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3D-Printing with Biomaterials - The New Sustainable Textile Future? †

Manuela Polewka[1], Franca Enz[1], Marie Jennißen[1], Emilia Wirth[2] and Lilia Sabantina[1,3] *

[1] Niederrhein University of Applied Sciences, Department of Textile and Clothing Management, Moenchengladbach, Germany
[2] Independent researcher
[3] Berlin University of Applied Sciences - HTW Berlin, Berlin School of Culture + Design, Berlin, Germany; lilia.sabantina@htw-berlin.de, https://orcid.org/0000-0002-1822-7954
* Correspondence: lilia.sabantina@htw-berlin.de
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Abstract: Additive manufacturing (AM), also known as 3D-printing, encompasses a wide range of techniques for applications ranging from on-demand production to functional prototypes. 3D-printing is mainly used in industrial sectors such as aerospace, automotive, medical, dental, construction, art and fashion. Fossil fuel-based materials such as plastics as well metals, and concrete, etc. are widely used to produce 3D-printed products. More recently, innovative 3D-technologies using new bio-based renewable materials have shown promising results for everyday applications, opening up new opportunities for sustainable 3D-printing in the future. This review reports on developments in 3D printing of bio-based materials, direct or partial printing on textiles, etc., providing considerations, challenges and future outlooks.

Keywords: Sustainability; 3D-printing on Textiles; Fused Filament Fabrication (FFF); Recycling; Textile Manufacturing; Bio-Based Filaments; Biodegradability; Additive Manufacturing; Biomaterials

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1. Introduction

Additive manufacturing (AM), or 3D-printing is used in various industries, including health, transportation, food, and fashion [1-3]. One of biggest application fields is its ability to produce prototypes quickly and cheaply traditional injection-molded prototype, which is particularly important for industries such as automotive and aerospace [4]. In fashion, 3D-printing has been used to create unique and sustainable pieces that offer a high degree of design freedom in shapes and structures. With 3D-printing it is possible to reduce waste generation in traditional garment production during the cutting and the sewing process. Until now, this type of fashion has been developed for catwalks in the haute couture section. However, there are also challenges associated with 3D-printing in fashion, particularly in terms of comfort and flexibility so that the manufacturers have to choose between material and structure-based flexibility [3]. Many 3D-printed objects are relatively stiff when printed as whole piece, which can be uncomfortable to wear. To address this issue, designers and manufacturers have developed a few techniques, like direct-to-garment printing, partial garment printing, and fabric-like printing [4].

Direct-to-garment printing involves printing designs directly onto existing garments, which allows for greater flexibility and comfort. Partial garment printing involves printing individual segments that are then assembled into a larger garment, while fabric-like printing, one of the most versatile techniques, involves trying to imitate textile-like structures like a knitting, mesh or a net structure with geometrical forms, to achieve a higher flexibility, by using multiple assemblies. But CAD-systems have limitations in adjusting, creating, saving large amounts of data when wrapping linkages over complicated structures [5]. Material-based flexibility is still a small market segment due to the weakness and low tear-resistance of current rubber-like materials. The easiest way to create everyday fashion using 3D-printing is through the use of 3D-printed flexible, textile-like structures, which are currently the largest part of the 3D-printing market [6-7].

1. Biomaterials in 3D-printing

Various resources found on earth, including non-renewable fossil fuels and renewable organic biomass. Manufacturing 3D-products from biomaterials contributes to sustainability and resource savings by using natural polymers that have similar material properties to their fossil counterparts, while offering better sustainability and biocompatibility. In general, the most used thermoplastics is polylactide acid (PLA), a biobased plastic. The second dominant is acrylonitrile butadiene styrene (ABS), a fossil-based plastic [8]. To meet the needs of future generations, a fundamental transition to a bio-based economy is required as the demand for and availability of 3D printing continues to grow. This can lead to a rise in waste that is not correctly disposed or recycled at the end of its lifetime [9]. Therefore, material sustainability is investigated in the following, especially with regard to the use of biopolymers instead of non-biodegradable, fossil-based polymers.

1.1. Bioplastics

To produce biomaterials, in particular bioplastics, various crops are utilized to withdraw starch, sugar, oil or cellulose, from soybeans, wood, wheat, perennial grass, maize to potatoes. Then the crops are transformed into intermediate products of bio based bulk chemicals via conversion techniques, which are then transformed into various bio-based plastics e. g. through gasification, leads to methanol, pyrolysis, results in bio-oil etc. [11]. Figure 1 gives a visualization of this production.

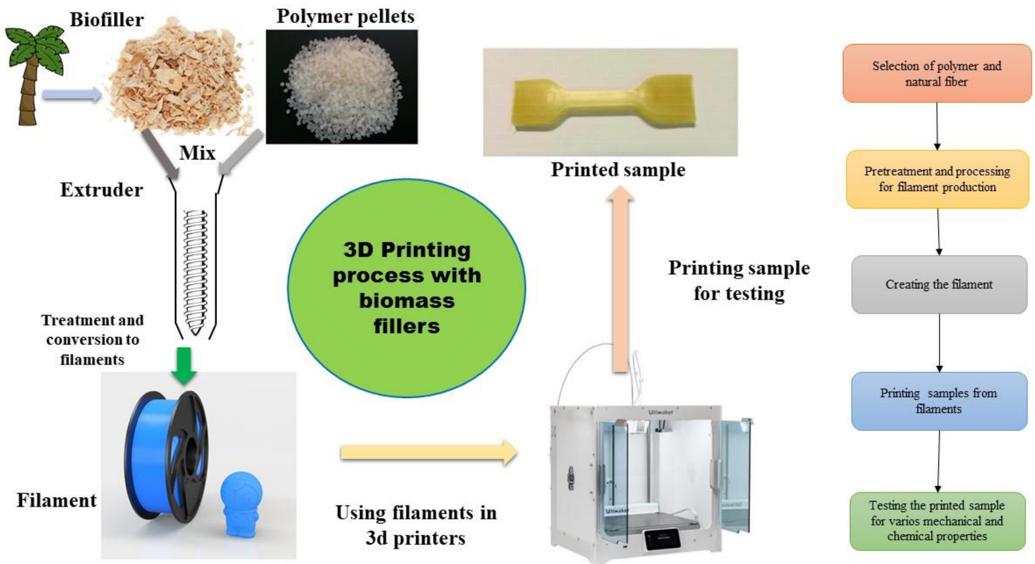

Figure 1. The cycle of 3D-printing using natural fibers. Reprinted from reference [11], originally published under a CC-BY 4.0 license.

3.1.1. Commercially available bioplastics

The bioplastic PLA has made its stance to become the most common material used for 3D-printing. Further advances were achieved with bio-based fibrous materials like wood and hemp etc. and towards a biodegradable economy [12].

3.1.2. Lignin filament

TwoBEars, a German start up, launched BioFila®, a biodegradable filament for 3D-printing in April 2014 with the promise to not use polymer outside of the food chain, rather manufacturing biopolymers on the basis of thermoplastic lignin. By changing the temperature of printing, the texture of surfaces can be varied [12]. In general, lignocellulosic materials are considered for the degradation of carbon emissions Lignin, an amorphous and aromatic polymer, can originate from lignocellulosic biomass [13].

3.1.3. Wood filament

The inventor from Cologne, Kai Parthy, has developed a new natural fiber filament, a more precise wood filament under the name "LayWood" that permits objects to be printed in a wood design depicting annual rings and which is compatible with the FFF process. The filament contains 40 percent wood fibers and a thermoplastic binder which has similar thermal properties to PLA. By changing the temperature, it is possible to create these wood-looking annual rings. Various color shades can be achieved; light colors at 180 °C and darker shades at 250 °C. Further, Parthy created another innovative 3D-printing material in 2018 "GrowLay", a bio-based biodegradable filament that was created to grow biological cultures such as grasses and mosses, fungi [12].

1.3. D-printing sustainability

The 3D-printing technology has been lauded as a key technology to reduce the environmental impact of production and improve sustainability-namely reduce, reuse, and recycle. However, there are also challenges to overcome.

4.1. Factors to overcome

Additive manufacturing has significantly changed parts of manufacturing, especially prototyping. It is often referred as to a more sustainable way of manufacturing, but there are still major factors to overcome, as procedures of production for various finished goods differ so extensively [13-15].

Recycling additional and undesirable material into feedstock, creating new procedures for material degradation or composting into nontoxic natural biomass is essential. Transforming material waste into novel filaments is an important recycling procedure, in particular for thermoplastics with close resin properties. However, transforming material waste can lead to degradation, which is an irreversible procedure that can lead to a significant change in filament structure and damage to properties [9,16-18].

Most 3D-printers' environmental impacts are based on electricity use, and not about material choice, and depend on changing power consumption by various plastics did not have a substantial effect in comparison to variation in utilization between devices. The machine idle time has a rather large impact on variation. Hence, the printer's energy usage holds the uppermost influence in the determination of total sustainability performance of a polymer. For clarification, "energy usage" incorporates electricity required for printing parts, also idle time, starting and halt [14].

Secondly, recent 3D-printers use energy mainly generated by power stations from fossil fuel [19]. As a consequence, the advantage of 3D-printing can only be fulfilled if machine utilization is adjusted in terms of evading wasted energy through idle time between prints, and unproductive print systems. PLA requires less energy consumption for 3D printers because of its lower melting point than ABS and is therefore less harmful to the environment overall than ABS. So, ecological influence can be optimized by selecting biobased, biodegradable plastics, but the right utilization has an even more critical part [20].

4.2. Positive effects

Of course, when claimed the new sustainable future, 3D-printing has several sustainability advantages. First, looking at the materials and the fact that PLA is nowadays the most used filament for additive manufacturing with a tendency to increase even more, one can say that a first step of being more sustainable within 3D-manufacturing is already done, but a deeper look into this is still necessary [16]. Unfortunately, the characteristics of biodegradable materials are often misleading, if not further defined. A biodegradable plastic such as PLA cannot truly degrade in natural environments, specific conditions of industrial composting i.e. higher temperatures, humidity levels and the presence of microorganisms, are needed. It needs to be acknowledged that, bio plastics besides fossil-based plastics are still plastics which can generate environmental pollution and first and foremost microplastics that need proper recycling [10].

It is already known that 3D printing produces less waste and has lower energy consumption than CM [21]. This is due to several reasons. Firstly, there is less waste because, unlike conventional processes, the parts are not cut out but produced directly in the required size and shape, the consolidation process. Additionally, the design is more efficient, which means that products that are usually made from several pieces can be done in one piece, which reduces the overall material used and leads to less waste also due to precisely calculated material demand. Hence, less joining is necessary, which leads to fewer seams and therefore better durability. Since printers are small and not stationary, it is possible to position them nearly anywhere and print the pieces locally with practically no emissions. [22-23]. So that there is no need for big factories which would be provided with a lot of electricity. The most sustainable way would be a print on demand system which would eliminate inventory and avoid unnecessary produced pieces of garment. An additional advantage in manufacturing is that the water consumption is insignificantly small in comparison to conventional methods using natural products for textiles, e.g., cotton or flax [21-22].

In general, 3D-printing enables a longer life cycle for the products in use due to the possibility of fixing broken parts easily by simply printing them out and joining them together or directly printing them onto the garments. The biggest point regarding a longer life cycle is probably the individualization of products. Individuals can have their clothing adjusted or designed to their preferences, and in some cases, such as in the shoe industry, customized to meet medical needs, particularly in the midsoles of sports shoes. The financial factor of such personalized items has a longer life cycle due to their perfect fit and aesthetic appeal resulting in people purchasing fewer items, leading to a lighter environmental impact [24].

Recycling is a crucial and complex topic in sustainable fashion as composting of plastics is impossible and even the PLA process requires a lot of know-how and technology [25]. However, additive manufacturing has the advantage of easily recycling polymers by remelting and printing new pieces, which hinders a time and cost intensive composting, and which enables a cradle-to-cradle principle. In addition, waste materials can be recycled and used as filaments, reducing the need for virgin materials and minimizing existing waste. This is already implemented in some bigger companies, e.g., Adidas uses waste out from ocean for the manufacturing of their shoe soles [23,26-27].

1. Conclusion and future outlook

To say whether 3D-garment printing is sustainable or not is difficult to answer because many aspects must be considered on the material side as well as in the whole life cycle of the product. The use of biomaterials, particularly PLA, is a step forward in the industry, but the misunderstandings surrounding its biodegradability highlight the need for clear communication of required composting methods and a national recycling plan to reduce the harm of plastics. Further research on possible other biodegradable biomaterials which do not depend on industrial recycling but are currently only used as additives in PLA filaments. A cradle-to-cradle system would be the most sustainable approach, but a comprehensive analysis of energy consumption and waste management must be conducted to evaluate the sustainability throughout the whole life cycle of 3D-printing compared to conventional manufacturing methods. For instance, 3D-printing can only be completely sustainable when all the energy used comes from renewable sources [14,28]. The approach of individualization and its contribution to sustainability needs more consideration. While individual products have the perfect fit and longer life cycle, the future possibility of mass individualization through accessible 3D-printers raises concerns about sustainability [29-30]. Overall, 3D-printing in the garment industry opens many doors towards a more sustainable production in the future by addressing customers and their consumption behavior and additionally focusing on more sustainable materials and production.

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