FASHION PRODUCTS THROUGH DIGITAL MANUFACTURING – A CASE STUDY WITH FDM TECHNOLOGY

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ABSTRACT: *We live in a digital world comprising the use of computer systems applicable to every process of manufacturing. Digital manufacturing is present in almost all areas of production by linking systems and process required from conceptualization to the final product. Through the use of digital manufacturing fashion products are designed and manufactured. Case studies of using the tools of 3D CAD software modeling to create novel products as textile structures, accessories and shoes parts as heels are presented. Taking inspiration from several sources, customized models are designed and with the great power of additive manufacturing as FDM technology, a non-expensive compared to the other types of additive manufacturing technologies, is implemented in the manufacturing of 3D CAD models. Without restriction on design, 3D models generated form CAD software are print directly by avoiding other process related to traditional manufacturing. The rise of new technologies in digital manufacturing releases new opportunities for companies to foster productivity, customization and sustainability.*

KEYWORDS: *Fashion products, 3D modelling, Digital manufacturing, 3D printing*

1 INTRODUCTION

Fashion products are of a great interest in consumer's everyday life. The reason to buy clothing has changed from necessity to reasons as being fashionable, attractive, etc. Now, consumers seek for personalized products where individuals express uniqueness [1]. A recent study by Deloitte reveals that "1 in 4 consumers are willing to pay more to receive a personalized product or service" and "in some categories, more than 50 percent of consumers expressed interest in purchasing customized products or services." [2].

Digital manufacturing which has evolved over the years is the use or integration of computer systems in product development. These technological advancements are part of fourth industrial revolution namely Industry 4.0. It was initiated as a strategic initiative by the German government in 2011 and it aims to drive digital manufacturing forward by increasing digitalization [3]. The fourth industrial revolution creates a world in which virtual and physical systems of manufacturing globally cooperate with each other in a flexible way [4]. Integration of digital manufacturing as one of the pillars of Industry 4.0 shows the reduction of time, costs and errors, while increases the production efficiency and product quality [5]. The digitalization of fashion industry is of a great interest even from the consumer point of view. The case of developed system based on deep learning for efficient fashion product searches can enhance consumer's satisfaction by recommending them the preferred style before starting the search process [6]. Use of 3D modeling software and programs development for automation of multiple design application confirms the time reduction and enhancement of product or system development [7] and providing a customized service to all customers [8].

1.1 Sustainability and the necessity for new ways of production in fashion industry

The case of fashion industry is of a great interest due to the impact of this technology has in environment. These impacts occur during manufacturing process and everyday use of apparel. According to a report released by the United Nations Economic Commission for Europe in 2018, the apparel industry produces 20 percent of global water waste and 10 percent of global carbon

emissions, while 85 percent of textiles — 21 billion tons — are sent to landfills each year. As a result, there are initiatives from European countries to bring environmental and economic benefit to the clothing industry. The results from the implementation of European Clothing Action Plan reduced water, CO2 and waste [9]. Fast fashion model implemented in the fashion industry is the one that contribute to pollution through fast time to market and low prices by making it more affordable. As a result, researches propose legal reforms and increased support for companies that implement sustainability practices in order to contribute with their slow fashion models for the future of global fashion industry [10].

Fashion brands are aware of the impact that this industry has on environment as the data published and there are attempts to go sustainable. A scoring system developed to measure sustainability, carried out by Boston Consulting Group and Global Fashion Agenda for the Copenhagen Fashion Summit in 2017, the fashion industry took 32 out of 100 [11] by showing that companies have to work on and go green. The traditional models of sustainability in fashion design include environmental, social and economic, and researches analyzing these tools have expanded with two other dimensions as aesthetic and cultural [12].

Increasing concern among consumers about social and environmental impact of their purchases push the business to explore sustainable design practices and efficient use of waste [13].There are promising projects even in the first steps, but acting as awareness for other companies. The cases include apparel and footwear, where 3D printing seems to be a promising technology for sustainable products including fashion industry as it represents a manufacturing technology with large sustainability potential [14]. The case of Streamateria garments presents potential benefits by reducing waste and over-production [15].

Designs inspired by nature have attracted attention of designers from various fields. Nature based design models are seen as a great opportunity for research and marketing in the retail industry [16-17]. Nature imitation remains an interesting methodology not only for product design but even for system simulation. Case studies presented are a great opportunity even in fashion industry. The scope of this work is to present case studies of using the tools of 3D CAD software modeling to create products as textile structures, accessories and shoes parts such as heels, by taking inspiration from several sources, customized models are designed. With the great power of additive manufacturing as FDM technology, a non-expensive compared to the other types of additive manufacturing technologies, the implementation in manufacturing of 3D CAD models offers advantages of product customization, reducing time and material waste. Fused Deposition Modeling technology has the same principle of the other type of additive manufacturing technology, it produces layer upon layer various materials and fuse them together.

Fig. 1 Workflow followed in this work

2 MATERIALS AND METHODS

To fulfill the objective of this paper creating fashion products through digital manufacturing, several products chosen for modeling are geometric structures used as part of the garments, shoes and accessories as rings, earrings. The ideas for designing are taken from nature, as a wide source of inspiration, which has inspired over the time designers in every field of research and development. These products are designed in 2D and after converted in 3D models. To create these CAD models, software for 3D modeling such as Tinkercad™ from Autodesk Inc. is chosen. The designed 3D models as heel has undergone to simulation process. This is the case of evaluating

the design and material selection for additive manufacturing. Figure 1 presents the workflow followed in our work with the main steps to create fashion products through digital manufacturing.

3D printing is realized on Geeetech A30 3D printer based on Fused Deposition Technology also known as material extrusion technique, with a single extruder system and operating with various types of filaments such as: PLA, ABS, nylon, wood polymers, etc. Before starting the 3D printing procedure, 3D models are exported as .stl format and imported on CURA™ slicing software and exported as a G-code. The main parameters of 3D printing process chosen for all the objects produced in this work are given in Figure 2. Depending on object size and geometry layer height is different.

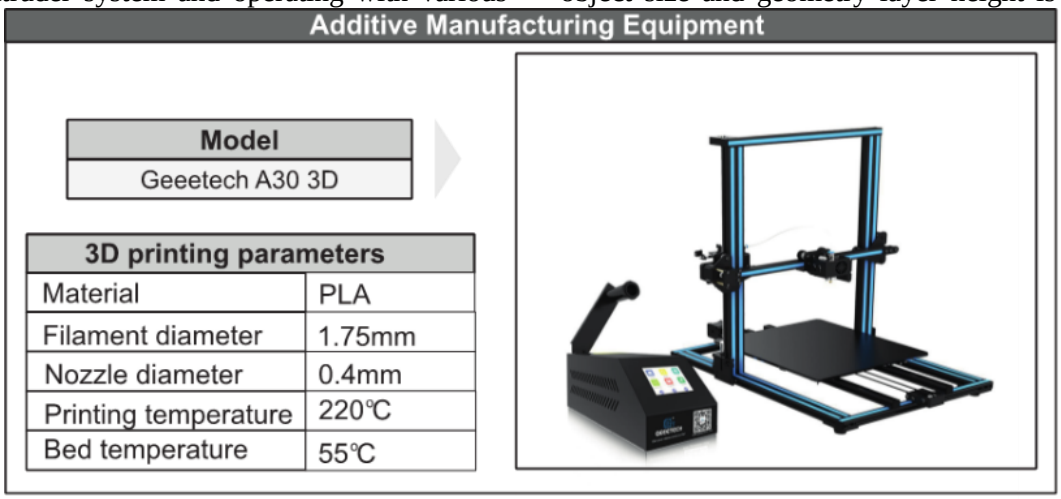

Fig. 2 Main 3D printing parameters and Geeetech A30 3D printer.

3 RESULTS

The results derived from each one of the objects taken into consideration as part of fashion products to be modeled and produced through additive manufacturing (AM), are given as follows:

3.1 3D printed structure

Textile structures are created by weaving, knitting and non-woven. Knitting is one of the mostly used techniques for textile production created by interloping one or one set of yarns in order to form a series of interlocking loops.

There are two basic types of knits, the weft and the warp knit. Here we present the case of a structure created based on the loop shape, which is the fundamental element of all knitted textile fabrics. The 3D models of the loops are arranged as petals of the Chelidoniummajus flower. The flower created (contains the four petals) is then multiplied, and arranged in various directions (Figure 3). Apart from structure created based on loop shape, the second case is the weft knitted structure. Modeling of this type of structure is also presented by other authors and 3D printed based in SLS (Selective Laser Sintering) and FDM technology [18-20].Our case brings the use of free modeling software for creating 3D weft knitted structures and a non-expensive 3D printing technology as FDM, Geeetech A30 3D printer.

The third and fourth cases are structures created by circles, which represent completion and harmony. By continuing using the main element of flower of life, here the circles shapes are assembled in a regular arrangement, in rows and columns. Figure 3 depicts views of various 2D concepts as knitting structure and harmony circles to create 3D models and produced by 3D printing.

3.2 Accessories

The other fashion products included in this work, as part of the digital manufacturing, are accessories that are used in everyday life. Design of jewelry can be realized by the use of different software available and inspirations can be derived from various sources. In this work, the realized items are rings and earrings models.

3.2.1 Rings

Rings are accessories used in everyday life. They vary from designs and materials from cheaper to more valuable. Design of rings with inspirations taken from geometrical and organic shapes are presented. The first ring is inspired by geometric shapes i.e. the sphere a three-dimensional version of the two-dimensional circle. The other design presented is inspired again here by the flower of life. Following with the other ring model compromised with the shape of a butterfly on the top. The inspiration for this model is based on organic shapes as it is associated with living beings.

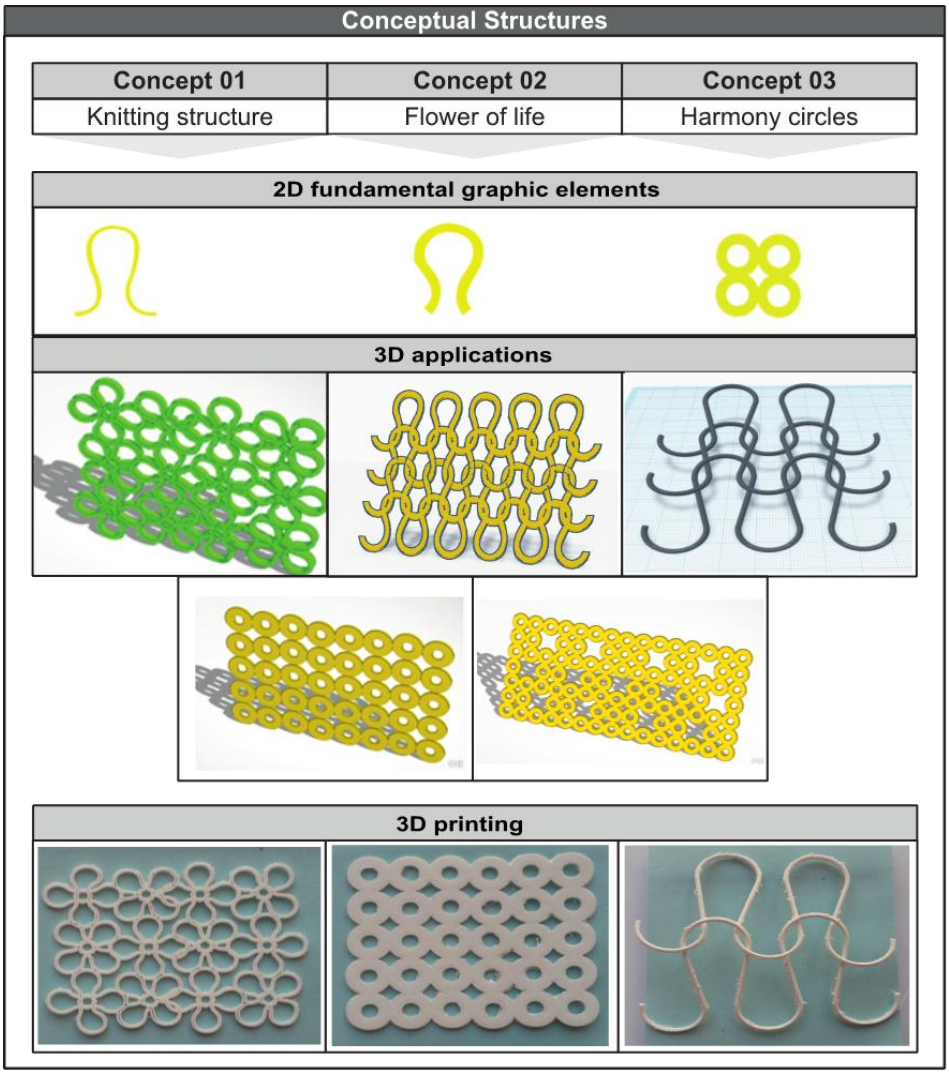

Fig. 3. From 2D concept to 3D structures

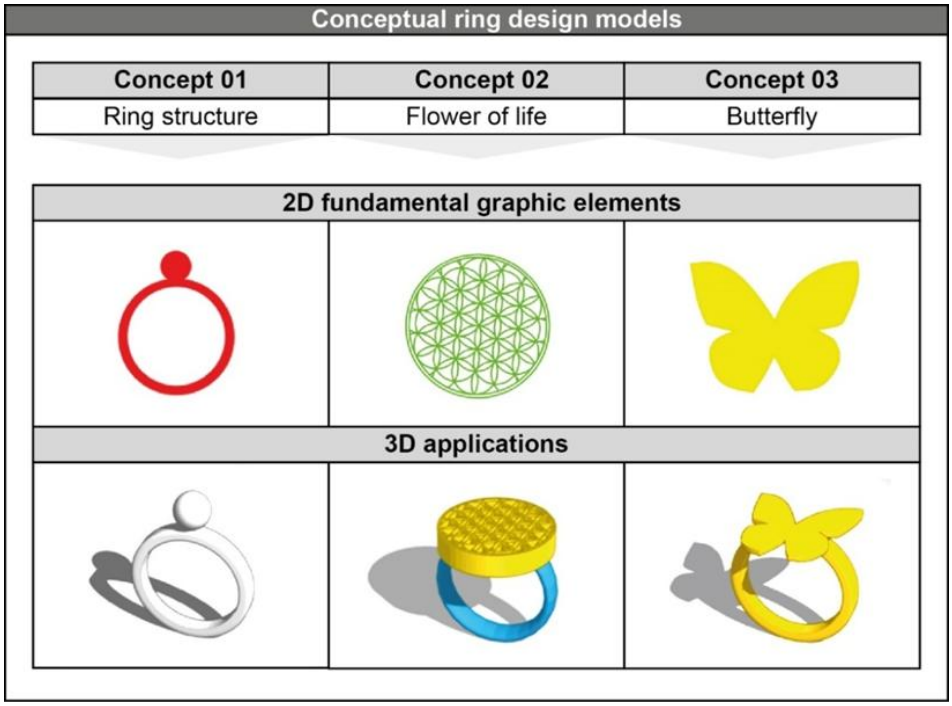

Fig. 4Ring models from 2D concept to 3D models

3.2.2 Earrings

The earrings shapes represent things from the natural world. There are various concepts modeled and they are depicted in Figure 5. Concept 1 presents earring with geometrical shape of the main circle and other in smaller radius included inside the main circle. Concept 2 presents earring with geometrical shape of ellipse and rectangles. Concept 3 present another earring model derived from the previous one but including spiral, which is a curve that winds around a fixed center point at a continuously increasing distance from the point. The case of concept 4 presents the combination of two spirals.

The other models depicted present the earring models with the geometric shape of a rectangle with curved edges as the main geometry and inside included the shapes of the sun. The others models present the sun shape inside the main circle and outside. The last earring models presented as Concept 7 are designed based on organic shapes as leaves from HerbaPolypodiumvulgare and flowers. The shape of the leaflets is particular, where they become much shorter at the end of the frond.

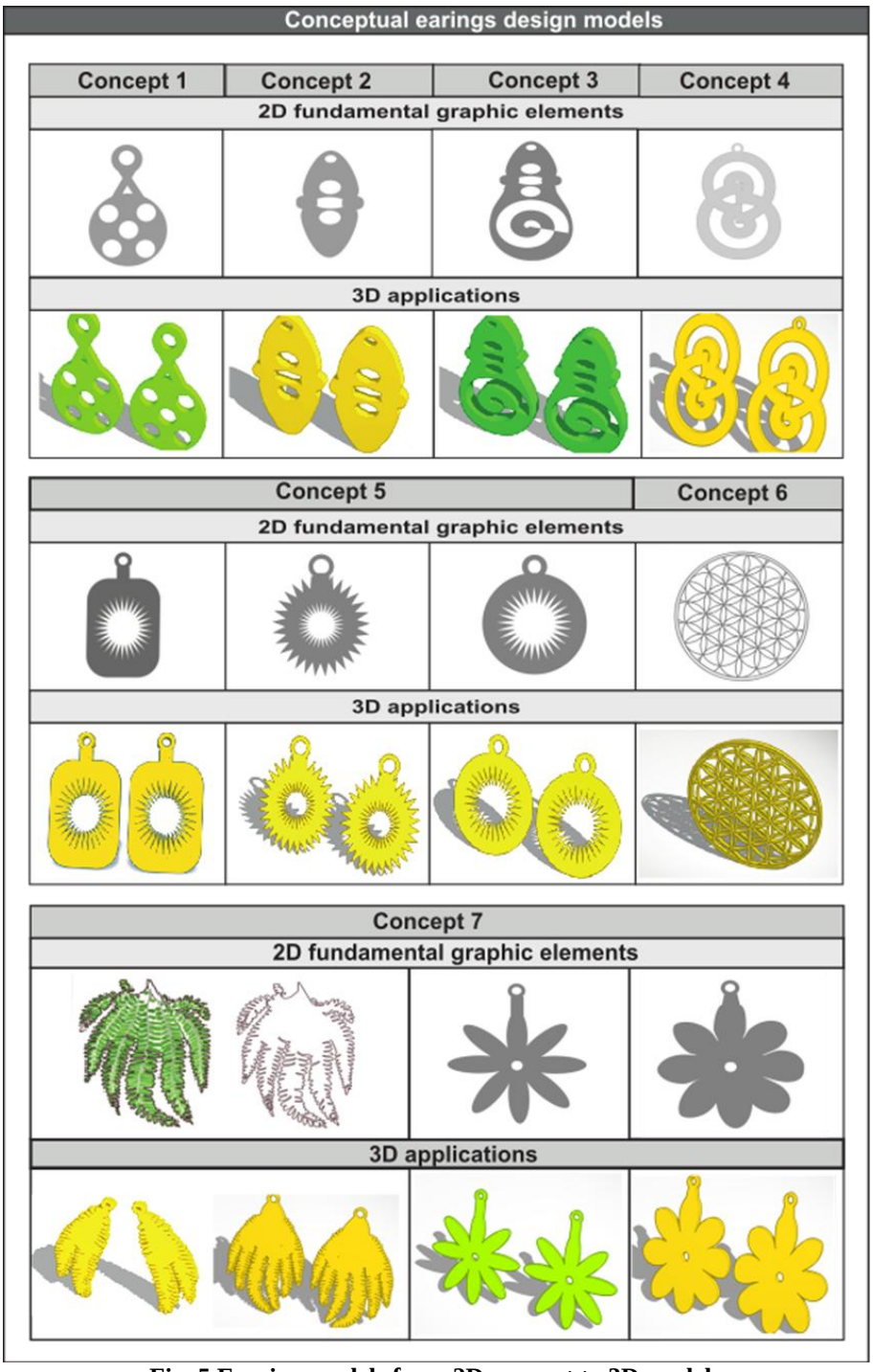

Fig. 5 Earring models from 2D concept to 3D models

Finally, the designed models can be produced with 3D printing technology by avoiding several steps of traditional manufacturing, focusing on product personalization and depicting again the advantages of digital manufacturing of fashion products. Figure 6 depicts views of produced earrings models by 3D printing technology.

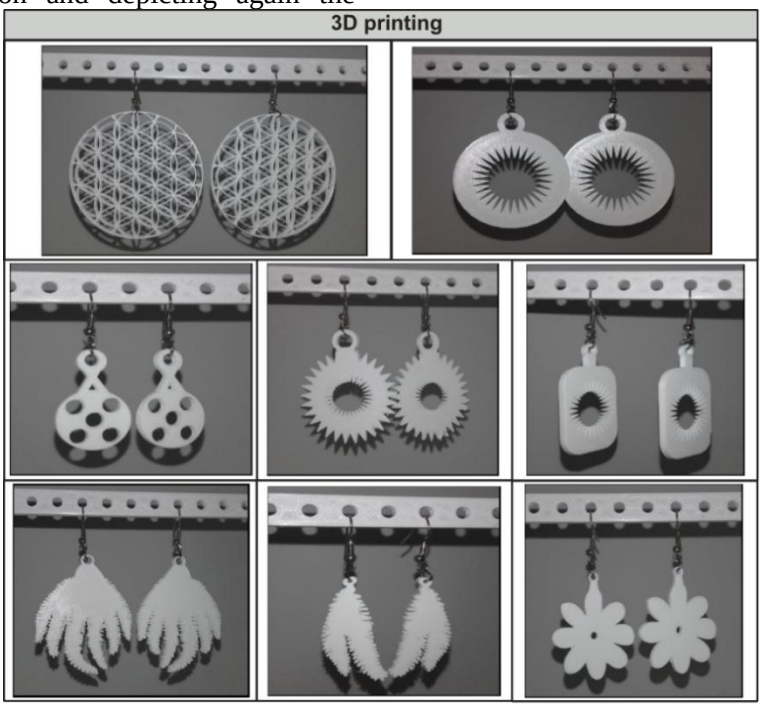

Fig. 6 Earring models produced by 3D printing

3.3 Shoes

Shoes' designing is a complex process as the shoe should fill not only the aesthetic part, but one of the most important requirements for shoes are both the fit and the comfort. Heels are a main part for elegant models and their shapes varies according to the model. Designing a new model of heel means fulfilling in the same time requirements for aesthetic part; withstand the forces without failure and also providing foot comfort. The inspiration for the heel model is taken by the binary system of numbers comprised only by two symbols: 0 and 1. This is the same system of binary-coded punched cards for operating looms developed in France by Joseph Marie Jacquard, and is the first binary controlled production machines [21]. Joining the binary system of numbers together with the upper part of a normal heel a new model is created. Figure 7 depicts the flowchart for heel creation.

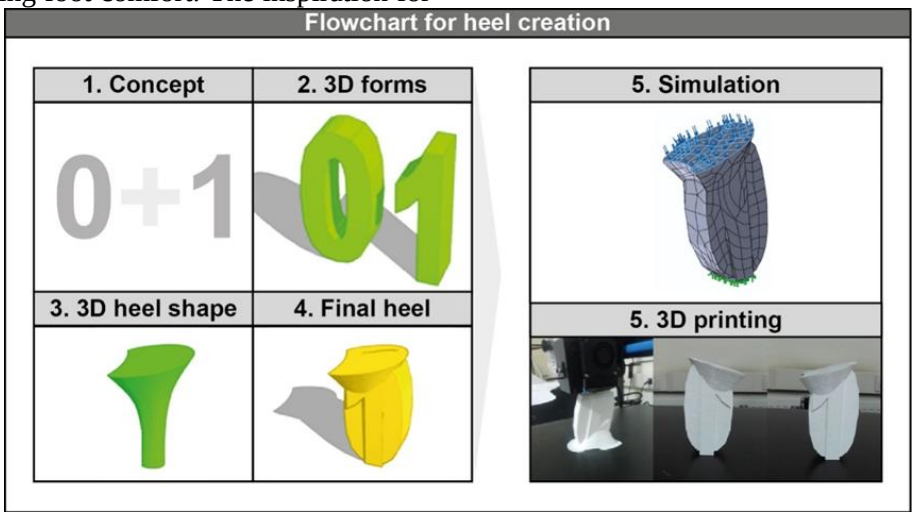

Fig. 7 Flowchart for heel creation

As the heel is subject to forces compared to the other items modeled in this work, further analyze is conducted. In our previous work, engineering design schemes are implemented for sole model [22]. In order to validate the mechanical performance of the designed heel and taking into

account that additive manufacturing will be used for manufacturing after data elaboration of the 3D model converting it into a CAD model, simulation process is undertaken on CAD software (SolidWorks™ 2019). As the objective of our work is to present case studies of additive manufacturing, the selected material for additive manufacturing is a polymeric material Polylactic Acid (PLA). This polymer demonstrates high mechanical strength. Figure 6 illustrates the loads applied on the heel model, which corresponds to the upper part of the heel in contact with the sole. Here the load considered is 60 kg. The constraints selected in the heel model, correspond to the lower part of the heel in direct contact with the ground (fully fixed). Figure 8 depicts the numerical results obtained from the numerical simulation.

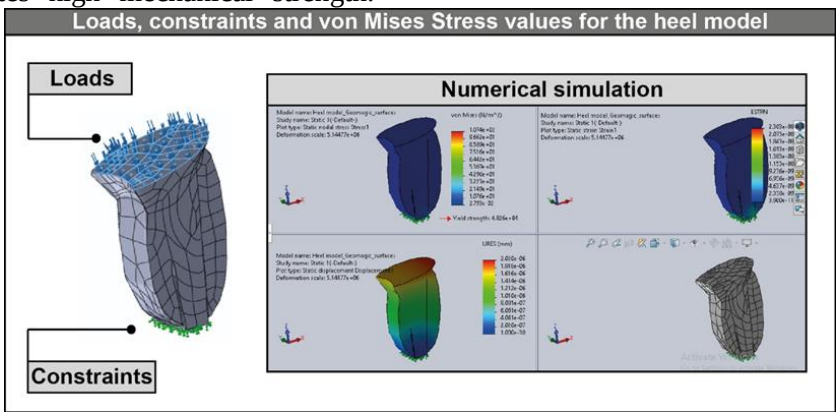

Fig. 8 Loads, constraints and von Misses Stress values for the heel model on SolidWorks™ software

The implementation of numerical simulation for the heel model is seen as a great advantage of products design in order to predict the mechanical performance of the 3D model at the first stage of designing. In this case, by avoiding errors related to design and selection of materials. As confirmed by numerical simulation, the new heel model can be used for production. In order to complete the shoe model in combination with the heel model, here again by using the binary system of numbers comprised by symbols: 0 and 1, are used for designing the upper part of the shoes. The software offers a wide range of last models that can be used for designing various shoes models. The last selected is a court last with a heel height of 86.387mm and by using Last Editing the heel height selected is 100 mm. Figure 9 presented view from 3D shoe designing process on 3D modeling shoe software Shoe Maker™. Numbers 0 and 1 represented by shoe-piece of the upper part of the sandal model are visible. After finishing the 3D modeling process the second phase is real shoes production. The patterns are exported from the 3D model, printed and used for leather cutting.

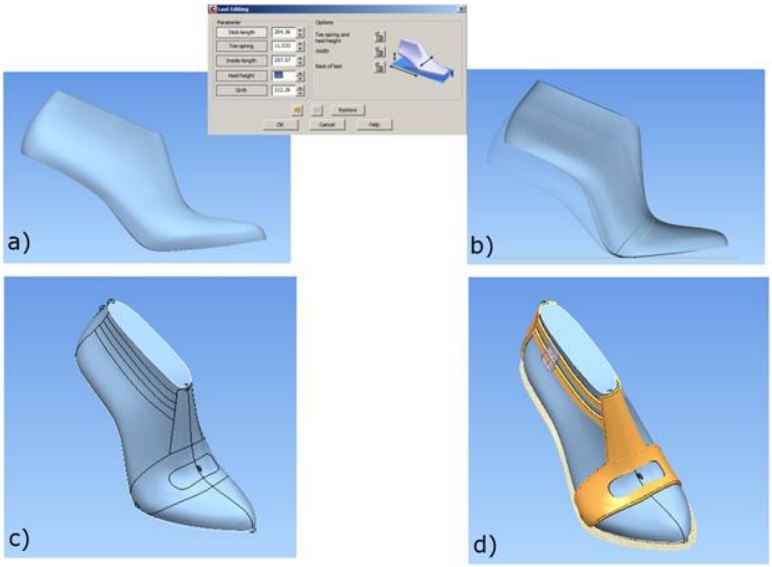

Fig. 9 3D modeling a) last model, b) modified last, c) upper part of designed model and d) sandal model

As confirmed by numerical results of simulation process, the designed heel model is then processed for additive manufacturing. The model is exported as .stl format and imported in the slicing software Cura™ by Ultimaker™. The infill pattern chosen is Cubic (subdivision), which is a strong 3D infill and

used to make the object equally strong in all directions, and in the same time reducing the material. Figure 10 shows the main parameters used for 3D printing and view from the slicing software of the heel model in solid and layer view.

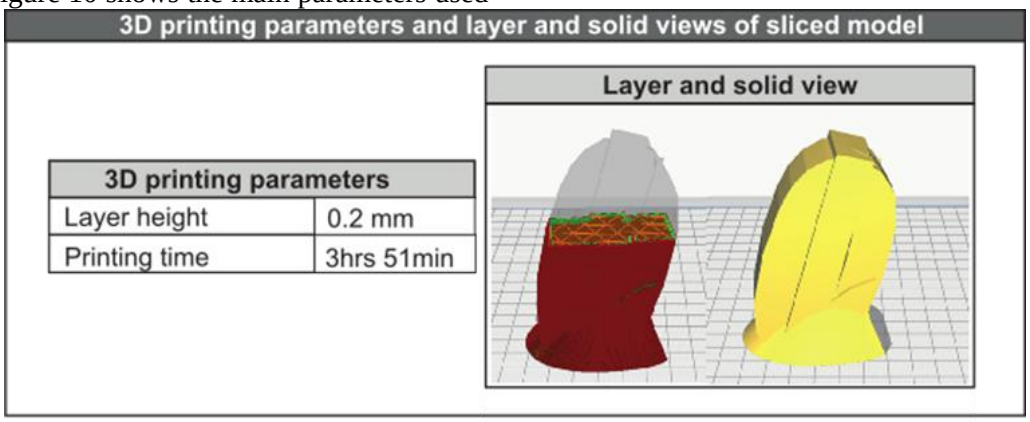

Fig. 10 3D printing parameters, layer and solid views of sliced model

The G-Code format, which contains all the necessary information for 3D printing, is loaded on the 3D printer. Figure 11 depicts views during the printing process and the final heel model on right and left view.

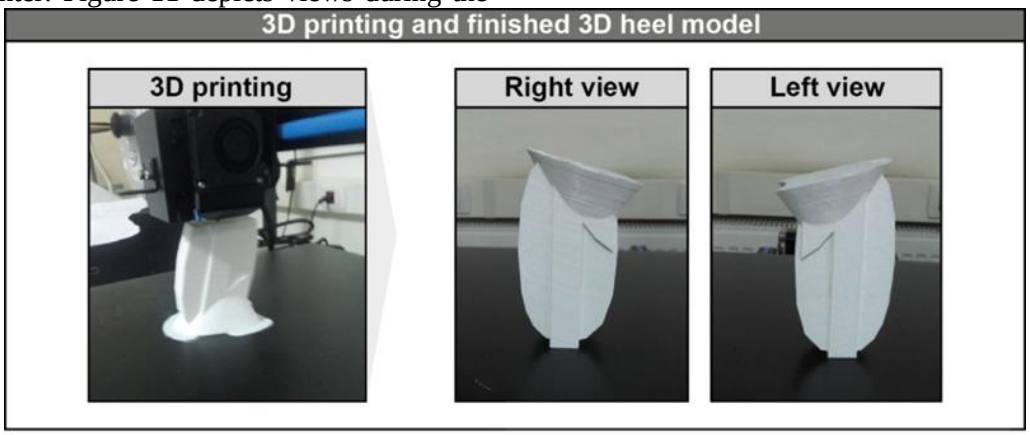

Fig. 11 3D printing of heel model. Right and Left view of the finished heel

Following, Figure 12 presents some of the steps during the process of shoe production. The 2D patterns exported from the 3D model are used for leather cutting shown in Figure 12a). In order to use the personalized last according to heel height, it is exported and 3D printed (Fig. 12b). As result the sandal model produced is given in Figure 12c).

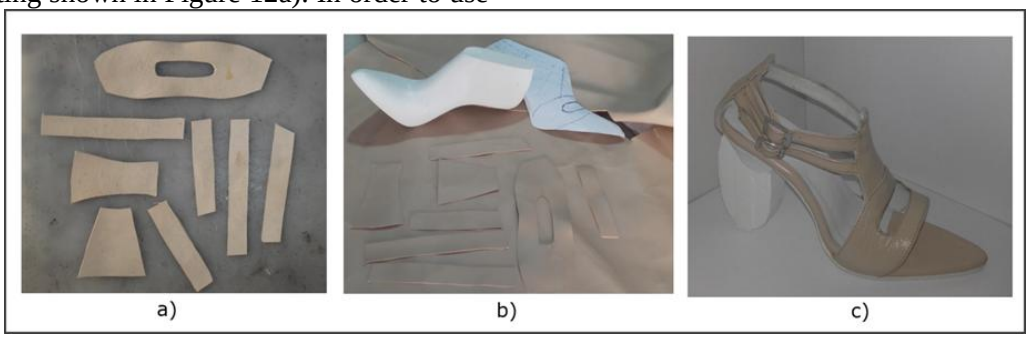

Fig. 12 From 2D patterns to final product: a) leather patterns, b) 3D last model and c) sandal model

3.4 Garments

The use of 3D printing for garment products is not new. Cases presented by well-known designers in collaboration with 3D printing companies and presented in catwalks confirms the wide spread use and the great interest that this technology has in fashion industry. 3D printing is used for full garment production, as part of the garment or 3D printed on textile fabric. The last case has shown a great interest due to the functionalities that can be added to textile fabric as in smart textiles. As we mentioned above, the geometric structure created can be used as part of the dress. From the structures created and presented, the most important of them is

the flower of life. It is one of the most powerful symbols, part of the sacred geometry used all over the world and representing the cycle of creation. Since in many traditions, circles and curves are believed that represent feminine, its implementation in a dress item fulfills it. Figure 13 presents more in detail steps followed for the digital manufacturing of the flower of life. At first a 2D vector, is created, following with 2D shape, the 3D model and its production by FDM technology.

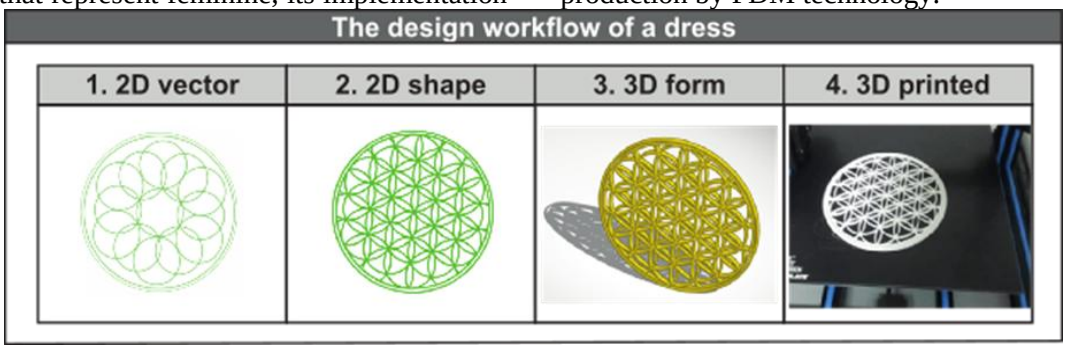

Fig. 13 From 2D concept to digital manufacturing of flower of life structure

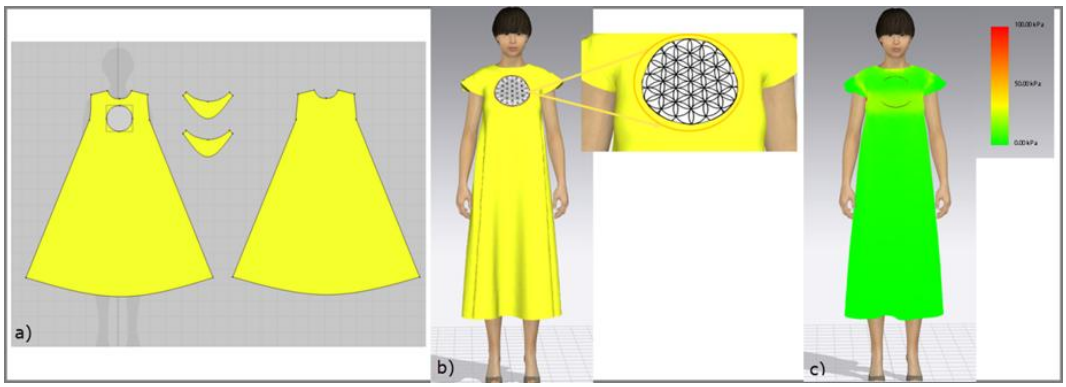

Fig. 14 Dress model: a) dress patterns (2D), b) virtual dress model and c) simulation and stress map

Dress patterns are designed on 3D modeling software CLO 3D from CLO Virtual Fashion Inc. 3D modeling of fashion products it is very import in order to improve productivity and quality. But due to the growing interest to reduce environmental footprint of fashion products, 3D modeling offers the possibility to evaluate a product in a 3D virtual environment. In the 3D modeling of garment products, through interactive modification of 2D pattern is synchronized with virtual sew and draping in the 3D model. As a result, avoiding several trials, time and costs included to produce a prototype. In this work, at first the avatar is customized with the main body dimensions of the model. Following the dress patterns are designed, virtually sewn and simulated over the personalized 3D model. The dress color chosen is yellow, as sun color. In order to better simulate the final dress which will include in the front part the 3D printed model of flower of life, the image of the flower of life is included as a pattern in the front part of the virtual dress. Figure14 presents some of the steps from 2D pattern design to 3D the virtual dress simulated on 3D body model and including the image of flower of life in front of it. From the simulation and stress map is evident that this model fits to personalized model.

Fig. 15 The dress with the model of flower of life and earrings produced by 3D printed

The dress patterns are exported printed and used cutting on textile fabric. The final dress produced is depicted in Figure 15. It can be seen that 3D printed model of flower of life is in the front part of the dress.

4 CONCLUDING REMARKS

Digital manufacturing is present in almost all areas of production by linking systems and process required from conceptualization to the final product. Case studies of digital manufacturing implementation as one of the pillars of Industry 4.0 to fashion products brings again its advantages in

fashion industry. By taking inspirations from various sources linked with nature and according to Albert Einstein quotes: "Look deep into nature, and then you will understand everything better", customized models with the tools of 3D modeling software and great power of additive manufacturing as FDM technology make possible realization of fashion products that can be used in everyday life. Moreover, the 3D models generated form CAD software are print directly by avoiding other process related to traditional manufacturing. FDM as a non-expensive technology compared to the other types of additive manufacturing makes possible the manufacturing of customized products without restrictions on design. The rise of new technologies in digital manufacturing releases new opportunities for companies to foster productivity, customization and sustainability.

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