WP T2 – INNOVATION ON TEXTILE WASTE MANAGEMENT

ACTIVITY A.T2.3 PILOT CASES

D.T2.3.2 PILOT CASES

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ENTeR – Expert Network on Textile Recycling

ENTeR works in five central European countries that are involved in the textile business, to promote innovative solutions for waste management that will result in a circular economy approach to making textiles.

The project will help to accelerate collaboration among the involved textile territories, promoting a joint offer of innovative services by the main local research centres and business associations ("virtual centre"), involving also public stakeholders in defining a strategic agenda and related action plan, in order to link and drive the circular economy consideration and strategic actions.

The approach of the proposal and the cooperation between the partners is oriented to the management and optimization of waste, in a Life Cycle Design (or Ecodesign) perspective.

CONTENT

1. Pilot case description – aim and scope

Thanks to the seven pilot-projects, the international partnership under the ENTeR project launched an overview and analysis of production processes and the use of secondary raw materials in order to contribute indirectly to the reduction of industrial waste for more efficient production.The study, which is the ENTeR 8 pilot, has been named “3D Printing in the Textile Industry”, and undoubtedly covers all the priority areas addressed by the project and not only seeks to summarise interesting research results, but also has successfully involved several local actors in this interesting and new experiment. It gave others the opportunity to learn about the latest and state-of-the-art techniques, and the samples produced by 3D printers printed on textiles were the first in the region to test, form an opinion, and thus help the professional progress of the ENTeR project and the knowledge of the consortium.

The further aim of the PBN was to examine how the project can be even more successful and innovative.3D printing is now well known and widely popular, even in a home environment suitable for prototype or small series production. The ordinary, though hand-held device capable of producing 3D print fibres from scrapped plastic granules in practice, 3D printing from various plastic materials is widespread, nowadays it is no longer a curiosum if metal-printed, high-precision and extremely varied geometry components are produced in different parts of the industry, which of course, in addition to prototype testing, can be used even in operating conditions.The speed of the technological development of 3D printing is exceptional, and the achievements achieved in this area over the last decade or even in the last few years are remarkable. In the eyes of many analysts, it is no longer a question of whether 3D printing will be the future in several industrial areas where material processing is being dealt with, but when the “throne of current technologies” will take place. Of course, we're not here yet and it’s a long way to go. In the case of serial production, 3D printing is higher than for example CNC.In many cases, however, this technology is more cost-effective than industrial counterparts. A good example of this is small series of plastic printing. Depending on geometry, printing thousands of copies may prove cheaper than making a injection mould.It is also a major advantage that, unlike conventional machining technologies, a relatively small amount of waste is generated by additive manufacturing technologies and that there are already different ideas and existing experimental solutions for the use and recycling of this small amount of waste in 3D printing.Furthermore, as 3D printing is now widely available, a huge user and developer community has developed, whose members are constantly sharing their experiences and suggestions in the online space. In addition to the forum discussions, a number of websites have been developed on which models created by others can be accessed, available or, in many cases, downloaded free of charge. And this can give a big boost to a beginner in the field of 3D printing. The above trend provides room for recycling of plastics on a new stage.3D printing in housing for non-industrial purposes can also be a clear area for recycled plastics. A more thorough discussion of this issue and the examination of its textile aspects motivated our activities within the framework of the ENTeR project.

In our study of the literature available to us, we concluded that the mechanical properties of the products produced from plastics suitable for 3D printing are already well known, and these parameters have already been compared with those of injection moulded samples with the same materials. However, no studies have been found to determine how the mechanical properties of each type of plastic are modified if they contain to some extent recycled raw materials. This appears to be less relevant to the manufacturer’s eyes, since, for example, when injection moulding increases the amount of regranulate in the process, the optical properties of the manufactured product deteriorate. On the other hand, 3D printing technology – especially when used at home – tolerates minor beauty defects and lower values in mechanical parameters, since 3D printed products do not usually face high mechanical stresses and increased aesthetic expectations. That's why this area is so promising in plastic recycling, and many creative and useful long-term tools can be made from shredded old parts. During our studies, we made 504 test samples on the 3 3D printers available in am-LAB, of which 216 were tested in Charpy impact tests, 216 in a tensile test and 72 3 point bending tests in the mechanical laboratory (ELTE SEK) of the University Centre of ELTE Savaria. The hardness of 3D printed samples against breaking on a Zwick/Roell HIT 5P standard Charpy percussion with a 5 J hammer, while the elastic modulus, bending modulus, and tensile strength values were tested using a Zwick/Roell Z100 tensile machine. The geometry of the 3D printed test bodies was performed in accordance with MSZ EN ISO 179-1/1eA for impact tests, MSZ EN ISO 20753: 2014 for tensile tests, and 3-point bending tests in the case of MSZ EN ISO 178A. The test bodies were manufactured with 3 FDM type 3D printers made from 3 different materials. We have chosen the PLA (polylactic acid), which is common in print 3D.Although this plastic can be obtained from a renewable raw material (maize starch), it is not a self-degradable plastic, which, contrary to popular belief, would require special conditions, bacteria, which are not available at most waste sites. The PLA raw materials tested are made of plastics that do not contain recycled plastics (originals), partly (up to 90 %) recycled plastics and 100 % recycled plastic.

Testing of different 3D printers was justified by different printer geometry and manufacturer-specific Slicer programs converting 3D files to printable G-code series.The test bodies were prepared at different printing layer thicknesses, infill percentages, printing temperatures and the raw material dried or used without drying.

At the end of themechanical tests, the surprising and initial hypothesis was partially refuted, that with the increase in the amount of recycled plastic, the 3D printed samples do not always produce worse results than the original, factory filaments. It was shown that the choice of the 3D printer could have a serious impact on the mechanical parameters, but we also found significant differences depending on the print parameters tested. As a conclusion, it can be concluded that it is justified to use filaments made of recycled plastic in print 3D. Neither its mechanical properties nor the optical appearance of the printed torso nor the cost of the raw material showed any outstanding differences compared to the test bodies made of factory filament. Ordinary 3D prints in our opinion can make these raw materials absolutely applicable. After verifying that recycled plastics can be used in 3D prints, we have made an attempt to ironing 3D printed logos from 100 % recycled PLA material to textiles and to test those items in real life.

As an ANNEX 1, the entire study has been provided.

2. Theoretical part

The main objective of the enter project is to reduce waste and prevent the depletion of non-renewable resources in the textile industry. The high-priority focus of the project will be on improving the innovation capacity of the middle - European textile industry and textile manufacturers, highlighting the need for closer cooperation in the area of waste management and circular economy in the textile sector in the region.

The partnership of the project consisted of five central European countries.

1. Italy
2. Czechia
3. Poland
4. Hungary
5. Germany

All five regions are active in the textile industry and have an international textile platform. As already mentioned, the priority areas under the programme are accelerating cooperation and promoting the use of innovative tools, for which the partnership would like to use a so-called “Virtual Platform”.The objective of this Virtual Platform is to ensure that as many textile and industry-related companies from the Central European region register and, thanks to a so-called “match-making” process, they may use waste stamped as unnecessary by another producer for their own or charitable or research purposes. In this way, it has been proven that the project will not only gain successful experience in the field of waste reduction, but it will also support the European textile industry’s networking methodology.

Pilot cases:

The transition to a more sustainable economic model that improves environmental conditions is supported by all industrial and economic areas as well as by the enter project.

The enter project identified seven “pilot cases” in the Interreg Central Europe area in order to highlight the best practices of individual industrial companies and to outline problems related to recycling. The aim is to study the difficulties of textile manufacturers in terms of recycling in order to fully understand the problems they intend to work on sustainability.

There are logistical, technical, material, social and obviously economic problems in the five countries participating in the Enter.

The consortium of the project originally identified seven “experimental cases” and it is expected that:

knowledge of technical processes and treatment methods for waste management, recovery, reuse and recycling, improved experience with analytical testing methods, development of new testing methods to identify and characterise recycled textile materials;

support monitoring systems and methods and support the study of the waste recovery model;

support the development of the M3P platform for the cataloguing, use and exploitation of industrial textile waste and waste;

Enhance the environmental awareness of companies by putting forward technical knowledge and experience on environmental sustainability and traceability of processes and products: life cycle assessment (LCA), environmental product declaration (EPD)

examine the training needs of companies in order to introduce circular models in order to develop appropriate training courses.

Thanks to the seven ‘experimental cases’, the enter project has started the process of analysing and studying production processes and using secondary raw materials, and indirectly contributes to the reduction of industrial waste for more efficient production.

However, in order to extend the project activity, the PBN considered that it would be useful to look at how it could contribute to the success of the project from a unique, innovative and modern perspective.

In today’s world, state-of-the-art techniques, such as 3D printing, play an unnegligible role. A number of important actors in the textile sector have already tried and are currently trying to implement this technology effectively.

Am-LAB, the lab for digital technologies, has already been successfully proven in several projects as a start-up of the PBN group, and the only digital innovation hub in the Central European region has all the technologies and know-how available in the area, so it can undoubtedly take on the lion’s share in pilot 8 of the enter project.

The study, which is an enter 8 pilot activity, was named “3D printing in the textile industry” and undoubtedly covers all priority areas addressed by the project and seeks not only to summarise interesting research results, but also to successfully involve several local actors in this interesting and new experiment. Among other things, it provided the opportunity to learn about the latest and stateof-the-art techniques and to test the samples produced by 3D printers printed on textiles as first in the area, to form an opinion and thus to support the technical progress of the enter project and the knowledge of the consortium.

3. 3D printing in the textile industry

3.1 Textile history

In recent years, the textile and fashion industry has been increasingly accused of being the second most polluting industry after the oil industry. This is due to the high level of CO15 emissions during production and chemical pollution, the increasing amount of litter from discarded clothes and, not least, the waste of water.

FEE Gilfeather, Oxfam’s expert, in a statement to Euronews, looked at pollution in the textile industry. According to his statement, 13 years would be necessary for someone to have the water needed to prepare a T-shirt and jeans. According to Euronews, according to the UN, industry accounts for 10 % of total waste and 20 % of waste water. According to a 2017 report by Dame Ellen MacArthur’s foundation, fashion production accounts for 1.2 billion tonnes of greenhouse gas emissions per year.

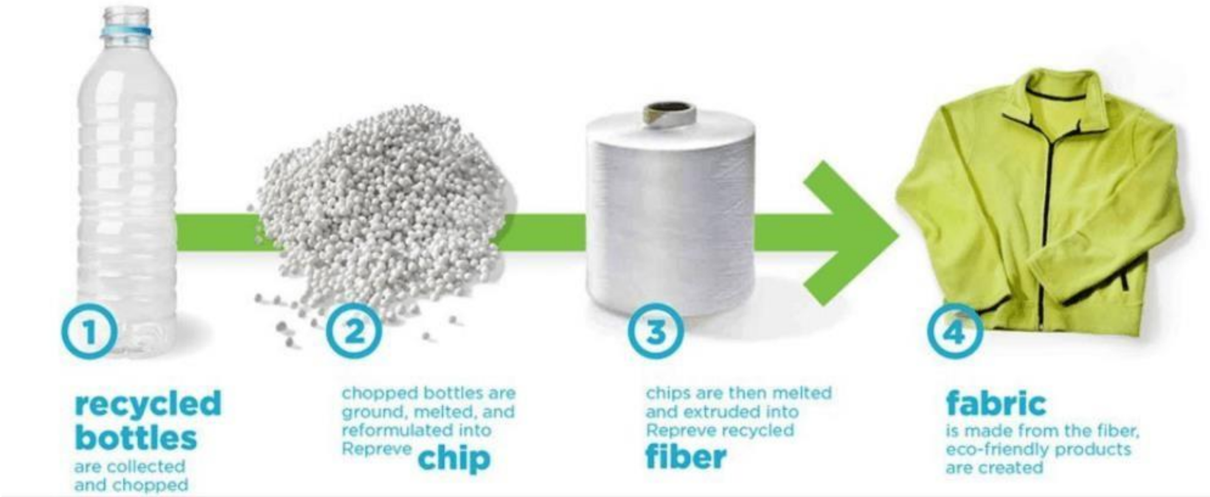
These problems are greatly exacerbated by the spread of fast fashion. This is the phenomenon of rapidly changing small-scale goods in clothing stores, as manufacturers are trying to bring the most recent branded models to consumers as soon as possible. To this end, they have their own design team for copying the samples, so that the new fashion, just published, is often available to customers within two weeks. The product is roasting, new fashions are coming and going, and even during the season, the phenomenon is being enhanced by shops. This leads to a large number of people buying new clothes in line with fashion changes, while former “valueless” odour pieces are carried out in litter. For example, H & H, Zara, Deichman, C & A or New Yorker.

Textile waste

The aim of our study is not to investigate environmental pollution caused by the textile industry, but we wanted to highlight the factors that may have led to the emergence in recent years of environmental directives, the pursuit of sustainability, participation in the circular economy concept and, as a result, experimentation with recycled or recyclable materials in the production of textiles and the manufacture of clothing.

If we go a little on this issue, we can find a number of pilot projects under the heading “Sustainability”, aimed at creating new types of textiles that can fulfil the above-mentioned objectives.

Unifi, United States, is one of the largest contributors to the production of textile fibres made from recycled materials. Until 2019, the company reused more than 19 billion plastic bottles. The recycling process starts with the collection and sorting of used plastic bottles, and the textile fibres are produced after washing, cutting, mixing and thinning, which are used to make sports and fashion goods. The name of the material produced in their own production is REPREVE, the marketing of which is based on sustainability. According to the company, the material is produced with less greenhouse gas emissions and with a lower use of water and energy than would be produced as ‘virgin’, i.e. not recycled material. Textile fibres made from recycled materials produced by Unifi are already used by 84 brand manufacturers, including brands such as Ford, Fossil or Patagonia.



Plastic recycling process

The idea of making recycled clothing from plastic litter has been followed by a growing number of companies, clothing companies, environmental organisations, celebrity and fashion designers. There are one-off initiatives, such as the campaign launched in 2014 by the composer and singer Pharell Williams to raise awareness of plastic pollution in the seas, by presenting several pieces of clothing made of recycled plastic bottles removed from the oceans, or by an action in which the entire Brazilian football team worn a messenger made of recycled plastic bottles on the last World Cup. However, in addition to the movements and initiatives, find companies whose main activity is the manufacture of clothes from recycled plastic, such as the Chinese rooted parent company of Waste to Wear, who have been producing tissues and textiles from recycled plastic bottles since 2008, and the Liar the Label brand also produces sustainably produced bath clothes from recycled polyester.

Another direction of making clothes from plastics is when the complete clothes are produced by aiding 3D printing. This is even a relatively new area of application for 3D production, but for the time being it can only be seen as attempts rather than mass production (although it is possible to find examples of production with a larger serial number), the idea of sustainability for designers has also been raised in this area, as technology is developing more and more, with the potential for re-use of the plastic materials used for 3D printing. If the material properties of recycled filaments allow it to do so, they can even facilitate multiple recycling and thus contribute to the fashion industry in a much more sustainable way, even by joining the concept of a circular economy.

However, with regard to the above vision, it is important to note that many conditions are still missing for any industry, including clothing, to function sustainably, whether of textile or plastic. Fundamentally, a change of approach would be needed to make waste recycling a central issue and a more important one, but the development of infrastructure and technology is essential for its implementation.

3.2 3D printing in the fashion industry

3D printing offers many opportunities for designers and can significantly expand the creative potential of fashion design, but its adoption and widespread use in the textile industry remains hampered. The technology is already well developed to allow easy preparation of a shoe sole or jewellery, but it is still a challenge to make complete garments that are suitable for everyday use.

3D printing allows shapes and shapes to be shaped without templates, thus producing extremely complex elements that cannot otherwise be accessed but are typically used to produce rigid, non-flexible bodies. Due to the rigidity of the materials made with this technology, most of the printed garments can only be viewed in fashion presentations and museums and are not likely to spread quickly as part of everyday wear.

One of the main challenges for designers exploring the potential of technology is how to make

3D printed pieces flexible in a way similar to traditional textiles. Although most of the printed clothes are made on the pitch for top-quality fashion, it can be seen that most pilot projects are aimed at creating practical printed materials that can be worn by ordinary people, imitating their textile properties. To this end, large brands and famous designers have also carried out experiments with various materials, structures and printing methods over the last decade. Non-exhaustively, Adidas, Nike, Under Armour, Victoria's Secret, Karl Lagerfeld, Chanel and Iris van Herpen, all fashion brands whose designers deal with 3D printed fashion.

It can also be seen from this that technology is in any case a new kind of innovation in the fashion industry. If development projects help to tackle the problems of the rigidity of materials, 3D printing could be brought closer to the goal of creating clothing suitable for ordinary people and exploiting its potential in the area of mass customisation.

In the case of 3D printed textiles, the most important issue is how to create a fully Rigid flexible, tailor-made textile. The typical mechanical properties of these fabrics also depend on the raw material used and the production technology. PLA and ABS are the most commonly used materials for the use of 3D printing and are hard materials that are difficult to bending and are therefore basically incapable of making or printing textiles or clothes, but flexibility is the most important factor in the case of printed fabrics, as without them the clothing made of it becomes unsuitable for wear. In addition, the heat-bearing and absorbing capacity, softness and elasticity, which are also characteristic of the substance, are also important factors.

One of the most obvious ways of creating an appropriate material structure is to assemble Rigid materials on the basis of a structure similar to the chaining structure, consisting of small parts which are loosely connected to each other, thus providing a flexible and flexible surface [25].

Printed suits of plastic with chain structure

The fact that the materials most commonly used for 3D printing are not suitable for printing flexible objects on their own is also a problem for many other materials, including metals, carbon fibres, glass and other plastics. It follows that the possibilities of construction, vehicle design and many other industries are limited due to the limitations of the uses of these materials.

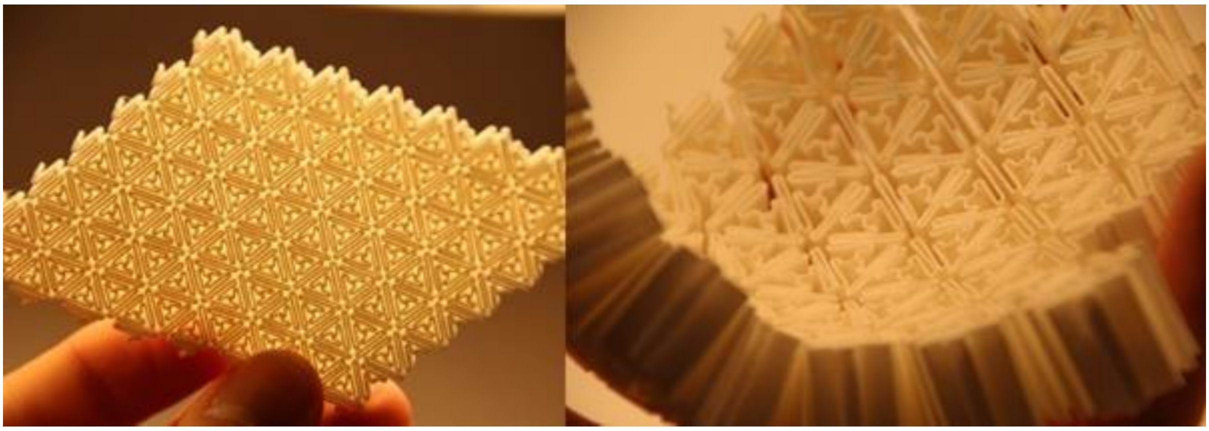
At present, the majority of composite materials in architecture are given prominence in the design of the façade. In these cases, the structure used is based on the hexagon pattern of the spleen honey, thus achieving a minimum of flexibility, but the architects' hands are still bound by the mechanical properties of the materials.

The first use of mesostructure structures in 3D printing is in the name of Andreas Bastain, currently working as a researcher at Autodesk CAD software development company in San Francisco, the State of California.

Due to their interesting geometrical construction and design, these materials exhibit behaviours that differ from ordinary materials. This is simply due to their hollow and structured training, the technological implementation of which has so far not been widespread or possible at all before testing in 3D printing.[26]

During the procedure, the physical properties of the raw material itself do not change, but only change the layout and structure of the material, thus allowing printed objects to add new physical properties. For example, the same metal used for the production of metal rods is suitable for the production of metal spirals and springs, as it has different mechanical characteristics due to different structural constructions in both cases. One is firm and strong, the other is flexible and flexible. Bastian's mesostructural procedure for plastics is based on this principle.

Andreas is currently using an ordinary FDM 3D printer to develop mesostructures, but is working on the design of a unique self-built 3D printer that is able to print mesostructural forms much more efficiently, in larger volumes and in a variety of materials. The main problem with traditional FDM printers is that the production volume is significantly limited, making it impossible to produce larger meso-structural elements. It currently designs a printer with an unlimited building axle, so that any length of structure can be printed.



Metal Structures

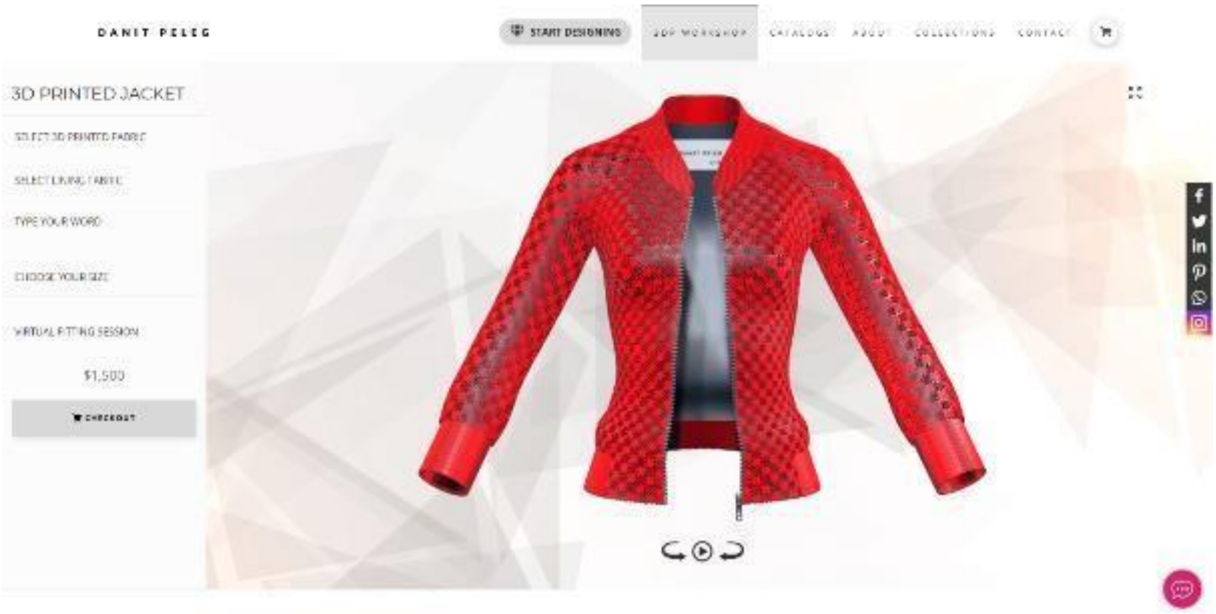
3.3 3D printing applications in clothing manufacture

One of the most famous examples of the use of 3D printing in the fashion industry is the name of Danit Peleg. In 2014, the Israeli fashion designer started working at the University of Shunkar for his degree work, examining the specific possibilities of clothing design. It then started to look more closely at 3D printing and looked for ways to create garments with this innovative technology. Its purpose was to create a simple clothing that could be made using a 3D printer that could also be used at home.

Printed clothing collation of Danit Peleg 3D

In his attempts, he first produced a 3D model of a coat using the modelling software Blender, which made it possible to experiment with various materials and printers. During the production of the coat model, several software was tested and, finally, AccuMark was able to create a fully printable model.

Following the production of the model of the coat to be printed, the printing technique was clarified. Danit spent one month experimenting with PLA, which is a hard, fragile material, so this did not lead to far-reaching, because the flexibility, which is the presentation of “genuine” textiles, is completely lacking in the PLA.The breakthrough occurred when he became acquainted with Filaflex, a new development in 3D printing, a slidewriter, strong but very flexible material. Finally, from this material, a Witbox printer was used to print out the planned red coat out of 5 separate elements.



Model of the famous 3D coat of the Danit Peleg Collection

The aim of Danit was then to examine how more complex textiles could be produced for the rest of the collection, thus starting to experiment with different samples. It then discovered the material structures created by Andreas Bastian. On the basis of these patterns, Danit made its own samples for the rest of its collection.

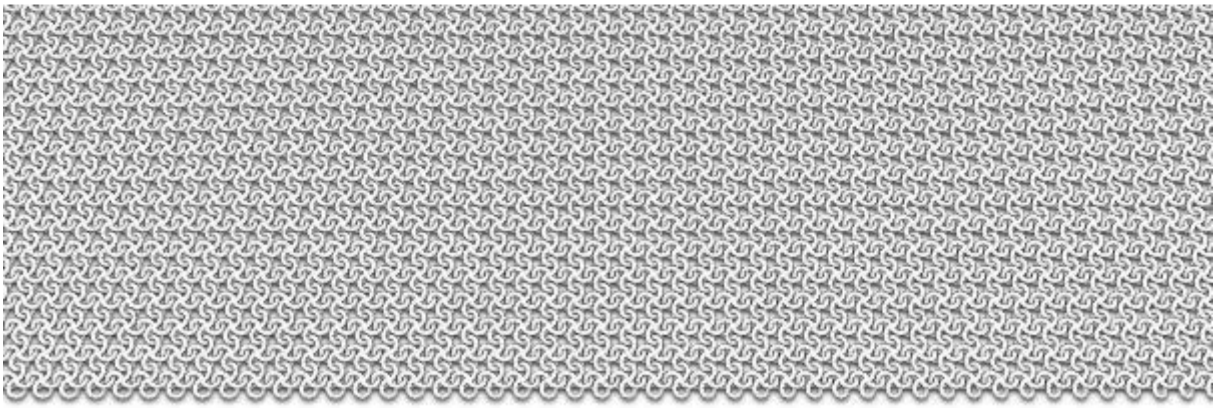
The individual structure of the coat it designs may be bought by anyone at a price of $1500, after having adapted its characteristics, colour, inscriptions and size to its own taste, making it entirely personal.

Another interesting example of the use of technology is the “drawing” of the garment. Even within 3D printing, Maartje Dijkstra used a special method to prepare his collection. With the aid of a 3D printer, the components of his garment called Suspended Animation, which were later sewn together with polyester silk fibres. The 3D pen operates on practically the same principle as the traditional 3D printers. It is injected into the end of the feather, then it is heated in the body of the feather through its tip. Maartje used a flexible filament as a raw material for the 3D pen. It aims to combine the latest technologies with the traditional fashion industry. It used raw materials of a total value of EUR 1000 for the prepared clothing.

3D-printing garments made by means of pens

A solution similar to that developed by Danit Pelege was developed by Digital Hack Lab and the University of Hertfordshire. They are jointly developed by MODECLIX, a 3D printed textile that is intended to make flexible products. They made their own sample collection from this material, but the material can be used not only to prepare clothes, but also to prepare accessories, toys and internal decoration. The purpose of the makers was to create a material that could be re-used and re-used, once in the form of clothing, then in the form of a bag, and thirdly in the form of a hat, thus reducing the amount of clothing and textiles thrown away by consumers. The MODECLIX project is an excellent example of how sustainability and environmental protection can be integrated into the 3D printed clothing industry.

The MODECLIX Collection contains a total of 8 ensembles and 2 headsets, which can be fully modified according to specific needs. The material consists of simple connecting components which, after printing, can be freely variable, dismantled and assembled into other shapes, so that it can be easily recycled, thereby extending the time of use and the life cycle of the product. It is easy to adapt and follow the shape of the wearer.



Structure of the modeclix substance

An EOS Formiga Industrial SLS 3D printer was used for printing and the plastic textile was made from white nylon powder material. The time of printing varied depending on the complexity of the material, but on average a full cloth was printed in 62 hours. At the end of the printing, the individual elements were cleaned by means of a vibratory scrubber and the clothes were assembled after hand-painting.

Julia Daviy, a fashion designer in the field of clean technology innovations, is a well-known form of efforts to make the fashion industry sustainable, with the aim of producing 3D printed clothes made of biodegradable or recyclable materials that help to reduce the amount of waste and the ecological footprint of traditional fashion methods.

3D printed garment collapsing made of biodegradable material

Opportunities and obstacles

Our study is not intended to examine the raison d'être of printed clothes made of plastic, but for the time being it can see that 3D printed clothes are not able to compete with textile clothes in many areas. So far, the expectations of traditional clothes are not met either in terms of price, practicality, convenience or production time. These disadvantages limit the mass production of printed clothes. Their greatest value for the garment industry lies in the fact that it can be used to create spectacular pieces. It is precisely for this reason that the film industry is also encouraged to make specific signs, for which functionality is not the main requirement, but a special awareness-raising view.

Despite this, the fashion industry is still trying to move towards making 3D printed clothes available to ordinary people and, thanks to the fact that people have started to become more familiar with 3D printing technology and many have even started to carry out home-based experiments with 3D printers, the idea of making home-based printed clothes has increasingly been raised.

The production of 3D printed clothes at home could ideally reduce the lead time, but the modelling and printing of individual clothes would require a certain amount of technical and product development skills that an average person does not necessarily require. According to the basic idea, home printing would take place in practice by providing the consumer with instructions on how to install and use the printer, as well as receiving the print file or simply downloading it from the internet, changing the model to be printed, making the piece of clothing completely unique.

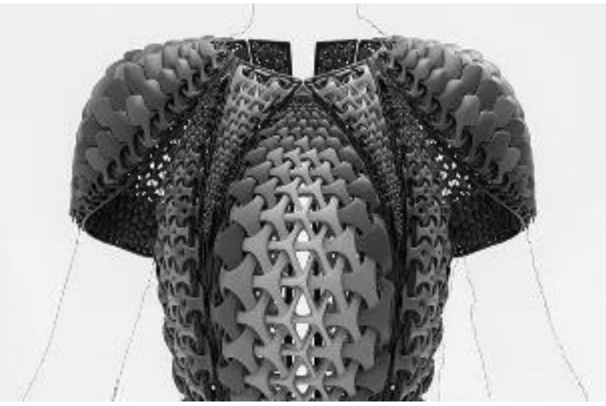
In this case, quality control may be a problem, as large brand manufacturers usually spend a lot of money to ascertain the quality of the product in order to protect and protect the brand name. In the case of 3D-printed clothes at home, the issue of guarantee may also be problematic. Even if the user does not modify the file containing the delivered clothing to be printed, it is possible that an error occurs during the actual 3D printing. If a problem arises during the process, the final product will be defective, it is difficult to determine who is responsible for it and in which cases there is a guarantee problem.

Contrary to the above concept, from a feasibility point of view, a more practical way of spreading 3D printed clothes is to develop shops with a higher 3D printing capacity to which anyone can go and print their own clothes with the help of specialist staff, instead of printing them at home.

The disadvantage of the current 3D textile printing process is that it takes a very long time, cannot compete with and is far more cumbersome than fast-fashion methods. Over time, as technology becomes more widespread, it can be expected that more and more will be competent, even at the hobbies level, so that the time from idea to production is significantly reduced [25].

At present, the printing of such a garment may take several hundred hours, depending on the complexity of the material, its pattern, thickness and other characteristics, to which the time of assembly of the various elements is added, as it is characterised by the fact that the printed clothes are not complete in their entirety but are made up of fittings that can be assembled.

The first attempt to produce 3D printed clothes was extremely lengthy, taking a whole week, with the printer operating 24 hours a day, and Travis Fitch's famous Threeasfour Pangolin was printed 500 hours.



Structure of the Threeasfour Pangolin garment

In addition, high costs limit the uptake of 3D technology in the garment industry. Neither the raw material, whether based on filaments, resins or powders, nor a 3D printer, is inexpensive in relation to the cost of traditional textiles and the cost of sewing or even a sewing machine, as well as the salaries of specialist staff, who are essential for the modelling and printing of the clothing designed to be printed.

If, as technology develops and spreads, 3D printing becomes cheaper and quicker, and a satisfactory solution is found to the problems of flexibility and flexibility, this can boost the supply and availability of printed clothes, but there are many technical issues related to the handling of the clothes.

Due to the plastic base material, printed clothes are presumed not to require ironing and could even cause problems if plastic with a lower melting point were melted during ironing, but the issue of cleaning is also relevant for these clothes, as they may be divided in the same way as a traditional cloth. It is not a matter of the basic material from which each piece of clothing is made. It is possible that a rubber-like garment made of flexible material can withstand washing by mechanical means, while a hard plastic netting cloth can only be washed by hand because it could easily be damaged during washing by mechanical means.

The question of how durable or vulnerable a printed garment will be, whether it allows the wearer to move freely, is it able to stretch according to movements, how it vents or is it able to keep the heat? If it is indeed possible that printed clothes may spread in everyday use, designers should take these issues into account during the product development phase.

So far, 3D printing has been used mostly to print solid items in the clothing industry, such as spectacle frames or shoe soles, as the industry is far from reaching the characteristics of the printed fibres. Due to the pore structure and air permeability, clothes are convenient and this cannot yet be achieved by 3D printing. This is also the reason why printed tissues are not yet available to large masses. At present, it is not possible to see that large fashion companies work with 3D printed textiles for commercial purposes, most projects are carried out on an experimental basis rather than on an occasional basis, or printed clothes are produced to the extent of one-off display items.

It is also due to the above obstacles that the use of 3D printing is mainly limited to the area of accessories, where it develops at a much higher rate than in the area of clothing manufacture. There are many examples of 3D printed shoes, watches, jewellery, bags using 3D printers [24].

However, the positive aspect of 3D printed clothing is that technology allows for the rapid testing of new elements and the reduction of material waste, as only the necessary material is used for 3D printing, is not generated, or only a negligible amount of waste is generated. In this respect, 3D printing is more environmentally friendly than traditional clothing production, which generates a lot of textile residues and wastes.

However, when considering environmental factors, it is important to note that the printed clothing industry alone will not be sustainable by making recyclable clothes if there is no person to recycle them, and taking into account that in this case the entire garment is a large piece of plastic that comes into contact with the skin on a large surface, it will not be detrimental to the possible adverse health effects of this.(This phenomenon should also be considered not only in the case of printed plastic clothes, but also in the case of traditional textile clothes, a large part of which today also consists of fibres made of a kind of plastic.

3.5 Special applications in the clothing industry

3D-printed textiles can be the first major step towards seamless clothes, but technical textiles are also expected to develop. The importance of such research lies in the fact that new types of textile structures can be used not only in the fashion industry in general, but also in fields such as medicine or military industry. A growing number of materials and technological innovations related to 3D printing are expected to be available in the near future, facilitating such developments or opening the way to new, unknown solutions. These factors all contribute to the increased production of 3D printed textile structures and their spread across several territories.

In addition, there is great potential to motivate 3D-printed clothes for the fashion world. By installing sensors or other portable technologies in clothes, it will be possible for the clothes to “communicate” each other, vary their colour according to the time taken or depending on the weather or the amount of light [40].In practical life, performance-enhancing smart textiles for military, athletic and extreme sports can be of greater benefit. Their use in practice is still at an early stage, but development is taking place to create e-textiles that control body temperature, reduce medium resistance, control muscle regaining, protect against environmental hazards by integrating electronic elements into the tissue without sewing.

In 2019, a group of chemistry created, using a 3D printer, a textile that can be used in energy control and the fibres of which are capable of driving the current. With the aid of a special nozzle, the material has been printed so that its fibres are composed of two types of materials, one with a leading core in the centre and another with an insulating heel. It is theoretically possible to create flexible, biocompatible or watertight material by using the technology with other materials.

To sum up, it can be seen that, as 3D printing is an extremely complex process, despite the high potential of the garment industry in many areas, its use is limited to areas of top-quality fashion and art. The main challenges are the rigidity of materials, environmental problems, high costs and limited accessibility, but the main question is whether 3D printed clothes have value? Perhaps not the very existence of 3D printed clothes as such is interesting, but the use of certain elements of technology, such as making the cloth with a single fibre, can innovate for the fashion industry.

Normal uses

In view of the difficulties in using 3D printing in the garment industry, we have tried to find projects and other methods where we see more sense to connect between 3D printing, recycled or recyclable plastics and the manufacture of clothing.

One of the most obvious solutions is 3D printing of buttons, press releases, buckles, cuffs and similar small pieces, usually made of plastic or metal. Many examples of this can be found on the internet, and there is only one step in printing these components from recycled filaments.

3D-printed buttons

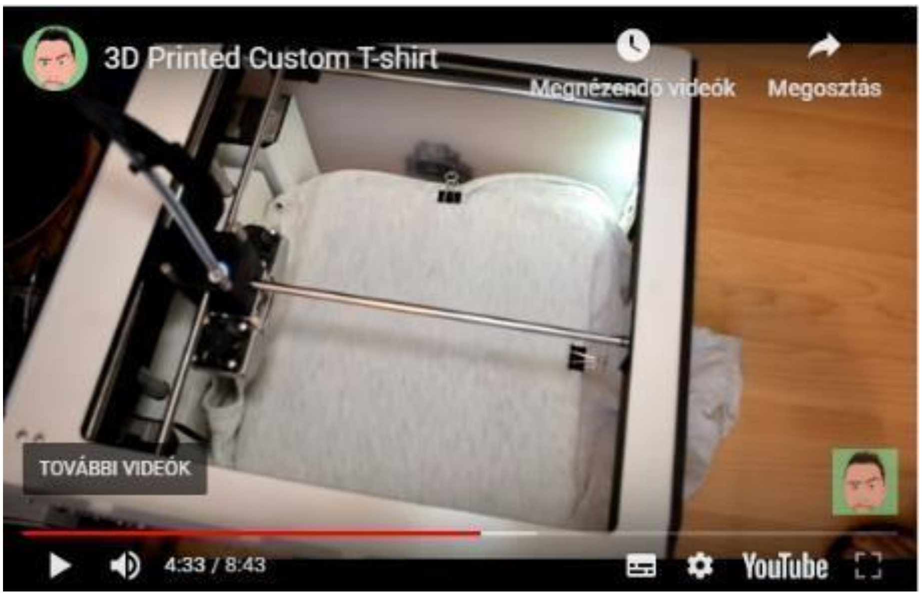
The 3D printing industry, Heisel, whose R & D activities are aimed at developing sustainable products, produced buttons by recycling the dashboard of a car that can no longer be used to recycle 3D printing.

Another possibility of application is the printing of an apparel-supplementary slide from recycled material. The raison of this can become more and more evident as recycling in the clothing industry develops. Due to the adverse effects of the textiles and clothing industry on the environment, due to pressure on them, an increasing number of garment manufacturers are starting to recycle used textiles and produce and offer new saleable products. For these products, customers may also benefit if not only the textile itself, but also its accessories, zip fasteners and other parts of buttons are made of recycled materials, such as non-conventional plastics.3D printing is well suited to printing even small elements such as a zip-fastener head, so that there are no technological obstacles to the idea.

3D-printed zip fasteners

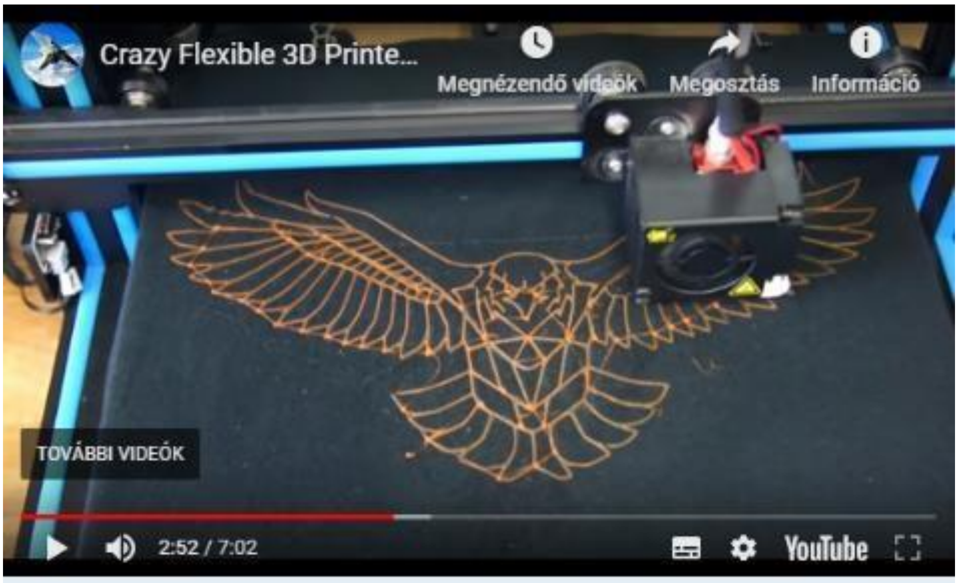
3D printers also allow the printing of completely unique decorative patterns on clothes, even from flexible materials, in order to minimise the vulnerability of the design during use.

On the subject, Simon Fontana produced a tutorial on how to make personalised decoration using 3D printing. A sticker depicting PacMan, printed on a T-shirt using PLA material with a diameter of 2.85 mm in three layers.



Affixing a T-shirt to 3D printer

Simon Sorensen, author of the RCLifeOn Youtube Canal, further developed the method and produced a video after unsuccessful attempts with hard PLA, in which NinjaFlex used flexible filament to print the 3D printed sample directly on a T-shirt. The previously used Rigid material was destroyed and cracked in the washing machine, and the idea of testing the flexible base material emerged. The challenge in the project was to ensure that the filament melts flow and melt across the fibres of the fabric. First, it printed the pattern in two layers on the garment and, at the end of the process, it found that the print could be removed from the textile too easily, even on a weak pull. He then tried to print the shape in a single layer, which proved to be a success. After successfully attaching the garment to a 3D printer and under the appropriate settings, this method also makes it possible to create completely unique samples and the basic idea is much more realistic for everyday use than complete 3D printed garments.



Affixing a T-shirt to 3D printer

Make estimations based on your practical experience. Where you have no information, think of general practices in the sector. Rate on a scale of 1-2-3. 1 is a process of slight environmental impact, 2 with a medium, 3 with a large environmental impact.

Process:						
Environmental impact	Energy consumption	Waste generation	Air pollution	Water pollution	Soil contamination / usage	Total

Value of the stage	1 – Process or method with low energy consumption	2 – Average energy consumption	3 – Large consumption	1 – Little waste, no hazardous	2 – Average waste, no specially high volumes or risks	3 – High volumes, also hazardous waste	1 – No air pollution at this stage	2 – Some air pollution, but not considerably high	3 – Considerable air pollution	1 – No water pollution at the stage	2 – Some air pollution under control, (treated)	3 – The process often pollutes water, or high risk of that exists	1 – No potential to contaminate soil	2 – The process potentially pollutes the soil, but it is not likely	3 – Frequent occurance of normal or accidental soil contamination	Sum up the values in the row
Stages	Before/After			Before/After			Before/After			Before/After			Before/After			
Extraction of resources	1/3			1/3			NR			NR			NR			/
Transport of resources	1/3			1/3			NR			NR			NR			/
Storage of resources	1/3			1/3			NR			NR			NR			/
Manufacturing, assembly	1/3			1/3			NR			NR			NR			/
Storage of finished products	1/3			1/3			NR			NR			NR			/
Use, useful life	1/2			1/2			NR			NR			NR			/
Waste transport	1/3			1/3			NR			NR			NR			/
Waste disposal	1/3			1/3			NR			NR			NR			/

3.1. Conclusions

Filaments with different levels of recycled plastic have been tested and compared in the FDM technology of 3D printing. In total, 504 samples were mechanically tested. A Charp impact test of 216 samples, a tensile test of 216 samples and a bending test of 72 samples of 3 points were carried out. Summarising the results and experience of mechanical measurements and examining the distributions of the measured data graphically according to several criteria and presentation methods, the following relationships can be derived:

The nominal longitudinal dimensions of the samples could be returned with the smallest defect on the products manufactured on the Czech 3D printer Prusa i2 MK3. Here, the measured values are scattered around the nominal, drawing value.

The Dutch printer Ultimaker 3 Extended was able to return the nominal longitudinal dimensions of the samples with the highest degree of precision depending on the selection of the individual raw materials. Here, however, the measured values are not scattered around nominal values, so it is recommended to fine-tune the printing parameters.

The Z-directional height of the samples was also best produced around the nominal design value by the Czech printer Prusa i3 MK2.

The slicer programs of the three FDM type 3D printers have printed samples of different weights for different alignment possibilities. The samples produced on the Dutch printer Ultimaker 3 Extended were the least weight samples in distribution, while the samples produced on printer Prusa i3 MK2 were the samples produced on the highest weight in total.

The effect of statistically significant differences in mass distributions is not reflected in the suction to impact, but in the tensile strength and elastic modulus values. The samples manufactured on the Ultimaker 3 Extended printer were the weakest, while Prusa i3 MK2 was the strongest samples against the tractive loads. This may of course have been influenced by other settings of printers (print speeds, material recycling settings, etc.) in addition to the weights of the samples.

The measured and derived mechanical parameters of samples of the type Extreme Builder 1000 manufactured on the Dutch industrial FDM printer provided the lowest standard deviation, i.e. this printer was capable of producing the most reproducible mechanical parameters.

In line with our initial expectations, increasing the thickness of the printing layers has on average reduced the values of the measured mechanical parameters, but on several occasions, this is dependent on raw materials and printers.

In line with initial expectations, we obtained stronger samples on average (positive correlation) by increasing internal filling (infill), but this is also dependent on material and printer selection in detail.

Contrary to initial expectations, no increase in the mechanical parameters with a slight increase in the printing temperature (zero correlation) has been observed, but an in-situ maximum of the measured mechanical parameters has been observed at 200 °C over the temperature range considered.

Contrary to initial expectations, the drying of raw materials (filaments) did not lead to any significant improvement in mechanical parameters.

Contrary to initial expectations, recycled plastics did not fulfil weaker mechanical parameters compared to 'original' plastics that do not contain recycled plastic. Although the image is mixed, for certain parameters where one and the other material were found to be stronger, for several settings, samples manufactured from fibre containing recycled plastic showed better mechanical parameters. Thus, the use of recycled plastics is a reality. Neither did they behave worse during 3D printing, nor did we see in their mechanical behaviour that they fell short of the original filaments recommended by the manufacturers, which in principle did not contain recycled plastic.

However, the fact that mechanical tests have given such a variety of results, that one substance and the other substance have acted better, unfortunately the reasons for this have not been revealed in the context of the present research. However, we see an interesting opportunity that the issues raised here could be identified in the case of a larger number of studies, where a specific description of these links would be targeted.