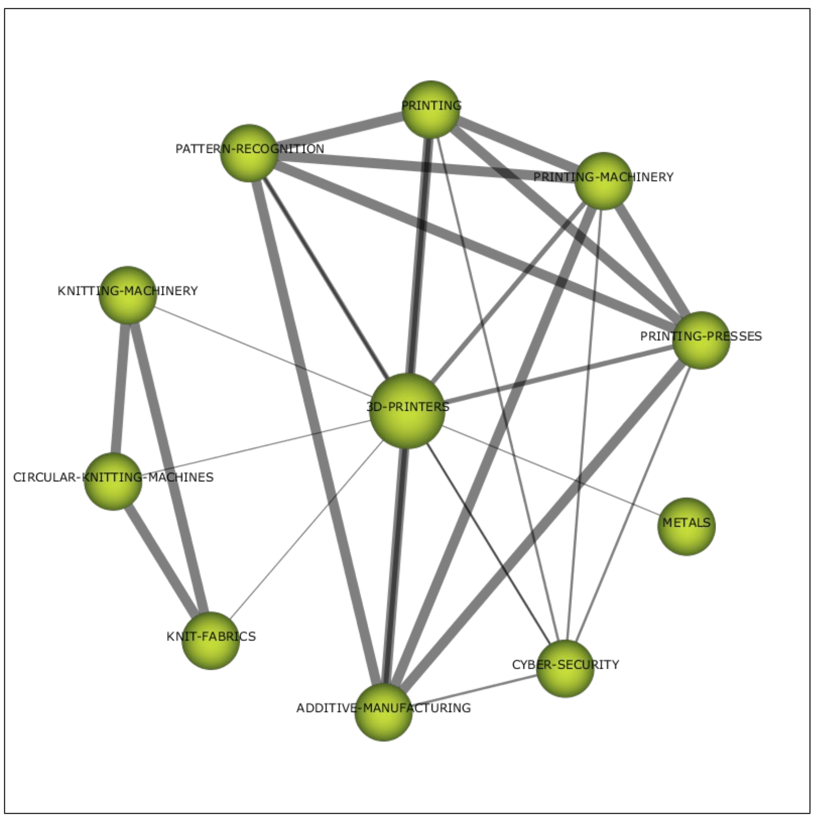

Figure 3. Cluster 3D Printing using SciMAT.

In Table 1 it is possible to notice that the strongest internal relations with the additive-manufacturing are printing, pattern-recognition and printing-machinery.

Table 1. Internal links extracted from SciMAT related to additive-manufacturing.

Node A	**Node B**	**Weight**
METALS	3D-PRINTERS	0.12
CYBER-SECURITY	3D-PRINTERS	0.12
CYBER-SECURITY	ADDITIVE-MANUFACTURING	0.25
CYBER-SECURITY	PATTERN-RECOGNITION	0.25
CYBER-SECURITY	PRINTING	0.25
CYBER-SECURITY	PRINTING-MACHINERY	0.25
CYBER-SECURITY	PRINTING-PRESSES	0.25
3D-PRINTERS	ADDITIVE-MANUFACTURING	0.5
3D-PRINTERS	KNIT-FABRICS	0.12
3D-PRINTERS	CIRCULAR-KNITTING-MACHINES	0.12
3D-PRINTERS	KNITTING-MACHINERY	0.12
3D-PRINTERS	PATTERN-RECOGNITION	0.5
3D-PRINTERS	PRINTING	0.5
3D-PRINTERS	PRINTING-MACHINERY	0.5
3D-PRINTERS	PRINTING-PRESSES	0.5
ADDITIVE-MANUFACTURING	PATTERN-RECOGNITION	1
ADDITIVE-MANUFACTURING	PRINTING	1
ADDITIVE-MANUFACTURING	PRINTING-MACHINERY	1
ADDITIVE-MANUFACTURING	PRINTING-PRESSES	1
KNIT-FABRICS	CIRCULAR-KNITTING-MACHINES	1
KNIT-FABRICS	KNITTING-MACHINERY	1
CIRCULAR-KNITTING-MACHINES	KNITTING-MACHINERY	1
PATTERN-RECOGNITION	PRINTING	1
PATTERN-RECOGNITION	PRINTING-MACHINERY	1
PATTERN-RECOGNITION	PRINTING-PRESSES	1
PRINTING	PRINTING-MACHINERY	1

PRINTING	PRINTING-PRESSES	1

Finally, the bubbles in Figure 4 highlight relationships with major themes such as industry 4.0 with embedded systems, smart fabrics or/and product development with digital transformation (continuous line).

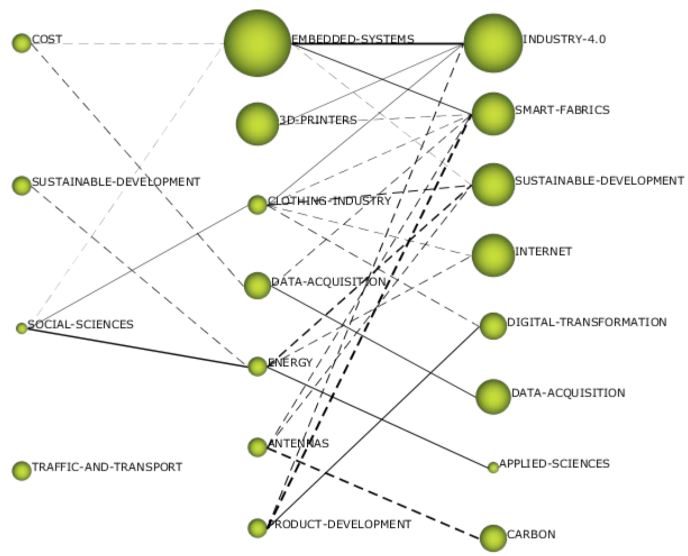

Figure 4. Longitudinal result view.

3. Advantages and Disadvantages of 3D Printing Applied to the Textile Industry

Consumers are increasingly seeking product or service offerings that go beyond traditional concepts of quality and value. In addition to these, sustainability and customization criteria have come to integrate their desires (Gibson et al. 2014, Arribas and Alfaro 2018, Bruno 2016).

A 2013 survey by the Fraunhofer German Institute asked German manufacturers of textile and fabric equipment what would be the key parameter for success in today's scenario. Of those interviewed, 98.6% pointed to “flexibility” as a fundamental parameter for success (Matthews 2017). Achieving this level of service is a major challenge for the apparel industry, whose products have a short life cycle, demands fluctuate widely and customers increasingly seek originality and identity in what they consume (Matthews 2017, Straub 2017). In this context Bruno (2016) described that the 3D Printing stands out because in its conception technologies play a central role in production, reducing the distance between the principles of mass production and customization.

The interest around 3D printing in the textile universe has increased considerably worldwide. Beecroft (2016) wrote that people can see fashion shows where models use accessories and even complete collections produced from additive manufacturing. The Figure 5 presents some projects using 3D printing technology in the textile area.

However, despite developments, most of these articles have features of a “sculpture” on the body, lacking the flexibility and functionality found in conventional textiles. In order to break this barrier some research has been developed (Beecroft, 2016).

At the Institute of Textile Technology (ITA) at the Technical University of North Rhine-Westphalia (RWTH) in Aachen (Germany), researchers present studies focused on the development of three-dimensional meshes using large circular diameter looms to combine the high productivity achieved by looms with the flexibility offered by additive manufacturing. At the end of the study, they present the prototype of three-dimensional fabric building by means of an electronic selection of needles during knitting (Simonis et al. 2017).

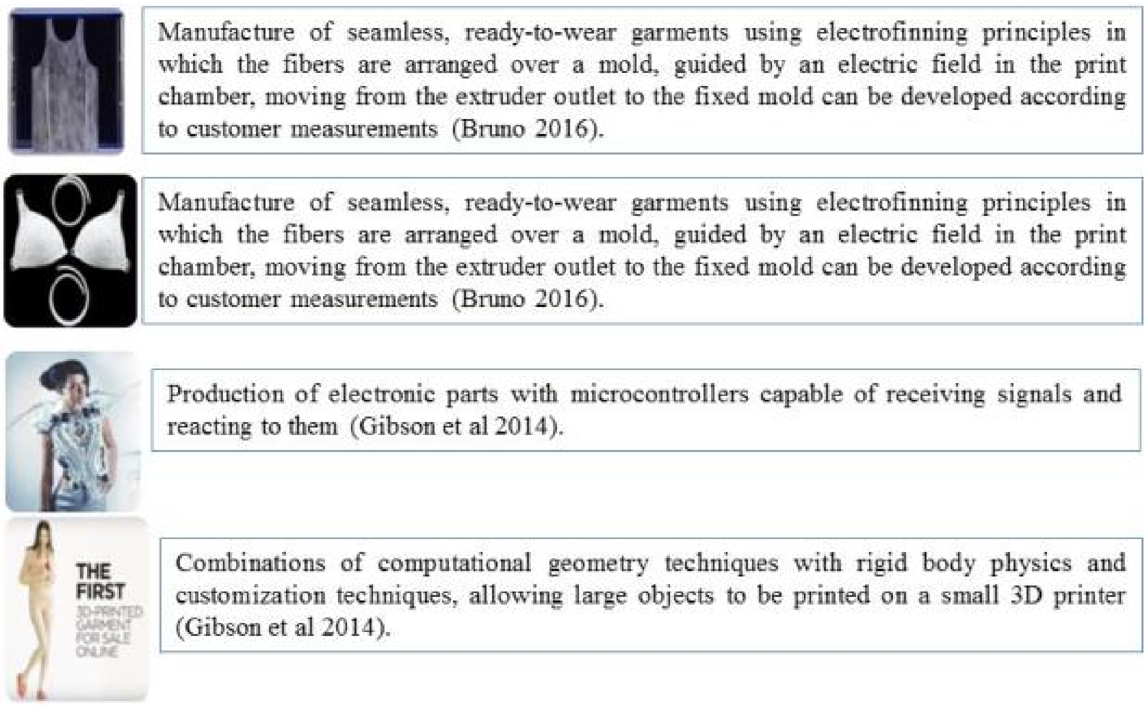

Figure 5 - Clothing produced by 3D printing.

The authors (Simonis et al. 2017) highlight that Jacquard circular looms can also adapt to this technique, requiring a small investment to modify the machine. Figure 6 shows the three-dimensional mesh prototype produced.

Figure 6 - Three-dimensional mesh (Simonis et al. 2017).

In another study (Beecroft 2016), knitted weft structures are printed based on selective sintering, where by means of a computer-guided laser the polyamide powder (PA12) is fused to solid, forming flexible, elastic three-dimensional objects and resistant with characteristics similar to traditional textiles. The results of the research present structures constructed using the jersey mesh principle (structure obtained from single front loom) and interlock (structure obtained from double front loom). The structures presented good mechanical properties, strength and elongation, as well as flexibility, which enable them for applications in the textile and fashion industry. Figure 7 shows the weft mesh structures built at the end of the study.

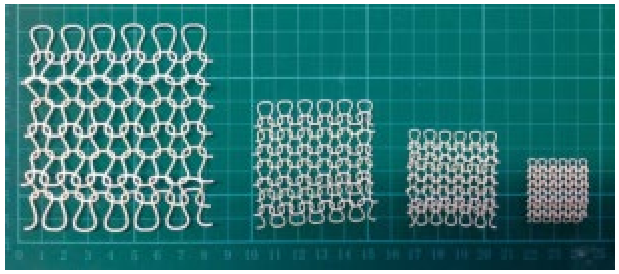

Figure 7 - Printed weft mesh structures (Beecroft 2016).

Another possible use for Additive Manufacturing in the textile area is the application of this technique on a textile substrate, where the substrate enables the article to be used for clothing and 3D printing promotes the freedom of creation to decorate the substrate.

In this type of application the fusion deposition printing technique is used. This technique is based on the extrusion of filaments that will be deposited on the printing line by the printer, and the deposited filaments solidify giving the printed structure 3D format (Sabantina 2015). Figure 8 shows the result of applying the printing technique on different types of textile substrates.

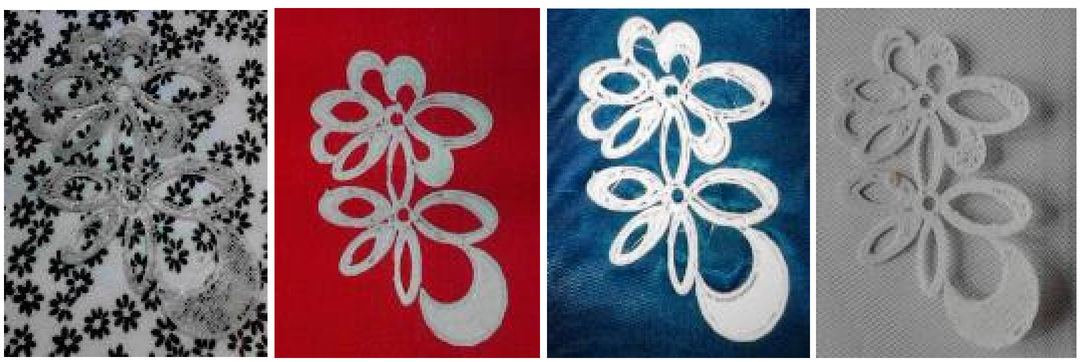

Figure 8 - Textile substrates decorated by 3D printing (Sabantina 2015).

So-called smart textiles are products that have the ability to change their characteristics and properties when exposed to external stimuli. In this context there are also studies that propose the construction of these articles by 3D printing, where from the FDM technique thermoplastic filaments are sequentially deposited on a conventional textile substrate, building a 3D object that, due to the polymer used in its construction. It has the ability to change shape when exposed to a certain temperature.

Shape memory materials or as known worldwide Shape Memory Materials (SMM) can find various applications in the textile industry, using their characteristic behavior of change and shape from a given temperature. Figure 9 shows a schematic of shape memory material printing.

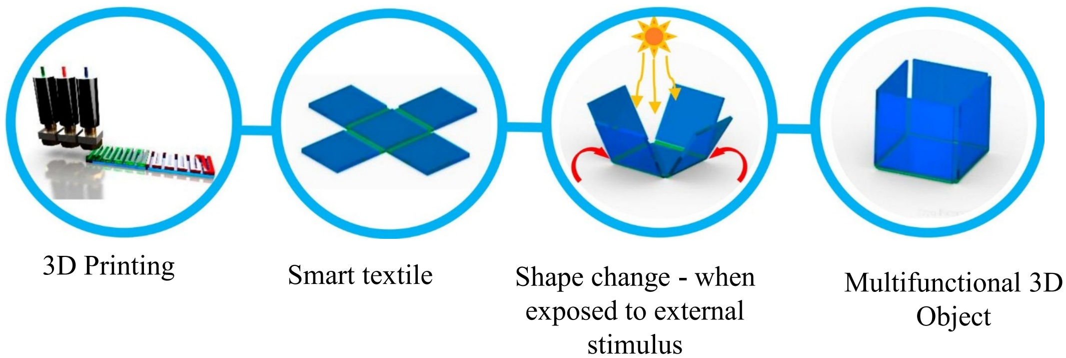

Figure 9 - 3D printing using SMM polymer (adapted from Leist 2017).

The technology of 3D Printing, when applied to the textile area, can bring benefits to customers and suppliers, among can be highlighted some of these (Bruno 2016, Schwab 2017):

- Product development shared by suppliers and customers.
- Reduction of time between product development and production.
- Virtual testing of software projects, reducing material waste.
- Clean and compact manufacturing, which allows the installation of productive structures in large urban centers.
- Reduction of distribution costs and delivery time.
- Dramatic reduction in stock of materials and products, as production is initiated only after the customer orders, or may even be performed by the customer, who in the future may "print" their clothing.

But, this technology faces some challenges for its expansion into the textile chain. Among them, it is possible mention some challenges (Schwab 2017):

- Production of anisotropic parts, ie their properties are not equal in all directions of the part.
- Cause reduction of jobs in conventional production structures.
- Difficulty in controlling the originality of products produced, as well as their quality.

4. Final Considerations

This paper introduced the technology of the fourth industrial revolution known as 3D Printing or Additive Manufacturing. For the textile industry, it is necessary to adapt the existing machines in the market, because unlike the traditional methods, there are interlaced textile layers in different heights.

The literature review conducted with SciMat Software helped map the state of the art of this technology in the textile sector, pointing out the steps for implementation, highlighting examples, and listing the advantages and challenges.

The 3D fabric printing has several benefits, such as high-detail prototyping, the ability to build custom and individualized parts, the possibility of storage and custom production, and reduced time, costs and materials. The main advantage is making multiple materials with one machine.

There will also be a big investment in sustainability in the textile industry, and 3D printing contributes a lot to that, as it wastes less material and uses fewer chemicals in its manufacture.

Future studies will describe the other 4.0 industry technologies - Big data (sensors), Robotics, Simulation Systems Integration (Information Technology), Internet of Things (IoT), Cyber Security, Cloud, Augmented Reality. After, the researchers will do benchmarking and survey about the 4.0 industry in the textile sector in South Brazil companies.

References

Arribas, V., and Alfaro, J. A., 3D technology in fashion: from concept to consumer. *Journal of Fashion Marketing and Management: An International Journal*, v. 22, n. 2, p. 240-251, 2018.

Beecroft, M., 3D printing of weft knitted textile based structures by selective laser sintering of nylon powder. In: *IOP Conference Series: Materials Science and Engineering*. Vol. 137, No. 1, p. 01, IOP Publishing, 2016.

Borgianni, Y., Maccioni, L., and Basso, D., Exploratory study on the perception of additively manufactured end-use products with specific questionnaires and eye-tracking. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, v. 13, n. 2, p. 743-759, 2019.

Bruno, F. da S., *A quarta revolução industrial do setor têxtil e de confecção: a visão de futuro para 2030.* São Paulo: Estação das Letras e Cores, p. 76, 2016.

Celaschi, F., Advanced design-driven approaches for an Industry 4.0 framework: The human-centred dimension of the digital industrial revolution. *Strategic Design Research Journal*, v. 10, n. 2, p. 97-104, 2017.

Cobo, M. J., López‐Herrera, A. G., Herrera‐Viedma, E., and Herrera, F., SciMAT: A new science mapping analysis software tool. *Journal of the American Society for Information Science and Technology*, *63*(8), 1609-1630, 2012.

Gibson, I., Rosen, D. W., and Stucker, B., *Additive Manufacturing Technologies*. New York: Springer, 2014.

Gutiérrez-Salcedo, M., Martínez, M. Á., Moral-Munoz, J. A., Herrera-Viedma, E., and Cobo, M. J., Some bibliometric procedures for analyzing and evaluating research fields. *Applied Intelligence*, *48*(5), 1275-1287, 2018.

Kipper, L. M., Furstenau, L. B., Hoppe, D., Frozza, R., and Iepsen, S., Scopus scientific mapping production in industry 4.0 (2011–2018): a bibliometric analysis. *International Journal of Production Research*, 1-23, 2019.

Leist, S. K., Gao, D., Chiou, R., and Zhou, J., Investigating the shape memory properties of 4D printed polylactic acid (PLA) and the concept of 4D printing onto nylon fabrics for the creation of smart textiles. *Virtual and Physical Prototyping*, v. 12, n. 4, 2017.

Matthews, M. J., Guss, G., Drachenberg, D. R., Demuth, J. A., Heebner, J. E., Duoss, E. B., ... and Spadaccini, C. M., Diode-based additive manufacturing of metals using an optically-addressable light valve. Optics Express, v. 25, n. 10, 2017.

Montero-Díaz, J., Cobo, M. J., Gutiérrez-Salcedo, M., Segado-Boj, F., and Herrera-Viedma, E., A Science Mapping Analysis of'Communication'WoS Subject Category (1980-2013). *Comunicar: Media Education Research Journal*, *26*(55), 81-91, 2018.

Nascimento, D. L. M., Alencastro, V., Quelhas, O. L. G., Caiado, R. G. G., Garza-Reyes, J. A., Rocha-Lona, L., and Tortorella, G., Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. *Journal of Manufacturing Technology Management*, v. 30, n. 3, p. 607-627, 2019.

Sabantina, L., Kinzel, F., Ehrmann, A., and Finsterbusch, K., Combining 3D printed forms with textile structures-mechanical and geometrical properties of multi-material systems. In*: IOP Conference Series: Materials Science and Engineering*. IOP Publishing, 2015.

Schwab, K., *The fourth industrial revolution*. Currency, 2017.

Simonis, K., Gloy, Y. S., and Gries, T., 3D knitting using large circular knitting machines. In: *IOP Conference Series: Materials Science and Engineering.* IOP Publishing, 2017.

Straub, J., Identifying positioning-based attacks against 3D printed objects and the 3D printing process. In: Pattern Recognition and Tracking XXVIII. *International Society for Optics and Photonics*, 2017.

Biographies

Ana Julia Dal Forno is an Associate Professor of Engineering at the Santa Catarina Federal University (UFSC) - Blumenau campus and vice director of the same institution until December 2020. She is also Collaborator of PGETEX - Master in Textile Engineering. She has a postdoctoral degree in Production Engineering (UFSC-2014), where she is also a PhD from the same University and a Sandwich from Technische Universität Berlin (TUB - Germany). Master in Production Engineering from UFSC (2008). Research Focus: Lean Product and Process Development Management, Innovation Management, Benchmarking, Lean Manufacturing, Process Improvement, Lean and Industry 4.0. In addition, she has experience in the industrial area of various branches, including survey in Brazilian companies.

Fernanda Steffens is Doctor in Textile Engineering from the University of Minho, Guimarães, Portugal (2015). She holds a Master of Science degree in Textile and Ready-Made Clothing Technology from Technische Universität Dresden, Germany (2011). Degree in Textile Industrial Engineering from Senai-Cetiqt Institut (2005). His area of expertise consists of textile engineering and apparel, the development of textiles with auxetic behavior, technical and intelligent textiles, fibrous materials and product development. In 2015 she started her activities in the Textile Engineering Department of the Federal University of Santa Catarina (UFSC). She is also a professor at the Postgraduate Program in Textile Engineering at UFSC (PGETEX).

Walakis Vieira Bataglini works at na Lunelli Textile Company and started Master's Degree student since March, 2019 at UFSC Blumenau.

Antônio Augusto Ulson de Souza is a Research Productivity Fellow 1B - CA EQ. Scopus Author: ID 35593447900, ORCID: 0000-0002-7115-2621, and Researcher ID: K-1051-2012. Mr. Souza is graduated in Chemical Engineering at UFRJ in 1982; Master's degree in Chemical Engineering at UNICAMP in 1985; PhD in Mechanical Engineering, Federal University of Santa Catarina in 1992; and post-doctorate in Chemical Engineering at the University of California at Davis - USA, in 1997. He is currently a Professor at the Federal University of Santa Catarina, and the leader of CNPq's Research Group: TECTEXTIL - Textile Technological Development, since 1999. He was Head and Deputy Chief of the Department of Chemical Engineering and Food Engineering at UFSC.

Liane Mählmann Kipper is Professor at the Santa Cruz do Sul University. Mrs. Kipper works in the Graduate Program in Industrial Systems and Processes in the areas of knowledge management, innovation and creativity, and management of research processes and methods and techniques developing activities mainly on the following topics: process improvement, lean systems: innovation, creativity, design thinking, product development and knowledge protection; and in process and technology management for process optimization and improvement. Currently working with UNISC undergraduate and technological extension courses at TECNOUNISC coordinating the implementation of the Interactive Creativity Laboratory (LIC) and with the Master in Industrial Systems and Processes.