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3D Knitting for Upholstery: Guidelines to Design at the Interface of Sustainable Fashion and Furniture

Benedetta Cerulo[1], Flavia Papile[1], Martina Motta[1], Andrea Marinelli[2], Giovanni Maria Conti[1], and Barbara Del Curto[2]

[1]Design Department, Politecnico di Milano, Milano (MI), Italy
[2]Department of Chemistry, Materials and Chemical Engineering "Giulio Natta", Politecnico di Milano, Milano (MI), Italy

ABSTRACT

Textile products always played a fundamental role in furniture design projects. Recently, the furniture sector was called to meet the growing demand for sustainability. In particular, the disassembly phase is usually very difficult when talking about upholstery, where the padding material is hardly reused, recycled, or recovered at the product's end of life. This research focuses on the interface between innovative textile technological processes (i.e. 3D knitting) and upholstered sofas and armchairs design, to foster sustainable production in the furniture sector. By analyzing 3D knitting either in literature and business cases, this research discussed the environmental, economic, and social potential of 3D knitting for upholstery products. The research output consists in providing specific design guidelines for 3D knitted upholstery that were defined, discussed, and applied in the early stages of the development of a lounge chair.

Keywords: 3D knitting, Sustainability, Upholstery, Furniture sustainability

INTRODUCTION

The remarkable economic expansion in the last century has given rise to the phenomenon of consumerism which grows on a linear system of consumption and production. In the abovementioned system, products are mainly obtained from resources extraction and their journey ends in landfills, rivers, incinerators (Ellen MacArthur Foundation, 2020). The furniture sector, for the reasons mentioned above, due to the impact of virgin materials used and the high amounts of municipal waste produced, is considered one of the sectors with the most significant impact (Barbaritano et al., 2019). At the same time, it constitutes an extremely profitable market in global trade and one of the sectors with the highest priority and opportunities to convert to the Circular Economy (EFIC, 2021).

Turning into circularity means reinterprets the "end of life" phase of products as a way to give materials several chances to enter again in production systems as raw material (Bompan & Brambilla, 2016) and create long-term resilience, generating countless benefits for the environment, businesses, the economy, and society (Ellen MacArthur Foundation, 2020).

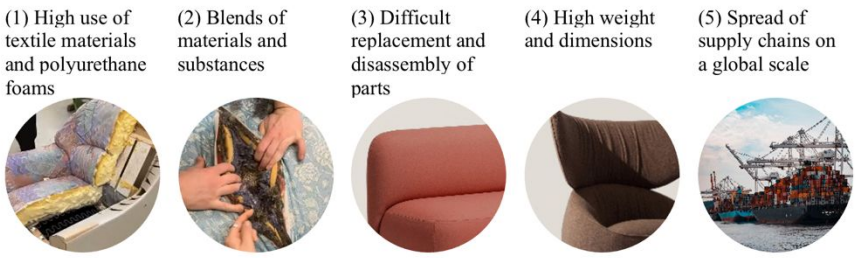

Figure 1: Identified issues in existing products.

METHODOLOGY

An analysis was carried out on the state of the art of furniture products, belonging to different market segments, focusing on the categories of upholstered seats (lounge chairs, sofas, armchairs). The main companies belonging to the different market categories were taken into account and an average of five products for each were examined. The analysis, of approximately 50 products, was focused on: how many materials and which one constitutes them, in particular the paddings, how the product is conceived, if the cushions are removable or if the components are replaceable, and focusing also on product size when packed for sale. This analysis was compulsory to understand the existing design opportunities to implement the circularity of upholstery products (Figure 1).

The issues highlighted in existing design upholstery consist in: (1) high use of textile materials and of polyurethane foams, which have a significant impact on the environment during the disposal phase, since them are mainly used to energy recovery, because reuse and recycling are expensive and logistically complex (Letsrecycle, 2018); (2) blends of materials and substances in each piece of furniture make the recycling path difficult at the end of its life cycle; (3) difficult parts replacement and disassembly in products like armchairs, sofas, lounge chairs that are made up of components that cannot be disassembled or replaced individually (for example cushions covers that cannot be removed), demanding for the replacement of the entire product; (4) high weight and dimensions of upholstery usually brings to higher fuel consumption during transport and to a large use of packaging materials, generating high emissions into the atmosphere and generating waste; (5) and the spread of supply chains on a global scale with suppliers from different regions (Guolo, 2021).

Those drivers emerging as possible intervention areas for sustainable design have been already implemented in certain upholstery products, determining interesting trends in furniture design (Figure 2).

These trends are: (a) having flat packaging helps in reducing the product's dimensions during transport and imposes the elimination of pre-assembled furniture, in order to optimize product stocking and at the same time reduce carbon emissions per unit (Imm Cologne, n.d.) in the transportation phase; (b) design for disassembly is one of the main strategies of circular design as it

Figure 2: Identified trends in furniture design.

facilitates the replacement of individual parts of a product and the easy reuse of the materials that constitute it (Design School Kolding, 2018), (c) the use of recycled or recyclable materials avoids the extraction of virgin resources; (d) preferring a local production allows the involvement and development of local producers to significantly reduce the carbon footprint due to transports resulting from a chain too extensive (Imm Cologne, n.d.).

3D Knitting as a Sustainable Technology

3D knitting is part of the knitting process, that creates fabric through the interlacing of yarn in a series of concatenated loops (Spencer, 2001). Although this technology was introduced in 1995, only lately has been understood the great potential of this technology not only for application in the clothing sector but also in other fields such as automotive, sports, aerospace, healthcare, smart textiles, and furniture (Shima Seiki, 2018). The three-dimensional knitting process corresponds to one of the most recent advances in the field of weft knitting (Kincade & Gibson, 2010). Starting from yarn, the coordinated movement of the needles - which work on the four needle beds of the machinery- creates a complete product, including possible pockets and decorative elements (Peterson & Ekwall, 2007). One of the peculiarities of the process is to make the production more sustainable in environmental terms because it does not generate production waste thanks to the possibility of creating 3D shapes without the need to resort to cut and sew processes. Additionally, such computer control limits the number of prototypes needed to achieve the desired result and allows an on-demand production. 3D knitting is the only knitting technology that does not require additional processes to obtain the complete product, leading to a downsizing of the production chain and the possibility of reorganizing production locally (Nawaz & Nayak, 2015). Finally, the structure of knitted products makes it possible and facilitates the recycling of yarns: using this technology yarns are not damaged, therefore it is possible to unravel the fabric to recover them easily and use them for creating a new product (Shima Seiki, 2021). On the social sustainability side, this technology eliminates the operations most subject to the exploitation of labor and at the same time involves a greater number of specialized figures (Peterson & Ekwall, 2007). In economic terms, this brings to a reduction of costs, due to saving of time as well as reduction of waste of materials and energy.

Contribution of 3D Knitting to Sustainable Production in the Upholstery Sector

The use of this technology in the furniture industry currently presents a few examples. Interface with knitwear technicians and product designers who work with this technology has brought out how this is still little known in product design but how at the same time it is emerging thanks to the type of sustainable production it would generate, especially in the upholstery sector. 3D knitting favors the creation of products composed of a few components and at the same time made of a single material and provides the possibility of obtaining different techniques, which generate parts of the fabric with distinct aesthetic and functional properties, using the same machine and the same yarn. Referring to the issues and trends of the sector previously intercepted is possible to say where the technology of 3D knitting can intervene on: (I) the replacement of padding materials with recycled and recyclable yarn (see (3) and (b)); (II) the generation of easily disassembled products thanks to the nature of knitting structure (see (2), (3) and (b)); (III) the creation of space-saving and light products thanks to the efficiency of techniques that machines can produce (see (4) and (a)); (IV) potential improvement of local production and easy product replication thanks to machine software (see (5) and (d)); (V) supporting the trend of flat packaging, providing the possibility to create products with a reduced footprint that do not give up the desired properties (see (4) and (a)); (VI) implementing the usage of recycled yarn both for the creation of the fabric and for the padded areas (see (1), (2), (b) and (c)).

RESULTS: GUIDELINES FOR 3D KNITTING

Once established the benefits of adopting 3D knitting in the production of upholstery, the technology guidelines have been defined to help the designer in the early stages of approaching the technology of 3D knitting.

Alongside a theoretical part, consisting of tables and information, a case study has been provided, which consists in the development of a 3D knitted lounge chair. Is necessary to keep in mind how designing for 3D knitting always needs feedback from specialized figures, like knitwear technicians. They, through their experience, are able to offer technical skills and translate them into better design solutions. Â-Â-Â-However, through these guidelines, it is possible to get oriented easily in the interaction with technology. Design steps identified are six and will be described in detail in the following paragraphs.

1. Product sketches

The first step in designing a knitted product is to define the shape it will have. In this phase, the idea is presented and components of the product are defined.

2. Definition of shape/dimensions/requirements

Generally, when one has to understand the actual feasibility of a product, it is necessary to understand first if the dimensions are in those of the machine (a common 3D knitting machine can produce with a range of 18 cm-254 cm) and think about how the machine works to create it. To do this is necessary to consider the machine needle beds and schematize the parts of the product

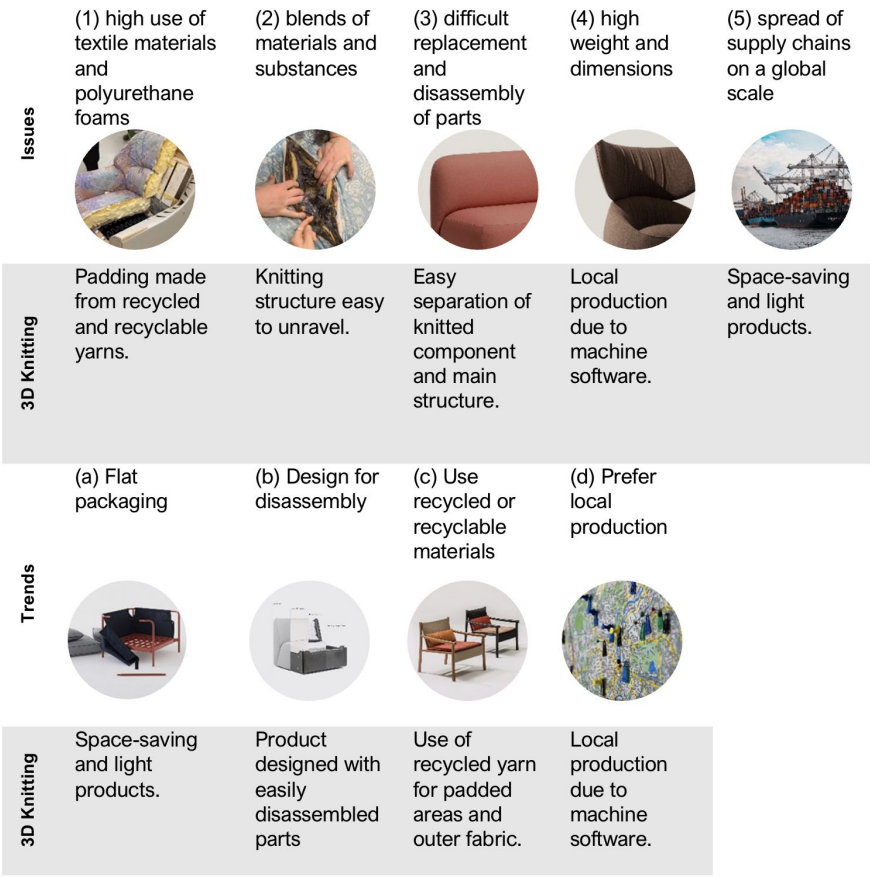

Figure 3: 3D knitting opportunities related to issues and trends.

as if they were planes. Each needle bed works on one plane and depending on what should be the final result, they work separately or together. Once product shape and overall dimensions have been defined, requirements that the product must fulfill are identified.

3. Selection of techniques

Once the requirements have been identified, it is possible to understand which techniques best meet the outlined needs. Techniques that 3D knitting machine is generally able to create are nine: Tubular knit, Three dimensional knit, Spacer structures, Padded structures, DOSs (Directional Oriented Structures), Multi gauge, Inlay, Jacquard, and Vanisè. Each technique is chosen following the design requirements.

4. Identification of compatible techniques

Some parts of the 3D knitted product may require the combination of two or more techniques, in this case, it is necessary to verify that knitting machines can effectively produce and combine those of our interest.

5. Selection of parameters for each technique

In the next step, parameters of the knitted product are established for each technique. These generally regard any texture of the fabric, type of stitches, type of yarn used, yarn count, and machine gauge.

Table 1. Knitting techniques.

Techniques	Description/ warnings	Compatible techniques	References
Tubular Knit	Simple shapes; Choose sections and tubular size.	All the techniques except 3D structures and Spacers	(Au, 2011); (Liu & Hu, 2015)
Three-dimensional Knit	Complex shapes; Software simulation is recommended.	All the techniques except Tubular knit.	(Liu &Hu, 2015)
Spacer Structure	Simple shapes; Variable thickness and properties;	3D structures, Inlay, Vanisè (Plating).	(Au, 2011); (Liu & Hu, 2015);
Padded Structure	Choose between inserts or yarns.	All the techniques except Spacers.	
DOSs	Horizontal insertion is the most simple to process; Tests are necessary to obtain desired results.	All the techniques except Spacers.	(Au, 2011)
Multi Gauge	Both directions of the fabric; Gradual effect transition are recommended.	All the techniques except Spacers.	(Au, 2011)
Inlay	Images full of colors (up to 36;42). Used with precious and expensive materials; Slow and costly process;	All the techniques but must be careful when combined with Spacers.	(Parrillo & Chapman, 2008); (Evans-Miellis, 2012); (Ray, 2011);
Jacquard	High definition images; Influences thickness of the fabric; Back fabric with floating yarns.	All the techniques except Spacers.	(Conti, 2013); (Parrillo Chapman, 2008)
Vanisè (Plating)	Design complexity and number of yarn reduced; Good quality of images on both sides.	All the techniques.	(Parrillo Chapman, 2008); (Ray, 2011)

6. Understanding feasibility (shape and size)

Once these parameters have been selected, is possible to verify the feasibility of the product, in terms of shape and size, based on what the machine can produce. Starting from that, the appropriate modifications to the product are made.

Guidelines Applications: 3D Knitted Lounge Chair

The product designed to put into practice the guidelines explained is a lounge chair, consisting of a soft knitted component, wedged on a tubular aluminum structure. The lounge chair was supposed: to be easily disassembled,

Table 2. Knitting techniques parameters to monitor.

Techniques	Description/warnings	Specificities	References
Stitches and textures	Technical knowledge required to appropriately choose stitches	From four main structures of weft knitwear (jersey, the rib knit, interlock, double jersey) is possible to get endless constructions and obtain different behaviors from knitted fabrics	(Motta, 2019); (El Mogahzy, 2009)
Yarn (Material)	Choice of yarn material determines the behavior and sustainability of the final product.	Not all yarns are suitable for 3D Knitting in the furniture field, the choice is often limited to man-made yarns (polyester is the most common).	
Yarn Count (Machine Gauge)	To understand how thin or thick the fabric will be, varying the value of fineness of processing. The higher the number of needles used, the higher is machine gauge.	Machine gauge value relates to yarn count (Nm). Generally, it is advisable to work with a yarn count of the same value of machine gauge (e.g. yarn count Nm 3.000 for machine gauge 3) or use neighboring values.	(Conti, 2013); (Motta, 2019)

to facilitate the replacement of the knitted component, to generate the least possible space during the transport phase, to make use of recycled or easy to recycle materials. The knitted component was developed following the above guidelines. Requirements were: soft areas, reinforced areas/pockets for the attachment to the aluminum structure, reinforced areas to support the weight of a person, areas with different colors. Once understood the techniques of our interest: tubular (to create the pockets for interlocking), padded (to create the soft areas), DOSs with insertion of the yarn horizontally (to create the reinforced areas), and inlay processing for areas with color variations, has been checked for compatibility. In the next step, the parameters for each of them were selected. To achieve the concept of sustainability, the knitted part was considered made of a single material, choosing recycled polyester yarns for both the outer parts of the knit and for the creation of padded areas. As a product that keeps contact with human skin, to obtain a soft touch effect, the knit structure selected was jersey knit. While this is a product that is put in tension on the aluminum structure, which therefore does not show elastic behavior, a high machine gauge has been selected, which consequently requires very thin yarns.

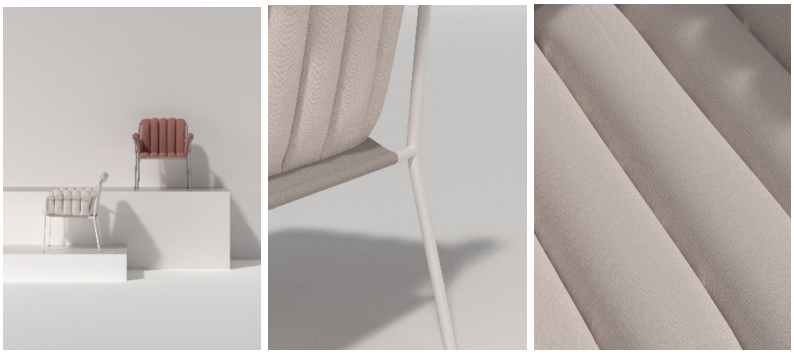

Figure 4: 3D knitted Lounge chair. (Image of the author).

DISCUSSION

The furniture sector, like many other production sectors, in the recent year, had to face the growing demand for circularity. This proposal has presented numerous benefits of 3D knitting technology, in environmental, social, and economic terms. A focus on the upholstered furniture sector has made it possible to understand how the technology is suitable to solve the problems and trends that the sector meets and to contribute to its conversion to sustainability. Finally, to provide a functional output, 3D knitting guidelines have been defined and the case study, of a 3D knitted lounge chair, explained. Through this last part of the research has been possible to create a tool to help designers in the early stages of the development of a 3D knitted furniture product.

These guidelines give designers the possibility to understand the limitations and opportunities of technology, providing an overview of the obtainable techniques and identifying all the parameters that are possible to manage.

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