twin revolution

Twin digital and green transition for furniture and textile industries

Twin transition in the manufacturing sector

A blueprint

Co-funded by the European Union

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Table of Contents

List of figures

List of tables

About TWIN REVOLUTION

The TwinRevolution project supports Vocational Education and Training (VET) learners from the textile and furniture industries on their twin transition journey. By improving their digital and green skills, the project wishes to prepare professionals from both industries to meet the requirements of a sustainable, circular, and digitally enabled industry.

The TwinRevolution project will develop the following results:

- A BLUEPRINT ON TWIN TRANSITION IN THE MANUFACTURING SECTOR: The Blueprint will bridge key enabling technologies with circular strategies to be implemented in textile and furniture industries; compile and analyse European policies that influence the twin transition and the current approach in VET offer; and define the necessary learning outcomes to reskill current and future workforce.
- A JOINT CURRICULUM ON TWIN TRANSITION IN THE MANUFACTURING SECTOR which will define the necessary learning paths to ensure knowledge acquisition, grouping key skills and competences into a set of training modules and units.
- A PORTFOLIO OF TRAINING MATERIALS ON THE TWIN TRANSITION FOR THE MANUFACTURING SECTOR. These online materials will be defined and developed to cover the knowledge gap for a successful green and digital transition.
- A DEDICATED E-LEARNING PLATFORM, which will host the learning materials.

For more information, go to www.twinrevolution.eu

Executive Summary

Although the twin digital and green transition is one of the main priorities of the EU, there is a lack of knowledge on how both transitions could act as complementary drivers for the traditional manufacturing industry, nor guidance on how to transfer this knowledge gap to the existing VET system.

The TwinRevolution project aims to set the ground and update VET systems for the current and future manufacturing industry to be aligned with the twin digital and green transition.

The report offers an overview of the current challenges faced by the textile and furniture industry and details how circular and digital strategies can support the transformation of both sectors. Best practices examples from both industries illustrated how smart and circular approaches can accelerate the transformation of these two sectors.

Following a literature review detailing the current state of industry 4.0 and circular economy in both sectors, the report highlights how specific Key Enabling Technologies can support a twin transition.

In this blueprint, we highlight eight industry4.0 technologies with great sustainability relevance:

Internet of things

Considered the most integrated digital technology for Circular Economy, IoT is useful to collect data during the product life cycle, tracking product flows from the design to the end of use, which can be applied for a better use of resources (product design) and the optimization of disassembly processes.

Big data & analytics

Big data and analytics, closely linked to IoT, serve the circular economy through their potential to optimise processes and enhance decision-making, using the data collected from the IoT to improve resource management across the entire product life cycle.

Simulation

Simulation can be exploited to virtualize/optimise different processes, such as disassembly processes, before replicating them in the real world. Thus, it is possible to analyse how some processes could be implemented and their respective level of sustainability.

Robotics

The implementation of robotics in manufacturing industries allow to employ robots in an increasing number of applications that could be aligned with CE practices, such as facilitating waste sorting and disassembly and remanufacturing processes.

Additive manufacturing

Additive manufacturing allows for circular design, introducing new materials (including recycled materials) and designs that facilitate product repair. Due to the additive process, it contributes to waste reduction, reduction of handling and transportation activities, and lower energy consumption.

Augmented and virtual reality

Augmented and virtual reality act as virtualization tools, that facilitate the redesign of more repairable and modular products thanks to the simulation of alternative concepts.

System integration

Cyber-physical systems could contribute to the internet of things, as the continuous real-time exchange of data via virtual network, allows the use of resources (material and/or energy) in a more efficient way. Thus, it is possible to inform customers about the different components of a product in order to ease their disassembly or recycling.

Artificial intelligence

Artificial intelligence can enable circular economy innovation across industries fostering circular design, through iterative machine-learning-assisted design processes that allow for rapid prototyping and testing. Moreover, artificial intelligence can also support the implementation of new circular business models, such as product-as-a-service and leasing, by combining real time and historical data from products and users. Finally, artificial intelligence can improve the reverse logistics tools necessary to close the loop of materials by boosting sort and disassemble, remanufacture, and recycle processes.

The implementation of these promising technologies to support a circular economy is not without barriers: different development speed between sectors, lack of standardisation across Europe, outdated waste management regulations, economic barriers, and lack of incentives to use secondary materials, as well as societal barriers are some of the reasons that hinder the full implementation of a twin transition. Beyond these systemic challenges, a successful transition should also take into account the risk of rebound effects minimising the sustainable potential of such innovative technologies.

Socially, the digital and green divide should be at the centre of the preoccupations towards a twin transition. As there is already a growing gap between highly skilled specialists who can use complex technologies and low skilled workers who might get unemployed because of automation, investing resources in upskilling the current workforce to the challenges of such twin transition remains a top priority. Improving the knowledge, skills, and competences of both the textile and furniture sectors to navigate this multi-sectoral green and digital revolution will therefore ensure that this transition is also socially sustainable. This is the objective of the TWIN REVOLUTION project, which will in a later phase translate the key learning outcomes identified in this report into a joint training curriculum detailing the learning pathways to be taken by the industry to successfully transition towards a smart and circular future.

1. Introduction

1.1 Context

The Green Deal, the European Commission Plan to work towards a climate neutral society, is expected to transform the EU into a resource-efficient and competitive economy. The plan outlines that digital technologies are a critical enabler to meet EU sustainability goals. Likewise, the new industrial and digital strategy *Shaping Europe's Digital Future* reflects the necessity to deploy new technologies to enable this change.

Accelerating the twin - *green and digital* - transition will not only require new technologies but will rely on a reskilled workforce: the European Skills Agenda and the Council Recommendation on VET has already expressed the necessity to update current VET programmes to meet industry needs on digital and green skills, while at the same time introducing innovative learning and teaching methodologies.

This necessity has become a key issue in fragmented and traditional industry sectors such as the Textile and Furniture sectors, as pointed in the "*SME strategy for a sustainable and digital Europe*". Europe has strong traditional manufacturing industries that were not born digital, nor adapted to a green economy. The twin transition of these industries will therefore require large investment in innovation, while simultaneously reskilling its workforce to ensure a successful transformation.

Among EU manufacturing industries, the furniture and textile are examples of traditional and fragmented sectors, with more than 90% of SMEs. According to Internal Market data, the furniture and textile industries are two labour-intensive sectors that employ a total of 3 million workers and generate an annual turnover of around EUR 262 billion. Despite this, their index of innovation, according to Eurostat, is lower than other manufacturing industries. Thus, a higher effort on their digital and green transition is required.

A Twin Revolution is required.

Although there is an increasing focus on digital and sustainable innovation within the textile and furniture sectors, there is still a striking gap in reaching the transformative potential of these two industries. As the furniture and textile industries are generally based on traditional SMEs with lower capacity of innovation and an ageing workforce, there is a pressing need to build new capacity and introduce innovative practices for a twin transition, in order to produce and design with less waste and with new sustainable materials.

1.2 Objectives

Although the twin digital and green transition is one of the main priorities of the EU, there is no specific report or blueprint that analyses how both transitions could act as complementary driver for the traditional manufacturing industry, nor guidance on how to transfer this knowledge gap to the existing VET system.

The TwinRevolution project thus aims to set the ground to update VET systems for the current and future manufacturing industry needs on the twin digital and green transition.

More specifically, the report aims to match current industry4.0 technologies with circular economy strategies, in order to analyse how to connect them in a complementary and win-win implementation. This blueprint will be used to frame how both concepts can be integrated in VET training.

2. Methodological approach

The literature review consisted of four stages: formulation of the central research scope, selection, and evaluation of studies; content analysis of selected articles; and description of the results. The literature review steps, and the selection results are presented in figure 1. below.

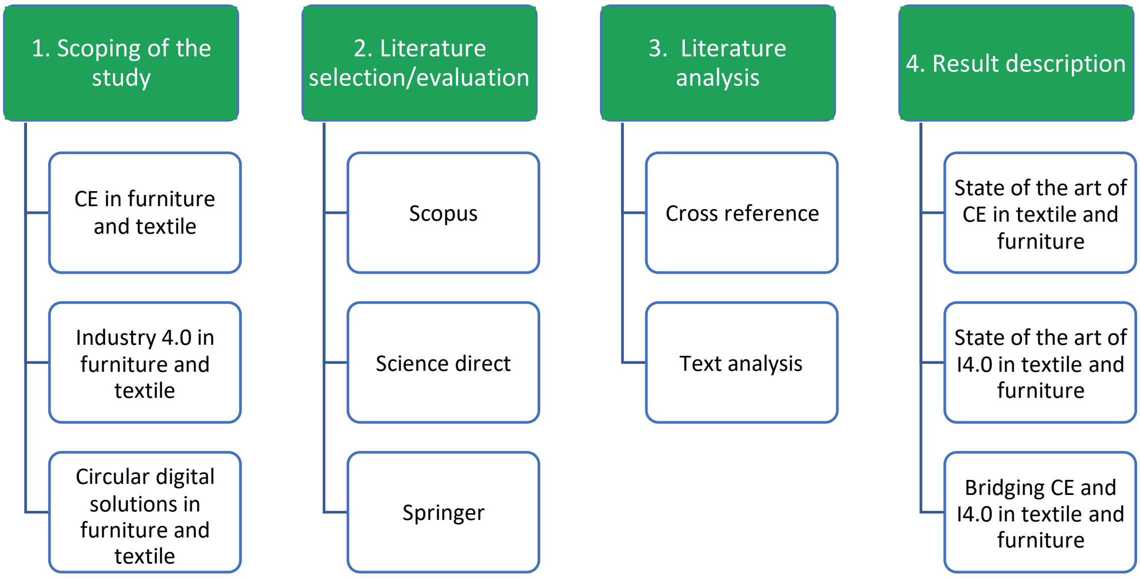

Figure 1: Methodological approach

The first step was to frame the scope of the study:

- Get an overview of the current level of implementation of CE as well as barriers, challenges and obstacles for the furniture and textile sectors.
- Get an overview of the current level of implementation of industry 4.0 in the furniture and textile sectors.
- Address how both digital and green transition are being tackled simultaneously in both sectors.

A literature review was then deployed to locate relevant studies and to evaluate their respective contributions. Electronic databases, including Elsevier (sciencedirect.com), Scopus (scopus.com) and Springer (springerlink.com), were used. The research used classifications for the nature of the objectives, including exploratory and descriptive inductive logic, with data collection from primary and secondary sources using a qualitative approach.

For the search of literature, we used “circular economy” “manufacturing” “furniture” “textile” “Industry 4.0” in different combinations of keyword strings.

In the second step, we conducted the search, considering only scientific papers from journals and reviews related to the environmental and social sciences, engineering or management that were available in English. In the third step, only titles primarily related to the topics of CE and Industry 4.0 were considered, and the authors reviewed the summaries and read the articles of all relevant texts, adhering to the themes mentioned above.

The results of the analysis are presented in the next chapters.

3. Furniture and textile sectors at a glance

3.1 Furniture sector overview

The furniture and wood industry has evolved throughout history by adapting the product to new materials and technological advances that appear on the market. That is why the evolution of this industry depends on the **economic situation**, which is related to the knowledge and availability of production technologies, advertising, design, business cooperation or raw materials. On a global level, the evolution of this industry began at the end of the 1950s and reached its peak in the early 1970s [1].

Today we can say that the furniture industry is concentrated in certain countries (China, USA, Italy, and Germany). The **furniture industry is a labour-intensive sector dominated by small and medium-sized enterprises (SMEs) and micro firms**, among which there is a strong fabric of family-owned companies that carry out generational management changes.

Covid-19 has severely impacted global furniture trade growth in 2020 – yet recovery is imminent, according to CSIL (Centre for Industrial Studies). **Global furniture production in 2020 was worth $420.000 million**, down almost 10% from the previous year [2]. Almost half of the world's furniture production in 2020 was in China. The leading **importers of furniture** are the US, Germany, France, the UK, and Japan. In the last 10 years, the international trade of furniture has consistently amounted to about 1% of the international trade of manufactures [3].

Furniture manufacturers in the European Union are highly regarded thanks to a number of factors, including job creation, **as the sector employs around 900.000 workers** in **120.000 companies**, generating an **annual turnover of around 92.000 million euros** [4]. On the other hand, European furniture is recognized due to its **product quality**, as approximately two out of three high-end furniture products sold in the world are produced in the EU, which reinforces **leadership of EU furniture manufacturers** in setting **global trends** [5].

Europe is ***the world's second largest furniture market***, with 26% of global consumption, second only to Asia-Pacific (43%) and larger than the North American market (23%). In contrast to the U.S. market, the European market is more dependent on domestic production, as more than 80% internal furniture consumption comes from European manufacturers [6].

Italy is the largest furniture producing country in the European Union with a production value of 22.365 million euros, followed by Germany, France, Spain, and the Netherlands [4].

Challenges, opportunities, and trends of the sector

"Future success in the furniture industry will be about setting up circular business models, making use of digital design & manufacturing tools and finding ways of using sustainable materials!"

Dr. Sascha Peters (Haute Innovation)

EU furniture manufacturers have a good reputation worldwide thanks to their creative capacity for new designs and responsiveness to new demands, about 12% of designs registered in the European Union Intellectual Property Office come from this sector. The industry is able to combine new technologies and innovation with cultural heritage and style and provides jobs for highly skilled workers [5].

Several challenges are currently faced by the industry [7]:

- Competition: the EU furniture sector faces enormous competition from countries having low production costs. China's penetration into the EU market is growing rapidly and it is now the largest furniture exporter to the EU and the main furniture producer.
- Innovation - the reliance on innovation and design combined with an increase in global trade and digitalisation, makes the sector more vulnerable to weak protection of intellectual property rights. Boosting research and innovation also requires finance that is often inaccessible to SMEs.
- Green and Digital Skills: The green and digital skills needs are also important for the industry since there are specialised and non-transferable skills. In

addition, the ageing workforce combined with difficulties in attracting young workers may lead to disruptions in maintaining skilled workers and craftsmanship.

The EU furniture sector has undergone significant changes focusing on upgrading quality, design, and innovation. These changes include restructuring, technological advances, and innovations in business models.

Several **opportunities** can be highlighted [8]:

- **Investment:** Investment in skills, design, creativity, research, innovation, and new technologies can lead to new products in line with changes in population structure, lifestyles, and trends, as well as new business models and supplier-consumer relationships.
- **Research:** Demand for high technology and knowledge intensive jobs is growing and the research in advanced manufacturing technologies can result in the creation of specific jobs which would give the sector the attractiveness it needs to attract younger generation employees. This could help rejuvenate the sector and keep it highly competitive on the global stage.
- **New market opportunities**. Opportunities for the EU furniture sector to seize other markets at global level (e.g., Russia, China, the Gulf area), in particular in high-end segments and emerging economies.
- **Synergies**: Opportunities with construction and tourism could also be exploited, building on the sector's excellent sustainability track record. In particular, the use of sustainably sourced raw materials in furniture production could have a positive impact on sales among environmentally conscious end-users.

In terms of the **main trends** identified in the furniture sector, several trends can be highlighted [9]:

- **e-commerce:** More demand for furniture via e-commerce due to customers are making the switch to shopping for furniture online as brands discover ways to showcase their furniture products in innovative and visually appealing settings using advanced technology like augmented reality.

- Sustainability: Many brands are focusing on developing end-to-end sustainable furniture products to meet the wants and needs of an exponentially growing customer base.
- Digitalization of the Manufacturing Process: With the rise of customisation, furniture manufacturers must also ensure they have the right tools in place to manage all configurations to produce error-free made-to-order parts. For many, this means adding certain technologies, such as digital printing and automated nesting, that will help them eliminate stock issues, reduce costs, and improve material utilisation.
- Smart furniture: Smart furniture, which enables a range of functional activities such as charging mobile devices, surfing the internet, listening to the news or radio, and more, is a rapidly growing market and is considered by many to be the future of furniture.

3.2 Textile sector overview

The European textile and clothing industry (T&C) includes 160,000 companies (of which 99% are SMEs), employing 1.5 million people and generating a turnover of €162 billion [10]. The sector has been showing a continuous increase in sales since 2010, which is due to the ability to offer the required products and high quality of goods, but also due to the development of innovative capabilities of companies. These are gradually becoming the most strategically important parameters, which will affect the long-term success of the industry as a whole.

The T&C sector covers a long supply chain: from fibres into yarns, into fabrics and into final products in textiles and apparel, some of which are strategic for the European economy. The sector also embraces textiles related services, textile care and labelling. T&C supplies other industries, including healthcare, agriculture, construction and automotive and is closely connected to the creative industry. Significant technological advances, successful pilot demonstrations and subsequent rapid industrial adoption in the broad areas of research and innovation will allow product, process, service innovation leading to a real 4.0 industrial revolution and digitalization.

But innovation itself must be constantly emphasised at both national and European level to become more competitive. Other economic, administrative, and marketing measures are also preconditions for development, which will allow to put research results into practice and bring them to market.

Quality & innovation are the main drivers for the EU T&C competitiveness, as confirmed by the number of patents (1303 at EU level, compared to 869 for China or 692 for the US) or industrial designs (over 200,000 for the EU; less than 50,000 for the US and 20,000 for China).

Currently, T&C industry is challenged for its environmental impact, in particular its use of natural resources, application of hazardous chemicals and significant amount of textile waste. This challenge is described in the next sections.

Since 2020, the pandemic situation has shaken the foundations of the textiles, apparel, and fashion industry. Global supply chains have been disrupted, retailers are restructuring their sourcing options, consumer behaviour is changing.

Challenges, opportunities, and trends of the sector

The future development of the textile and clothing industry depends on a number of technological as well as non-technological factors. Although global textile production is expected to grow in the future, the direction of this growth will be determined by the key challenges and trends that global society faces.

To define possible scenarios of development of T&C industry, it is possible to take into consideration current development trends, which will build /form the close future of the sector at national as well as at European level [11].

Social trends - Population´s aging

Demographic trends have long confirmed the aging of the population. By 2050 more than 30% of the population will be older than 65 years. The costs of daily care and improving the quality of life of seniors will place increasing demands on public health services. This will increase demand for new types of products and services for seniors in which textile will be required (everyday care, medical textiles etc.).

Lifestyle trends - Purchasing power of younger generation/customization

New technologies enable a high level of individual production, including changes in supply chains in the product category for the consumer market (B2C), driven by the fashion and functional comfort of textile products. Young people demand for SMART products, customised products, and services.

Technology trends

Industry 4.0 and digitalization will increase the functionality of production infrastructure. New technologies (internet of things, automatization of production process etc), smart products and services, will increase the demand for innovations and require more and more highly qualified staff [12].

Economic trends - Custom production, need for specialised production

The impact of these trends will be translated into high demand on know-how, high integrated approach to research and development and multidisciplinary cooperation between companies, universities, and research centres. This will create new opportunities for the development of new business models and new production approaches.

Companies will compete for highly skilled workers, as the supply of skilled workers will not match demand. To grow their competitiveness, companies will need a wide range of highly qualified staff and special know-how to meet the specific needs of the market. An acute shortage of middle technical management will need to be filled. Attention needs to be paid to maintaining the "know-how" associated with the generational change and restructuring of the sector.

Economic trends - Increasing the production of textile products for other application industries (electrical engineering, health, construction, automotive, agriculture, environment, aviation). In order to maintain a competitive advantage, production will respond sensitively to changes in demand and at the same time flexibly ensure rapid configuration of its products according to the requirements of other application industries. The trend expects a significant shift in diversification of production in smaller series.

Environmental trends

Global increase in raw materials and energy demand will have to be counterbalanced, with circular economy strategies, R&D in new materials, efficient new technologies for saving water, energy, and chemicals as well as new business models.

Political/legal trends – Government regulation, market regulation

This trend is nowadays closely tied with environmental requirements and the social responsibility of production companies. Responsible institutions have to cooperate with public bodies on the development of regulation frameworks, new standards, new tools, new business models. In the textile and clothing industry, new regulations are oriented towards compliance with health and safety standards both for the customer and the environment (REACH, emission limits, potential sanctions for waste production…).

4. Circular Economy in the textile and furniture sectors

4.1 Circular economy overview

Our current - take make waste - linear model is highly unsustainable and requires us to move forward with a sustainable way of conducting business and generating societal wealth. A more sustainable alternative, called the circular economy (CE) is seen as a viable option to replace the linear model. According to the European Union, CE is a model 'where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised' [13].

A circular economy describes "an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations" [14].

CE is based on three principles that outline the steps needed to achieve a fully circular system:

- Eliminate: Design out waste and pollution - The CE is a system where waste no longer exists, products are purposely designed to be disassembled and reused. Because waste no longer exists, pollution is also eliminated from the system.
- Circulate: Keep products and materials in use - To reach the goal of a waste-free system, the CE requires a shift in creation and consumption habits. We are moving from the "take-make-waste" mentality towards finding ways to keep products and materials continuously in use, thus "closing the loop."
- Regenerate: Regenerate natural systems - The CE aims to be a regenerative system, giving back to the environment by avoiding non-renewable resources and protecting and enhancing renewable resources.

At a more operational level, CE aims to reduce resources consumption by *slowing, closing, and narrowing* resource loops [15].

First, resource efficiency or "**narrowing resource flows**" requires the adoption of new processes to reduce the use of natural resources. It includes the first R principle (*Reduce*) in a wide sense. This reduction aims at minimizing the input of primary energy, raw materials, and waste, by improving efficiency in production (called eco-efficiency), as well as in the processes of consumption. This is achieved by introducing better technologies, making products more compact and lighter, simplifying packaging, having more efficient appliances, or simplifying the style of life.

The second strategy aims at "**closing resource loops**." In this case, the firm aims to close the loop between post-use and production stages looking for a circular flow of resources. Through different actions such as recycling, reuse, or recovery, firms attain to make their production processes more circular.

Recycling offers the opportunity to benefit from and reduces the amount of waste that needs to be treated or disposed of, reducing the corresponding environmental impact.

The principle of *Reuse* refers to "any operation by which products or components that are not waste are used again for the same purpose for which they were conceived". The Reuse of products means the use of fewer resources, less energy, and less work compared with the manufacture of new products from raw materials. *Circularity* also means adapting industrial processes through efficiency in energy consumption (using renewable energy and not only recycled materials).

Finally, the third type of strategy is associated with "**slowing resource loops**" that requires the design of long-life goods and product-life extension through remanufacturing and reparation. It consists of the design of new products or redesigning existing ones to make them more efficient throughout their life cycle.

The aim is to achieve goods and services that require: (1) fewer resources, and wherever possible renewable and/or recycled; (2) quality components that allow for longer product life, and (3) a design easier to maintain, repair (with the availability of parts), upgrade and recycle, whether for the original purpose or any other.

Opportunities and challenges implementing a circular economy

Implementation of the CE concept is a challenging task given the prevailing linear mindset and structures in industry and society [16]. While the benefits for the natural environment are simple to grasp and understand, the economic benefits in the context of CE are more complex to envisage. Despite existing success stories of circular system implementation in industry, large scale implementation needs radical change in the way businesses operate and requires commitment from higher management in industry.

Currently, industry is faced with a duality of opportunities and challenges to implement a CE [17]. The potential sustainability and business benefits from adopting a circularity mindset in industry are significant. In Europe alone, the business benefits linked with CE are estimated to be ca. 1.8 trillion Euro per year up until 2030 [18]. Nevertheless, despite the increased interest in CE implementation and the large amount of research and governmental incentives, companies still face challenges in successfully implementing CE. Challenges faced by manufacturing companies are connected to:

- Systemic nature: creating a CE requires fundamental changes throughout the value chain, from new business model innovation, product/service design and production processes all the way to consumption patterns and end-of-life scenarios
- High complexity: new uses of existing material flows increase the boundaries and the complexity of circular ecosystems. Furthermore, the evaluation of the sustainability performance of CE systems presents high complexity.
- High risks: the systemic nature and high complexity of CE also leads to high risks in the implementation of CE businesses
- Multi- and inter- disciplinarity: the complexity and novelty of CE requires the combination of several disciplines, such as natural sciences, engineering,

business, economics, and management which takes extra effort to orchestrate.

- Lack of knowledge: a successful CE implementation in companies requires new knowledge, capabilities, and skills (e.g., ranging from material composition to social behaviour).

4.2 Circular economy in the textile sector

Textile is part of our everyday life. Most often we use it as clothing, but it can be found all around us. The consumption and production of textile products tends to grow steadily, and with it the impact on climate, water, energy, and the environment. Global production of textile products almost doubled between 2000 and 2015 [19] and consumption of clothing and footwear is expected to increase by 63% by 2030, from 62 million tonnes today to 102 million tonnes in 2030 [20].

In the EU, the consumption of textile products, which are mostly imported, now has on average the fourth largest negative impact on the environment and climate change and the third largest negative impact on water consumption and land use in terms of total life cycle [21]. Approximately 5.8 million tonnes of textiles are discarded in the EU each year, or approximately 11 kg per person [22], and one truckload of textiles is landfilled or incinerated every second somewhere in the world [19].

The largest part of textile produced in the EU is focused on clothing (81%) (JRC, 2021). The garment industry contributes to unsustainable patterns of overproduction and overconsumption of garments that are only used for a short time and then thrown away. Growing demand promotes inefficient use of non-renewable resources, where reuse and recycling of textile fibres into new fibres is not ensured, which is an integral part of a linear economy.

Therefore, a new circular textile economy model is needed. To achieve a circular economy, the systems set up will have to change. The transition to a circular economy requires a rethinking of production and consumption. Products placed on the market should have a long lifetime and be recyclable. Products should be made from a high percentage of recycled materials, with both environmental and social rights being taken into account in production. Clothing products should be designed in such a way that they can be repaired or effectively recycled. Fast fashion will no longer be fashionable for consumers, but will be replaced by high quality, affordable textiles with a longer shelf life. Furthermore, cost-effective repair services and, where appropriate, alterations to a more fashionable look will be widely available. Emphasis should be placed in particular on extending the lifetime of garments to reduce pressure on resources, minimise the burden of chemicals on the environment, and reduce the burden of transport.

The garment industry could implement various strategies with the aim of achieving a circular economy with a zero-carbon footprint.

4.2.1 Circular strategies in the textile sector

4.2.1.1. Eco-design

Ecodesign, as defined by Eu directive 2009/125/Ec[1], focuses on incorporating aspects of environmental sustainability into product characteristics and processes throughout the product's value chain. In the context of textile, Ecodesign focuses on the principles that fashion brands, stakeholders and customers must consider environmental impacts throughout the life cycle of the garment.

Product design plays a key role in achieving this goal. Currently, 60% of products are discarded due to poor quality or product failure. Emphasis should be taken when designing the product to transform the garment from a fast fashion to a higher quality long lasting garment designed with the minimum impact on the environment.

Ecodesign considers environmental aspects at all stages of the product development process and aims for products that have the least environmental impact throughout the product life cycle, where economic aspects are also considered [23].

[1] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0125

As an illustration, the designs by Lada Vyvia meet all these requirements. The designer has applied nanotechnology to her garments with timeless designs that promote the longevity of the clothes. Nanotechnology adds functionality to clothes and reduced the need for washing.

Figure 2: Lada Vyvia Lova [24]

Ecodesign approaches can incorporate materials that would have been discarded otherwise to produce new fashion accessories. Industrial waste such as leather, tarpaulin, etc. can be upcycled to create new items.

A multitude of designer apply upcycling principles in their production. For instance, Kave sneakers are made from waste and residual materials locally in the Zlín factory, on Baťa machines from the first half of the last century with the help of existing equipment only.

Figure 3: Kave footwear [25]

Similarly, Medence re+concept bags are largely made of carefully selected, cleaned recycled and upcycled industrial raw materials, with local production, in the spirit of slow design.

Figure 4: Medence design [26]

4.2.1.2. Material innovation

The global fibre market is very intense and has a strong upward trend with. 111 million metric tons being produced in 2019, double the production from 20 years ago. The fibres that are used in clothing can be divided into two basic groups, namely natural fibres that are derived from plants including trees, animals, and insects. The second group are man-made fibres obtained by a chemical manufacturing process from natural or synthetic polymers. The largest proportion is currently polyester fibres.

Fibres make almost 98% of finished clothing. The 73% of fibres used in clothing ends up either in landfill or an incinerator with only 12% recycled [27]. Fibres are small and are exposed to rough processes during recycling which damages their quality, and thus only 1% of the recycled fibres can be utilised again in clothing. Most of the recycled fibres can only be used in other functions such as cleaning cloths, carpets, mattress stuffing, and related functions, which itself is a challenge as the quality is lost [28].

However, as a solution, new fibres can be readily blended with old recycled fibres to strike the right balance between quality and sustainability. In the case of synthetics, such as polyester, the fibres can be chemically broken down to their chemical building blocks and later melt-spun into new fibres with exactly similar properties as the new virgin fibres entering the circular loop [29].

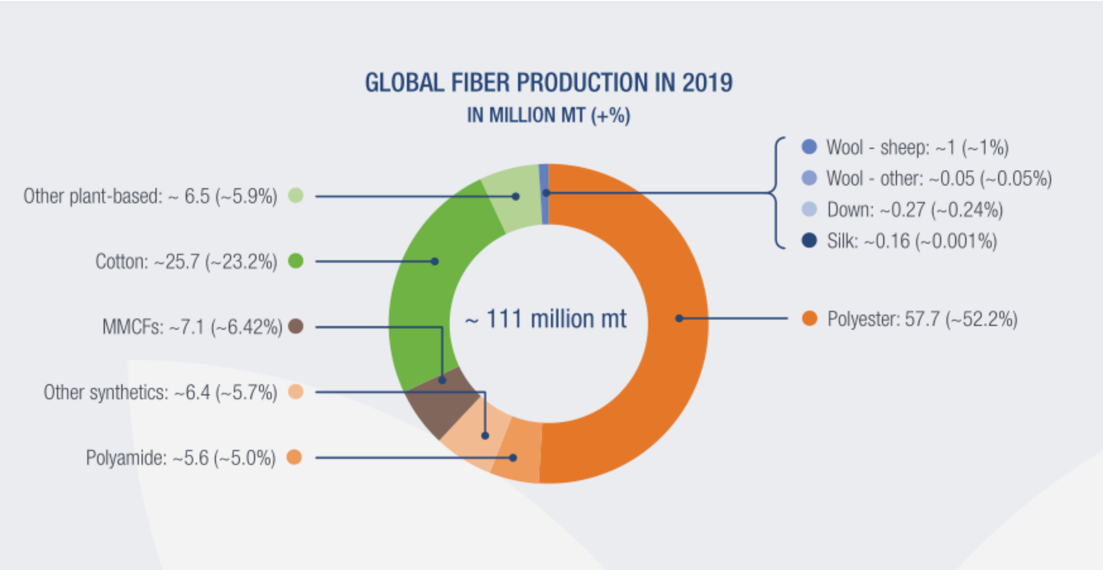

Figure 5: Global fiber production [30]

It is estimated that synthetic fibres will represent 98% of all future fibres. This increase poses an environmental problem from various perspectives. It is estimated that 98 million tonnes of oil are consumed worldwide each year for the production of synthetic polymers. These polymers are used to produce fibres, dyes, and finishes and are therefore dependent on fossil fuel extraction. Synthetic fibres have the disadvantage of not being biodegradable and remaining in the environment for many years. The fibres are very delicate relative to other plastics and tend to release nano and microfibers into waterways when clothes are washed. This causes immeasurable damage to vital ecosystems and cannot be easily traced. Manufacturers therefore need to have to look at new, environmentally friendly fibres for their products and incorporate more recycled fibres.

The world's largest production is for polyester fibres. Polyethylene terephthalate (PET) is the material of choice to produce recycled polyester textiles. This polymer is one of the most important and accounts for approximately 18% of global polymer production. Currently, the most common recycling methods used are mechanical recycling of PET bottles, where mechanical recycling produces rPET. In the case of other polyester fibre recycling, traditional technologies can be difficult. This is mainly due to the mixed nature of the materials, finishes, dyes, pigments, etc. This results in the downcycling of polyester textiles into lower value products. To achieve a better result, new technologies are used where the process uses enzymes, microwave radiation or glycols.

Emerging solutions

New technologies include "WornAgain" [31] recycling technology, which is able to separate, decontaminate and extract polyester and cellulose from textiles and polyester bottles and packaging that cannot be reused. This creates dual outputs of PET and cellulose, putting sustainable resources back into manufacturing supply chains.

Ioncell® [32] (Finland) technology is suitable for cellulose-based materials (both textiles, pulp, old newspapers). A solvent called ionic liquid is used in the process. In the dissolved state, cellulose can be transformed into beautiful, strong fibres. The only chemicals used are non-toxic ionic liquid and water.

Another technology for recycling cotton waste is REFIBRA™ [33] by Lenzing (Austria) REFIBRA™ fibre consists of 80% lyocell TENCEL™ (viscose fibres made from wood pulp) and 20% a blend of recycled cotton fabrics with cellulose fibres. The cellulose from the recycled cotton is dissolved using an organic solvent, mixed with the recycled Lyocell pulp, and processed into new fibres.

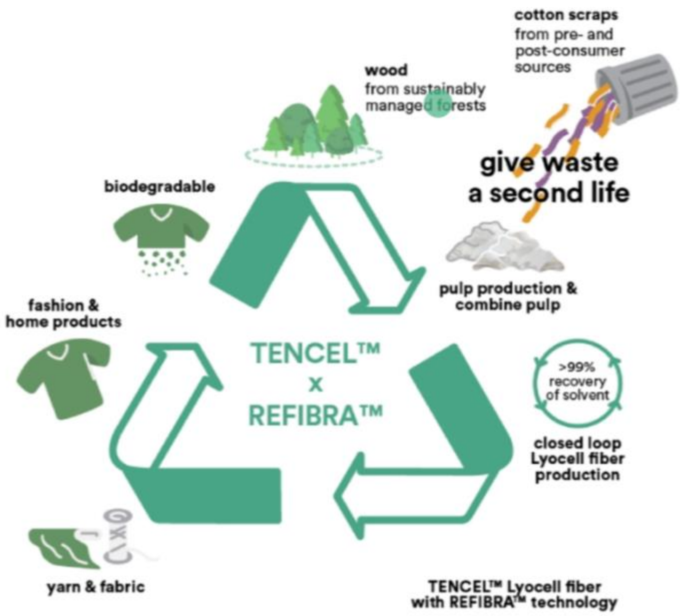

Figure 6: REFIBRA [33]

The process of converting domestic cotton waste into SaXcell [34]fibre is an abbreviation of Saxion cellulose. The input unit is a well-defined, sorted domestic cotton textile waste; the waste must be clean, so good sorting is necessary. After grinding, non-textile parts (nails, buttons, zippers) are removed. The dry mixture of textile fibres of different colours is chemically bleached; this mixture is now ready for the current wet spinning process according to the viscose or lyocell process.

After several years of research in recycling, the Mistra Future Fashion program has introduced the Blend Re:wind [35]process into production. This technology is capable of recycling polyester and cotton blends. There are three outputs from the process: viscose fibers from cotton and two pure monomers from polyester that can be re-polymerized into polyester.

Figure 7: Re:wind [35]

4.3.1.3 Reusing, repurposing, and refurbishing

Reusing and repurposing clothes are essential activities in facilitating a circular economy. Some countries (such as Germany) have high collection rates of textiles for reuse to a tune of 75% of textiles [36] which are usually exported to low-developing countries for extended use. However, in the countries where second-hand clothing is exported, similar collection infrastructures do not exist and thus used clothing end up in landfills (Watson et al. 2016). One of the solutions is to repurpose the clothing to new uses [29].

Refurbishment is the repair of an existing garment, re-sewing, or reuse, where waste does not end up in an incinerator or landfill but gets a new owner or a new look. The best-known approach in this case is second-hand.

4.2.1.4. Recycling

Recycling textile comes with two main challenges: sorting and economic viability. On the economical side, chemical fibre recycling has proven to be expensive, resulting in fibres that are far expensive than new virgin fibres.

Sorting is a challenge because clothes are usually made of blends, say natural and synthetic fibres or synthetic/synthetic blend with different properties which can be hard to separate to break the individual fibres in its chemical building blocks. On an extended note, blending in textiles can happen at the fibre level, yarn level, and fabric level. Some sorting challenges can be innovatively solved, as described below. Overall, it is simplistic to state that clothing is easy to recycle [37]. Respectively, chemists, environmental scientists, textile technologists, and policymakers need to innovatively think of several realistic approaches to overcome the involved challenges with recycling.

When sorting waste, the most important issue is to know what raw materials have been used for a given product and what process the product has undergone throughout its lifetime. The information should be clear, structured, and accessible on environmental sustainability, for example on substances of concern, treatments, or material composition. This can made possible by RFID (Radio Frequency Identification) tags or the so-called digital passport. Waste sorting with RFID tags uses the same approach as infrared sensors for automated systems in the plastics sorting industry. The tag is a source of big data for the manufacturer, where it can track product use and subsequent collection after use. Customers can enjoy fast self-service check-in at stores and can communicate with smart washing machines for optimal wash settings.

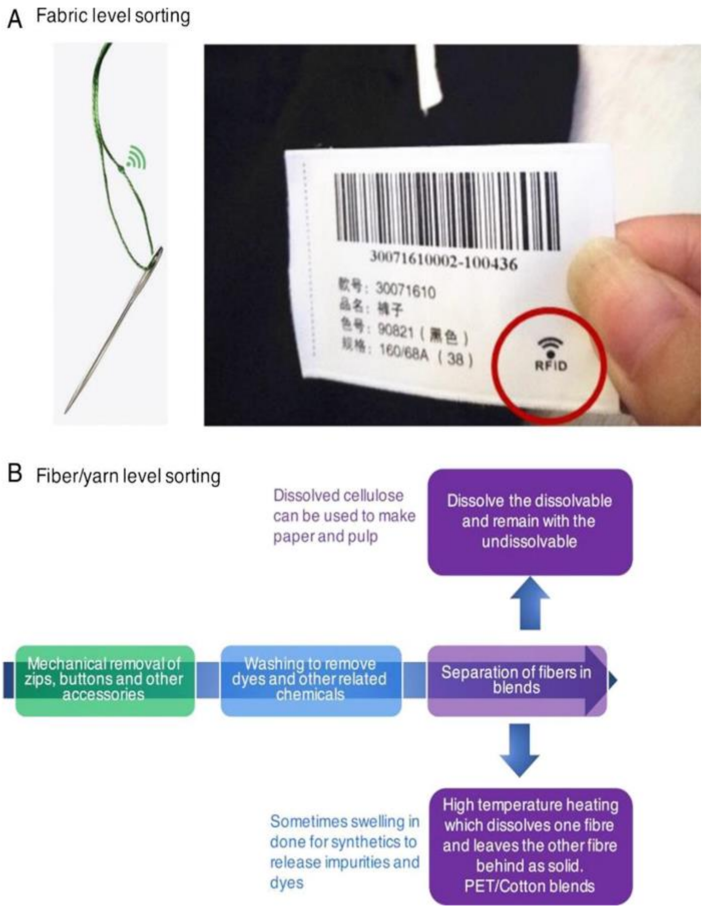

Figure 8: . Adetex sorting [29]*

**Sorting of fibers and fabrics before recycling. (A) Left: RFID yarn that can be woven into garment seams which can later be employed during the fabric sorting process. Right: Clothing label with RFID incorporated. (B) Fiber and yarn sorting can be done using physical and chemical solvent techniques.*

Further recycling possibility include solvent technologies. The approach is based on the fact that specific materials can be dissolved to retrieve other materials. For example, cotton/polyester fibres in fabrics can be sorted by dissolving cotton cellulose in a solvent and then leaving polyester behind. The cellulose dissolved can be used to make new synthetic fibres with natural recycled sources as in the case of Lyocell, Rayon, Cupro, and Acetate fibres. If the quality is lagging, the retrieved material can be used to make pulp and paper. These approaches are sustainable and the backbone of the circular economy. On the other hand, the latter approach depends on the melting temperature difference (higher difference) of the fibres to be sorted. For example, A/B fibres can be sorted by first swelling the two fibres at high temperatures to release the organic dye molecules and other contaminants. At a specific temperature, A will start to melt, but B will remain behind as a solid. These are then filtered for separation and proceeded for recycling. Scaling up these technologies is still a challenge but are key solutions to avoiding a linear clothing economy.

In case of necessity to obtain original monomers, it is possible to use technologies of biosorting, biorecycling by using living organisms or enzymes [38] [29].

Once the waste is sorted, the actual recycling of textiles takes place, which can currently be mechanical, physical/thermo-mechanical or chemical recycling.

Mechanical recycling is the most commonly used, involving operations such as cutting, shredding and tearing. The process results in nops, short fibres and fibre dust. There is a great loss of mechanical properties. The material is of lower quality, so it is mixed with virgin fibres most often used to produce new non-woven fabrics

Figure 9: Textile recycling - cutting of textile waste vs Textile recycling - resulting fibres [39]

Physical/thermo-mechanical - for textiles made from 100% thermoplastic fibres. Fibrous waste must be clean and free of non-melting impurities. The textile material is cut into small pieces and compressed into small balls or granules. The material is then melted. Then the screw in the extruder slowly conveys the material, mixing and homogenising the material, including the colours of the input material. At the end of the extruder, the material is cooled below its melting point, and after leaving the extruder it is cooled by air or water. The output is a thin string, which is then chopped into small pieces (a few millimetres long) - the so-called regranulate. The regranulate can be further processed, e.g., extruded into textile monofilament yarns. When heat is applied to the material, its properties are changed or reduced. This makes it difficult to reuse for the same applications

Figure 10: The extrusion-pelletizing line [40]

Chemical recycling: Chemical recycling processes convert waste textile materials through specific chemical processes into their basic components, which can then be re-spun into new fibres, yarns and textiles that are the same as the original fibres or can be even better without losing physical properties. The development of these processes is still at pilot scale.

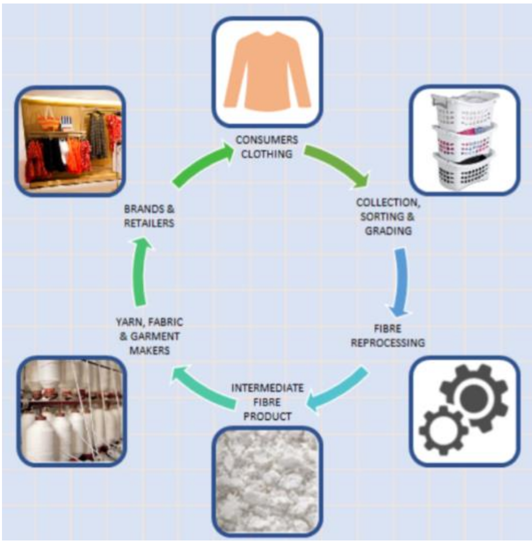

Figure 11: Fibre-to-fibre recycling. Source: WRAP 2017 Economic and Financial Sustainability [41]

4.2.1.5. Change in the distribution model

Thanks to the expansion of e-commerce, a new use of clothing goods is also emerging - clothing as a service. Extending the life of garments by reselling or renting is a growing trend in the fashion market. For example, the UK website https://www.hurrcollective.com offers the service of renting clothes for a certain period of time.

Laundries also offer textile rental for companies. When a laundry provides a company with clothing for their employees. Each employee is always provided with clean clothes of their own. The identification of each garment involves the use of either a barcode or a chip. This gives them information about the worker, the treatment, and the number of washing cycles the garment has been through.

The system receives all this information automatically and contactless when the laundry is received.

Figure 12: Laundry chip [42]

At the same time, this method of providing workwear or textiles to the operation (e.g., hotels and restaurants) is very environmentally friendly, because thanks to the higher quality of textiles, less waste is generated, the waste generated is further processed (laundries have contracts for the purchase of discarded textiles), and less water and energy is spent on washing and drying.

Table 1 below summarises all the previous strategies.

Table 1: Summary of Circular Strategies in the textile sector

Strategies	Description	Best practices
Ecodesign	Ecodesign takes environmental aspects into account at all stages of the product development process and strives for products that have the lowest possible environmental impact throughout the product's life cycle, where economic aspects are also considered.	- ensure maximum product lifetime - use recycled materials - ensure production sustainability
Material innovation	Innovation in materials, replacing fossil supplies with biobased and recycled content.	-substitution of fossil materials with biobased and recycled materials
Refurbishing	The process of repairing or restoring a garment, through which the garment is given a new life.	- repair of clothing - garment alterations
Recycling	Clothing recycling, where clothes are processed, and new fibres are obtained.	- use of technologies for easy recycling of clothing materials - use of digital passports - improving waste sorting
Change in the distribution model	To look at textiles in a new way, not only in terms of sales.	- offer textile lease/rental business models

4.3 Circular economy in the furniture sector

The European commission's *Zero Pollution Action Plan* states that, from 2050, air, water and soil pollution will be reduced to levels no longer harmful to health and natural ecosystems thus creating a toxic free environment. Numerous tools are to be used to achieve this aim. The change from the actual linear economy to a circular one is one of them.

To achieve the circular economy, the European commission intend to change/implement new policies and directives, that will shake and change the furniture sector as it will imply the design of new products and services, new business models and business relationships between suppliers and customers, but also the development of behaviours, regulations, and information dynamics. The implementation of policies such as the ESPR (The Ecodesign for Sustainable Products Regulation) and of the DPP (Digital product passport) will have a particularly strong effect on the furniture sector.

Although, by improving and developing already existing strategies into the current supply chain, the furniture sector can not only become sustainable, but also a driver of a circular economy worldwide, as Europe produces a quarter of the global furniture [43]. Therefore, different circular strategies could be implemented in the furniture sector with the aim to get a circular value chain (figure 13).

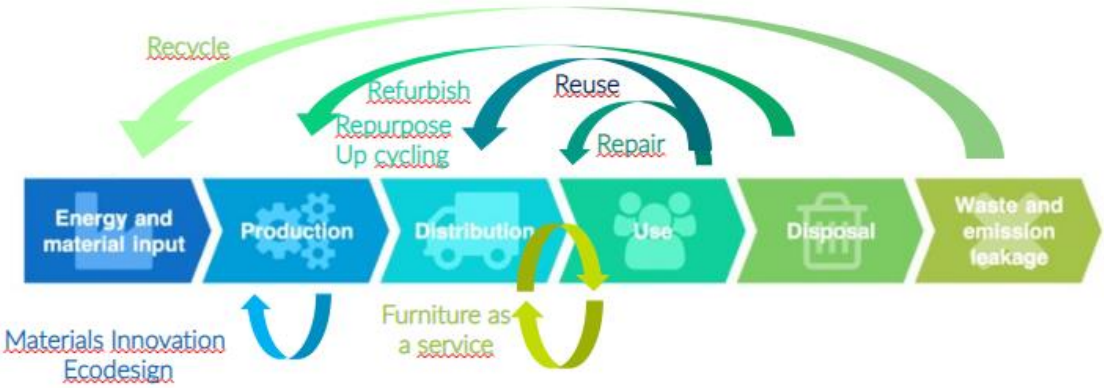

Figure 13: Circular Economy strategies in the furniture sector [44]

4.3.1 Circular strategies in the furniture sector

4.3.1.1 Ecodesign

The integration of environmental aspects into the product development process, by balancing ecological and economic requirements. Eco-design considers environmental aspects at all stages of the product development process, striving for products which make the lowest possible environmental impact throughout the product life cycle.

Dismantlable Furniture:

Dismantlable furniture, like the one sold at Ikea can be great to prolong a product's life, if the spare parts are easily findable. A company like Magis (Italy) don't staple/sew the fabric to the body of their sofa, as it is often the first thing to break. Instead, they use physical connectors. Indeed, a possible, non-destructive, reparation from the consumer himself is a good media to give a longer life to a product.

Figure 14: Sofa from the Magis company [45]

Dismantlable furniture is also good for transport and carbon footprint issues. A piece of furniture that is not assembled yet is way more compact during shipping, therefore more sustainable. This is seen for IKEA obviously, but also for other, more modest, companies such as TAKT (Denmark) that design their dismantlable furniture with wood from sustainable forest [46].

Modular/multipurpose furniture:

Buying furniture that serves multiple purposes reduces the consumer's need for different pieces that would turn to waste in the end (valuable waste is still waste). Some company like Stokke [47] (Norway) even create furniture that can evolve with a person, as their product "Tripp Trapp" is a baby chair that can change to different positions, therefor suite as much a baby as a child or an adult, eliminating the need to buy new furniture as one is growing up.

Figure 15: The "Tripp Trapp" different uses [47]

4.3.1.2 Material innovation

Innovation in materials is the process of meeting user needs through improvements in existing products or processes or creating and developing something completely new to achieve greater differentiation, a reduction in costs or sustainability.

Use of 3D printing, easily recycled materials:

Peter van de Water, Netherland, designed a 3D printed sofa (The De Sett) made from 95% of recycled materials and that could be reused/rebuilt/recycled ten times before needing to add some new materials to it [48].

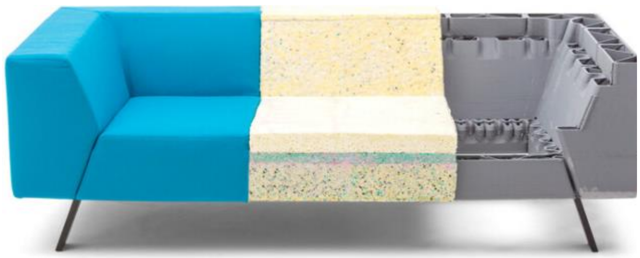

Figure 16: 3D printed body of the "De Sett" from Peter van de Water [48]

Use new ways of binding materials together:

Scientists now know that by rubbing two pieces of wood together with enough friction, the lignin (a mechanical component of wood) will liquify and act like a glue when dried [49]. That is what principle the BECK Fastener Group, in Austria, used to create their Lignoloc Wood Nails [50]. These nails, used with a nail gun, use the energy of the choc to liquefy lignin. Allowing to bond pieces of wood together without using any glue or petrochemical product.

Figure 17: Lignoloc wooden nails and pneumatic gun [51]

<u>Replace mineral/plastic/animal product-based materials to biobased ones:</u>

Paper, for now, is one of the most recyclable materials. But after a few times, the paper fibres can get too short thus, resulting in the non-recyclability of it. However, it is now possible to use paper as a raw material for particle/fibre boards. This is what the company Honext [52], in Spain, has been doing, going even further as they bind those cellulose fibbers imitating a natural enzymatic treatment.

In addition, new resources can be found to create new types of particle board such as seaweed, sunflower fibbers, artichoke thistles, coconut fibbers or even fish scale. Fish scale [53] particle boards, as Scale [54] (France) produced, could be a very nice product as it is stone like, but especially as it is 100% biodegradable. Indeed, the binding element used to achieve this result is already a component of the fish scale (Chitine protein). However, it reacts to water like wood would (deformation, swelling, formation of fungus…) so it might not be used outside.

Figure 18: Fish scales boards from Scale company [54]

Boards could also be created from residues of animal by-products like leather. As we tend to decrease the production of leather, their wastes are still here and must be reused if they can. However, leather alternatives for furniture are also a central question. Cork powder, orange peels, wine Trester, cactus protein, hemp residues are raw products that can be used to create leather alternatives. The product MIRUM (USA) is a 100% free of plastic, recyclable, biodegradable, leather like material that has already been used in some BMW car [55].

Other fabrics, like polyester have their alternatives, as the company Natural Fibber Welding (USA) found a way to "weld" cotton fibres together [56], giving it synthetic-equivalent performance to polyester.

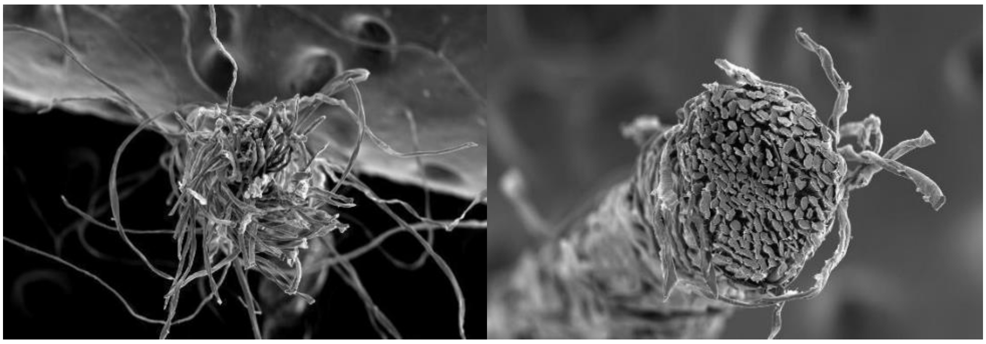

Figure 19: "Unwelded" cotton fibber (on the left) in comparison to "welded" cotton fibber (on the right)

<u>*The use of mushroom*</u>

As all these materials need biobased alternatives, the best competitor for them might be a mushroom: the mycelium. The Karlsruhe Institute of Technology (Germany) built a board from mycelium [57] that has high strength and water resistance. A leather alternative from the same mushroom has been commercially released the 7th of March 2022 during the Paris fashion week by the company Mogu (Italy) [58].

The mushroom can also be developed by taking the properties of a foam if its growth is geometrically guided. Ecovative Design (USA) [59], achieved this process to use as a Styrofoam kind of foam, but an application as a thermic insulation or as cushion foam is not to be excluded.

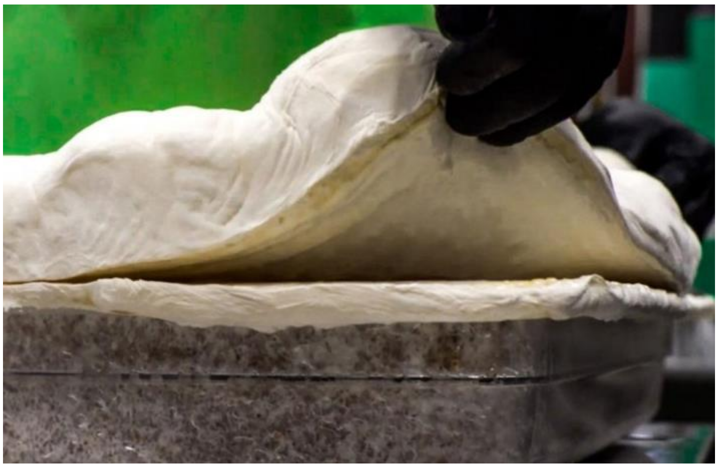

Figure 20: Mycelium foam developed by the ECOVATIVE DESIGN company for nutritional and packing uses [59]

Acoustically, the company Mogu (Italy) [60] developed an acoustic panel from a mix of the mycelium skin, upcycled fabric wastes and natural fibres like cotton or hemp.

Even though its use is not mainstream yet, the "mushroom industry" must be monitored closely. However, its expansion as a technology and production might take a while, as the process to create material from it (which consists of a lot of waiting for it to grow) is far from the current industrial mass production processes. Therefore, companies are being cautious to invest in those new technologies [61].

Give biobased materials new properties:

To give biobased/eco-friendly material new properties that can replicate the ones of others can be an opportunity for sustainable innovation and development. Taking some European [62] sapwood species and processing them through a hydraulic press with biobased reagents can give them tropical wood properties, without the transport issue. This is what the Swiss Wood Solutions company, based in Zurich, discovered. Engineers [63] also found out that, when bleached the wood loses its linin but it can be replaced with epoxy. Then, those wood properties can turn into those of transparent plastic, therefore becoming transparent and letting light go through them. Maybe a transparent wooden building is conceivable.

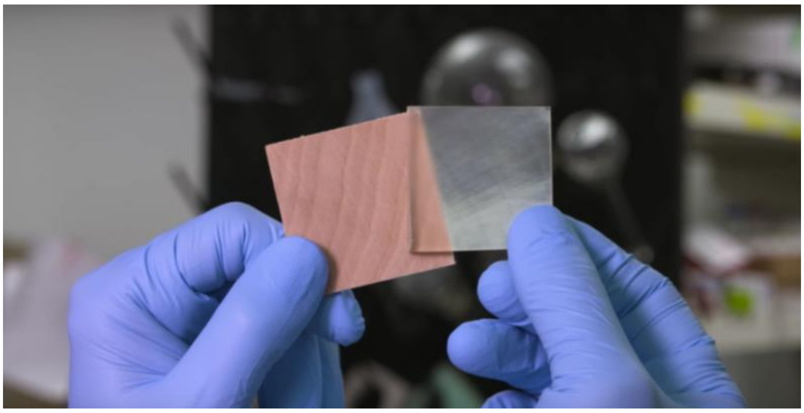

Figure 21: Translucent wood obtained by suppressing the lignin and replacing it with epoxy [64].

4.3.1.3 Refurbishing

This process can be seen as repairing, (reselling) and reusing an object instead of turning it into waste. Thus, bringing it back into another life cycle.

Second hand furniture business models:

Second hand furniture business model has an enormous potential as it brings back a "good as new" product to the beginning of the consumption process. The company Rype Office (UK) [65] repairs and resells office furniture while letting the costumer know the carbon emission of the product's life cycle.

In this way, the city of Berlin has also organised the "Noch Mall" [66], a recollection of old furniture around the city, letting the people judge of the quality of said products. Reselling them in a mall after the collection, this has been one of the first city scale "flea market like" second hand recollection and reselling in the world.

4.3.1.4 Repurpose/upcycling

Close to refurbishing, the aim of these processes will be to bring back a product into a new life cycle, but by changing its substance and function.

Use basic structures for pieces of furniture for a new different one (often used in individuals):

Often seen as a trend on the internet using pallet wood, upcycling is still a media to a circular economy. Even company, like l'Estoc (Spain) [67] has been releasing furniture made from pallet wood.

Figure 22: L'ESTOC furniture made from reclaimed and refurbished materials [67]

As companies don't often produce furniture from pallet wood, it could still be interesting for them to produce them using simple "detachable" structural elements so that, after the object is turned into waste, some of it can be easily repurposed to build something new, by an individual or a company.

4.3.1.5 Recycling

Recycling [68] is a resource recovery method involving the collection and treatment of a waste product for use as raw material in the manufacture of the same or a similar product.

Use multiple material waste to create a one material piece of furniture:

While plastic is not an eco-friendly material, it's non the less very versatile and very present around the world as a waste. Turning those waste into valuable material could help give them new purposes and turn their recycle process more valuable for the companies. As the possibilities of uses increases, the demand for this type of secondary raw material will follow.

The organization "the new raw" in Greece introduced "print your city" [69], a concept where multiple material urban waste is turned into one that can be processed through 3D printing. Thus, giving the possibility of building new public place furniture such as bench or chair, from the same wastes as the ones that where on these streets before.

Figure 23: PRINT YOUR CITY urban bench next to the waste needed to produce one of these benches [69].

4.3.1.6 Change in the distribution model

As the furniture industry can be seen as part of a secondary economic sector (aiming for a transformation of raw materials into a more elaborate product), it can be used for services purposes, thus, introducing this industry into the third economical sector.

Sharing/renting furniture network to avoid creating more waste:

As network and online sale platform use has been increasing, it is normal for the furniture sector to follow this trend. Recently new business models approaches have emerged, such as sharing and renting of furniture between people (Beleco Company, Sweden) [70] or setting a renting price by announcing how many months/years the furniture will remain with the customer (Lyght Living, London) [71].

Create information/data flow instead of material/substance flows:

Instead of buying a piece of furniture from another country, therefore increasing the carbon footprint of the product via transport, It is now possible to buy CNC plans (via Opendesk), ask a local woodworking company to process wood panels/particle boards and then assemble it yourself. More than just cutting transport price and effects, it is also possible to use local wood species for office/home furniture.

Figure 24: OPENDESK table prototype from which the CNC programs are available on their website [72]

All previous strategies are summarised in table 2:

Table 2: Circular economy strategies applied in the furniture industry

Strategies	Description	Best practices
Ecodesign	Ecodesign is the integration of environmental aspects into the product development process, by balancing ecological and economic requirements. [68]	· Dismantlable furnitures · Easily replaceable parts · Modular/multipurpose furniture
Material innovation	Innovation in materials is the process of meeting user needs through improvements [73] in existing products or processes or creating and developing something completely new in order to achieve greater differentiation, a reduction in costs or sustainability.	· Use of 3D printing, easily recycled materials · Use new ways of binding materials together · Replace mineral/animal product-based materials to biobased ones · Give biobased materials new properties
Refurbishing	This process can be seen as repairing, (reselling) and reusing an object instead of turning it into waste. Thus, bringing it back into another life cycle.	· Second hand furniture business models
Repurpose/upcycling	Close to refurbishing, the aim of these processes will be to bring back a product into a new life cycle, but by changing its substance and function.	· Use basic structures of pieces of furniture for a new different one (often used in individuals).
Recycling	Recycling is a resource recovery method involving the collection and treatment of a waste product for use as raw material in the manufacture of the same or a similar product. [68]	· Use multiple material waste to create a material that is more versatile.
Change in the distribution model	As the furniture industry can be seen as part of a secondary economic sector (aiming for a transformation of raw materials into a more elaborate product), it can be used for services purposes [74].	· Start sharing/renting furniture network to avoid creating more waste · Create information/data flow instead of material/substance flows

5. Industry 4.0 state of the art in textile and furniture sector

5.1 Industry 4.0 overview

Industry is currently transitioning to the so-called fourth industrial revolution or Industry 4.0. It refers to the intelligent networking of machines and processes in industry with the aim of using information and communication technologies [75]. These new technologies are considered a key instrument for boosting innovation and digital transformation. Thus, Industry 4.0 is a general description of an innovation and transformation process within the manufacturing industry. The goal of this process is to combine the real world with the virtual world. By means of the latest digital information and communication technology, the intention is to provide intelligent networking between people, machines, and industrial processes [76]].

There are many names for Industry 4.0: digital transition, smart factory, cloud-based manufacturing (CBM), factory of the future, intelligent manufacturing and digital manufacturing are all synonyms for this major revolution [77].

Prior to Industry 4.0 there have been three other industrial revolutions. The different changes have led to the characteristics of manufacturing: "mechanisation through water and steam power, mass production in assembly lines and automation using information technology." [78].

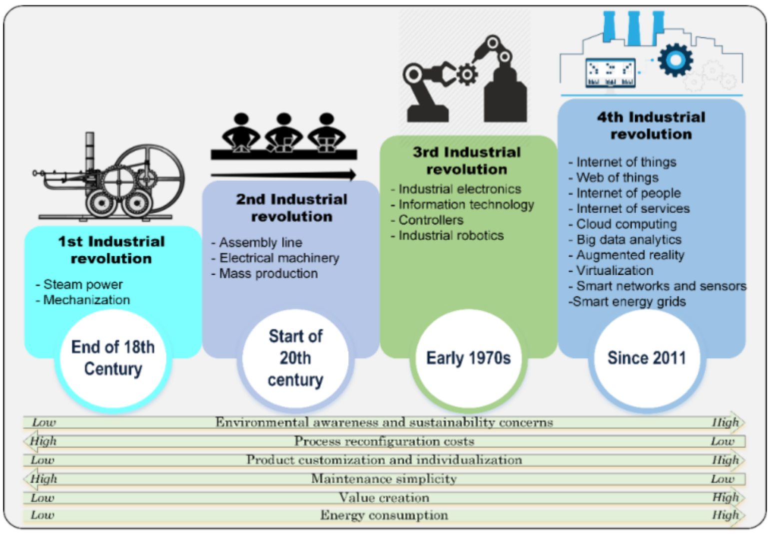

Figure 25: Industrial Revolution Steps [79]

5.1.1 Industry 4.0 technologies

In 2009, ten years prior to the Europe 2020 strategy release, the most promising technologies, also known as Key Enabling Technologies (KETs), were outlined. The European Commission developed a strategy of its own in order to introduce them into the society and economy of the European Union. The KETs have also been included in the Europe 2020 strategy and its related flagship initiatives, and are considered pillars of Industry 4.0, as advanced technologies that foster industrial innovation [80].

"The European Commission defines KETs as "the technologies that are the source of innovation and which, compared to other technologies, are linked to high technological intensity, high R&D capacity, fast innovation cycles, high capital costs and highly qualified staff" (European Commission, 2012)." [80].

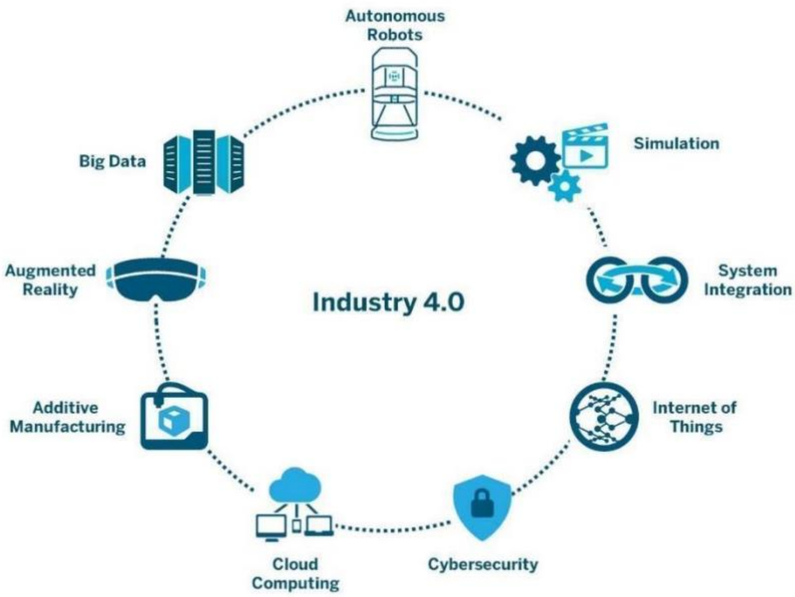

Figure 26: Industry 4.0 [81]

KETs, or industry4.0 technologies, represent knowledge-intensive technologies associated with high R&D intensity, rapid cycles of innovation, high capital investment and high-skilled jobs [82]. They facilitate process, goods and service innovations throughout the economy and are of systemic importance. They involve multidisciplinary and extend across many technological areas, with a trend toward greater degree of convergence and integration. KETs can help technology leaders in other fields capitalise on their research endeavours (European Commission) [83]. Table 3 describes the KETs that are key pillars of the industry4.0 transformation:

Table 3: .Key Enabling Technologies definition [84]

Key Enabling Technology	Definition
Internet of Things (IoT)	It refers to the connection of physical objects from the real world with a representative in the virtual world.
Big Data & Analytics	It is the use of large amounts of data characterised by their volume, velocity, namely the speed at which they are generated, accessed, processed, and analysed, and variety such as unstructured and structured data.
Cloud Computing (CC)	A network of remote servers to store, manage and process data
Simulation	A close imitation of a process or system operation, considering its characteristics, behaviour and/or physical properties. It can be used to reduce costs of production line processes and reduce the impact of modifications applied to it.
Virtual Reality (VR) & Augmented Reality (AR)	While Virtual Reality (VR) immerses users into a completely virtual world where they can interact with the environment, Augmented Reality (AR) adds virtual entities and information to a user viewport, combined with images of the real world.
Artificial Intelligence (AI)	Software that exhibits a behaviour traditionally identified as human intelligence that goes beyond what computers and machines are expected to do with conventional programming.
Additive Manufacturing (AM)	Additive Manufacturing (AM), also called 3D printing, is a process that creates a physical object from a digital design.
System Integration	To be a fully connected I4.0 factory, both horizontal and vertical systems need to be integrated together. Standard protocols and specific software packages should be used to achieve this integration among the disparate information technology systems used in the company.
Robotic	A mechanical system which executes various remote simple tasks with good accuracy. Autonomous and advanced robots are even able to adapt themselves to changes without any kind of human assistance.
Cybersecurity	It pursues the goal of preventing threats in the use of information technologies, such as confidential information, business secrets, know-how, employee and customer data, IT systems, software, networks, operational processes, and operating facilities.

5.1.2 Implementation of Industry 4.0: Technology trends of Industry 4.0.

The starting point for the development of Industry 4.0 is the **Internet of Things** (IoT). The resulting intelligent networking of machines already enables full automation, which was unthinkable just a few years ago. Tasks such as the maintenance of machines, which used to be carried out by individual employees, are now carried out independently. Access to a machine by an employee is only necessary in exceptional cases. Thanks to the wireless connection of the machines to the Internet, they can independently record, analyse, and link information and share it with other machines.

Information and communication technologies represent a central role for Industry 4.0. Without powerful communication technology, efficient manufacturing is simply not possible. Be it for wireless transmissions, the networking of all those involved in production, or even for the use of virtual reality [76].

Effective, economical production is an essential factor in every industrial company. This is where **artificial intelligence** comes in, as modern Industry 4.0 technologies enable machines to learn how to develop their own functions. This allows them to perform better when carrying out work steps. Artificial intelligence thus not only enables machine learning and the associated continuous product improvements, but also a new design of business models. The amount of data in the company is growing and growing... This is exactly what **Big Data** describes. By analysing these large volumes of data, a lot of useful information can be obtained for companies. With the help of intelligent, self-learning algorithms, links can be created between individual data. As a result, industrial companies can make more targeted decisions based on better predicted data and thus make targeted use of knowledge.

Through computer-aided models such as **virtual reality**, industrial companies can offer their customers a whole new buying experience. Be it the virtual tour through production or the experience of a new product. The modern technologies of Industry 4.0 can also simplify work steps and make them more efficient. Via smartphone or tablet, information about stock levels and required spare parts can be easily viewed. For example, the process of requesting spare parts as part of machine maintenance can be accelerated through the use of **augmented reality** [76].

Industry 4.0 quality management enables companies to optimise the quality of their entire value chain with the help of the latest technologies. Artificial intelligence and big data enable comprehensive quality analyses. Using the latest Industry 4.0

software, companies can identify potential errors or bottlenecks at short notice and react accordingly [76].

Industry 4.0 applies not only to technology, but also to new ways of working and the role of people in the industry. Increasing the level of computerization, communication and integration of artificial intelligence leads to a significant improvement of work safety and efficiency [85].

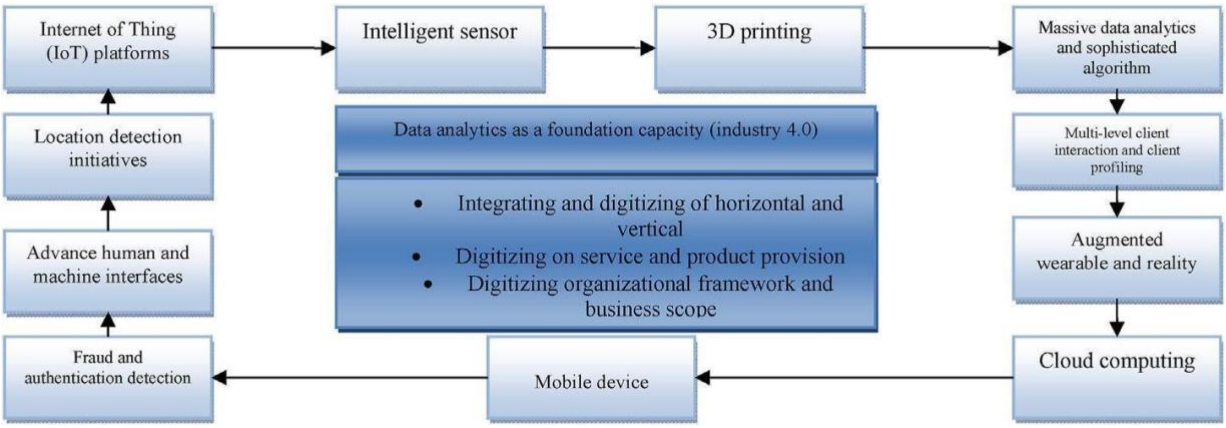

Figure 27: Data analytics as a foundation capacity [86]

5.1.3 Advantages and benefits

The promising and cutting-edge technology of Industry 4.0 requires significant upfront investment. For larger companies, the costs would inevitably be higher. But the expected return of networked, intelligent devices and an automated production process is promising [87].

Competitiveness has increased: Outsourcing to low-wage regions of the world used to be a must for manufacturers who wanted to remain competitive. Investment in technology, on the other hand, is now enabling more affluent countries to become competitive again. As a result, manufacturers can now choose locations based on their technical capabilities and closeness to consumer demand, rather than being primarily based on wages.

Productivity has risen: Automation, analytics and machine learning algorithms have taken much of the work away from human staff. This means faster, more efficient production, with human workers primarily monitoring and maintaining the systems [87].

Business benefits of Industry 4.0 in manufacturing

Industry 4.0 is revolutionising manufacturing, particularly when it comes to predictive maintenance. Predictive maintenance is a manufacturing best practice based on a theoretical rate of asset failure. Instead of waiting for something to break, manufacturers use predictive maintenance to pre-emptively replace parts or tools to reduce downtime. Using regular, data-driven maintenance schedules keeps the unused lifespan of a given part to a minimum. Downtime can result in extensive financial losses, something preventative maintenance can help to avoid. The increased long-term reliability of processes leads to greater output capacity, increased part quality, and long-term cost savings [88].

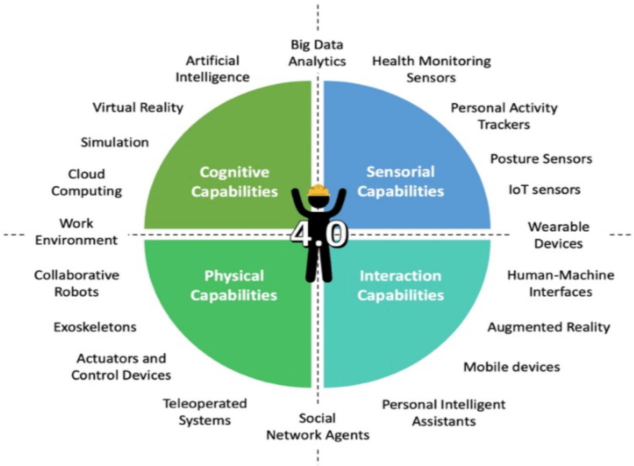

Figure 28: The Operator 4.0 Compass [89]

Though new devices, tools, and techniques can initially seem like an investment, the cost of using older tools in a rapidly innovating technological field can quickly stack up. Today, smart factories outfitted with sensors connected with resource planning software can detect when inventory levels are low and automatically reorder parts or materials to avoid production disruptions. This capability helps manufacturers build better parts faster and for less, while also helping them get the most out of their machinery [88].

Automated machines outfitted with smart sensors can take on the routine, laborious, and potentially unsafe tasks that operators would normally be responsible for, which frees these workers up for more high-value tasks and improves safety on the factory floor. From an administrative standpoint, smart automation can also increase the reliability of routine data entry and report generation so manufacturers can maximise efficiency and optimise internal processes [88]].

Use of Industry 4.0 technology in sustainable manufacturing

Sustainable manufacturing requires the engagement of all stakeholders in the collaborative creation of sustainable assets, but the fully interconnected character of Industry 4.0 enables partners in the value chain and even customers to become involved in sustainability. Industry 4.0 is a complex and multi-layered phenomenon that encompasses a wide range of technologies and applications in a highly interconnected industrial environment. Each technological trend of Industry 4.0 has a different impact on sustainability. Industry 4.0 technologies aim to address current issues such as global competitiveness, volatile markets and needs, increased adaptation through communication, information, and intelligence, and shortened innovation and product life cycles. Therefore, it was crucial to investigate the drivers for the adoption of sustainability [90].

The adoption of Industry 4.0 efforts in the supply chain can improve the overall sustainability performance of a company. In terms of economic performance, implementing these innovative technologies in the supply chain can save money by increasing productivity and providing a higher return on investment. These innovative technologies have the potential to significantly impact the social sustainability of supply chains by promoting transparency and strengthening commitment to sustainability to foster ethical collaboration at the supply chain level. In addition, these technologies can support early decisions about technologies, processes, resource use, and downstream and upstream flows, all of which are related to environmental performance. However, the socio-environmental impact of Industry 4.0 ought to be viewed in terms of the production-economy perspectives that digital transformation brings. When business survival becomes the most important strategic goal, manufacturers are not free to give priority to environmental protection and social improvement in the absence of economic sustainability [90].

5.2 Industry 4.0 in the textile industry

Strictly speaking, with regard to the textile industry, the upcoming automation in the clothing industry will make it possible to relocate part of this production from developing countries back to developed countries. But it will take some time before a substantial part of this volume will be produced in automatized factories.

Figure 29: Garment industry in developing countries [91]

"If the dressmaker sees that the fabric is throwing "folds", she will quickly solve the problem with clever hands. "If a robot has to manage this, it would need integrated sensors to recognize a complex image. Robots suitable for the textile industry are still small and are very expensive. In addition, textile and clothing is a "whimsical" field, often changing patterns, colours and cuts and dependent on trends and mood in the society. The robot has to be reprogrammed, which also costs a lot of money.!"

Herber Rainer (Director of Adidas)

As all product lifecycles are being considerably shortened, Industry 4.0 can help the textile and apparel industry solve these problems with the possibility of flexible manufacturing, industrial process redesign, and technological advances.

Most machines supplied by textile machinery manufacturers have built-in intelligent factory platforms so that they can collect, measure, and analyse data through sensors, data loggers, etc.

This information is used in the user interface to carry out actions or decisions. All processes related to manufacturing and logistics can become more flexible and agile in the textile value chain in Textile 4.0. This will help to respond quickly and effectively to market needs. The result of these constraints, ranging from the level of productivity and efficiency to quality, is always affected in most cases.

The machinery manufacturing Industry

Textile 4.0 Application by the Textile Machinery Industry following the footprint of the global manufacturing industry, it is also trying to align itself for innovations and upgrades. As most textile manufacturing companies do not have a flexible, digitised operating structure, they are not keeping up with the changes in the outside world and the demands of today's consumers. Although the textile machinery manufacturing industry, especially in Europe, is already fully aligned with Industry 4.0, the textile manufacturing industry is a little slower in this regard.

In fashion trends in all countries as well as global competition is increasing intensely. Therefore, greater reliance on the workforce with potential human errors in production, supply chain, etc. becomes an obstacle. Many of today's next-generation textile machines are IoT-enabled, digitized, and have AI capabilities. Many of the leading textile machinery manufacturers have introduced complete production process monitoring systems via the Internet of Things (IoT), which can provide various real-time analytical reports and offer numerous functions, and this is very useful for reorienting manufacturing processes. manufacturing. manufacturing, production, and quality for best results.

For some machine engineers, data collected through machine operations feed knowledge and is also used for predictive maintenance and the prediction of potential breakdowns (machine learning).

Textile Industry 4.0 and the IoT (Internet of Things)

With the adoption of the Internet of Things (IoT), the decision-making process for management is significantly reduced through real-time-based information and analytics. Industry 4.0 initiatives through the IoT are driven by thousands of smart devices that generate large volumes of data.

The rise of smart factories in textile manufacturing shows that the global textile industry is on its way to gradually adopt Industry 4.0, due to which a wide range of possibilities have emerged to use the various technologies mentioned above in its production and supply chain.

Artificial Intelligence

Artificial intelligence is used to analyse large blocks of data collected in manufacturing, purchasing, marketing, and logistics, etc.

Robotics and automation are advancing faster in clothing manufacturing. Sewbots (sewing robots) are widely used in China in garment factories, for example [92].

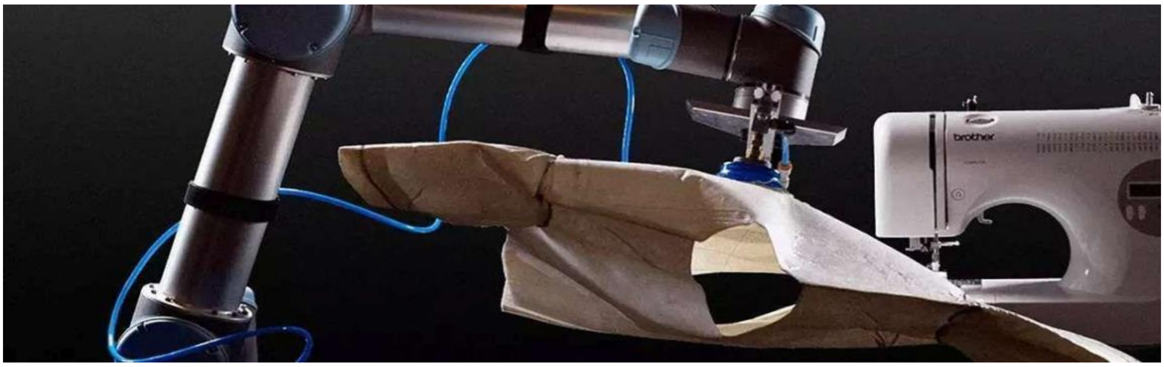

Figure 30: Application of Robotics in Textiles [93]

The application of such robotic automation has resulted in significant benefits to the textile industry. High levels of consistency and precision in work pieces and high levels of repeatability and accuracy in manufacturing equipment have been required. Economic justification can be shown only for large quantities of production. To achieve this, adaptive manipulation systems having some "Artificial Intelligence" are needed [93].

Automation is rapidly entering textile operations, and with its help, textile producers can improve productivity, quality, and reduce waste. This is used by textile companies for trend forecasting and machine diagnostics.

Technological convergence in Textile 4.0.

When it comes to the textile industry, different technologies are converging, resulting in a great disruption in textile manufacturing and also in products. The future of textiles lies in the potential for technological convergence that would lead to the development of smart clothing.

Figure 31: Sublimation technique [94]

3D printing and digital printing are expected to bring a big change to textile manufacturing in the future, providing flexibility in the manufacturing process to meet customer demands.

The future of the textile Industry 4.0

The use of electroactive polymers in textiles will give clothes light-emitting capabilities. Nanotechnology and plasma technology will be used more widely in textiles of the future for specific applications. The variable properties of fibres and filaments give textiles multifunctional capabilities.

Mainly it will go into haute couture textile products. Integrating electronic functionality into textiles will open up a new world of applications. Conductive fabrics with the possibility of using thermochromic ink (which undergoes a reversible change of colour when heated or cooled) for printing give the fabric very special functional capabilities. This, together with a higher level of automation and robotization of production and the deployment of artificial intelligence in its management, will offer promising opportunities for the transformation of the sector.

5.3 Industry 4.0 in the furniture industry

5.3.1 Industry 4.0 technologies implemented in the furniture sector

There is a wide variety of criteria when it comes to specify the technologies that allow the digital transformation of a furniture company. Depending on the source used, different classification criteria appear, or technologies outside the reach of most companies in the manufacturing sectors are mentioned. Some sources include the IoT as a digital enabler, while others refer to social media and broadband, or smart products and the Internet of Services.

To make progress in digitization, a company needs to adopt the technologies that are most in line with its needs and expectations. The level of digitization of furniture companies is relatively low, and the use of digital enablers is not very widespread. Nevertheless, different technologies have been detected, grouped in 6 technology areas, that have been more implemented and used in the sector (table 4).

Table 4: Technologies most implemented in the furniture industry

Technology area	Technologies
Collaborative platforms	Collaborative work environments B2B manufacturing platforms B2C and B2B e-commerce platforms
Business solutions	Enterprise Resource Planning systems - ERP Manufacturing Execution System - MES Customer Relationship Management system - CRM Business Intelligence system - BI
Additive manufacturing	Additive manufacturing
Robotic	Robotics in production Robotics in logistic Collaborative robotics
Mass data processing	Big data and analytics Machine learning
Sensors and embedded systems	Sensors and systems in furniture manufacturing processes Sensors and systems in habitat products

The following sections describe the technologies most implemented in the furniture industry that are considered key pillars of the industry 4.0: additive manufacturing, robotic, big data and analytics, artificial intelligence (machine learning) and internet of things (sensorisation).

Additive manufacturing

There are three areas of application of additive manufacturing in the furniture sector:

Prototyping

This application is currently the most frequent. The development of a prototype to scale, or with a plastic material that will not be the final one, is usually common to check various characteristics of the product: dimensions, assembly problems, interference between elements, relevant ergonomic aspects, aesthetics, etc.

Manufacture of finished products

This application is growing progressively, especially in industries with high added value products such as the aerospace industry, medical prosthetics, and special equipment. Complex elements are obtained that are very difficult or expensive to manufacture with conventional means, spare parts that lighten the logistics load, personalised pieces for specific customers, etc. In this case, the usefulness or customization of the piece justifies its cost.

Tooling manufacturing

In this case, the reference tools are usually molds or dies in which certain elements manufactured with this technology are inserted, which allow the wall thickness of metallic elements to be reduced, the mold to be better cooled and productivity to be achieved, injection defects to be eliminated and even manufacture complete molds for short and limited runs.

An example of application of additive manufacturing in the furniture industry is shown by Minale Maeda [95]. Thanks to additive manufacturing complex joining elements are developed and manufactured in plastic materials, which provide a differential aesthetic value.

Figure 32: Inspiration by Minale Maeda [95]

Robotic

The main advantages provided by robotics, as a means of automating processes of production for technological innovation are the following: productivity, flexibility, job quality and safety. Robotics are implemented in the furniture industry in production and logistics, and collaborative robotics is also growing nowadays.

<u>Robotics in production</u>

Industrial robotics is one of the great immersions that technology has made in the furniture industry. Industrial robotics has allowed factories to automate many processes in the production chain, allowing human resources to be allocated to other areas of the company. Thus, the applications of robotics in the furniture and wood sector are very varied, such as: handling of materials and components (load/unload); welding (arc, spot, laser, etc.), spraying (painting, varnishing, lacquering, enamelling, stickers, etc); couplings and assemblies; product packaging; assembly/disassembly; organisation of finished product and stocks; and other processes (cutting, cinching, sanding, machining…).

Robotics in logistics

Logistics is defined as processes that deal with the reception, storage, and movement within a warehouse until its consumption, of any material (raw material, semi-finished products, finished product, …) as well as the treatment of the data generated. The use of robots as a form of automation is especially interesting in logistics if employees are freed from difficult, stressful, and monotonous tasks. Different activities where robotics are implemented in furniture logistics are: Packing, palletizing, loading and unloading operations, storage, or picking.

Collaborative robots

Collaborative robotics is a form of industrial automation that complements the current offer. These kinds of robots are made up of robotic arms and are characterised by being light, flexible, and easy to install and interact with humans in a shared workspace without the typical security restrictions of industrial robotics, that is, it is not necessarily a security fence. Collaborative robotics in the habitat sector plays an important role since it is one of the areas in which repetitive work is carried out to manufacture the final product. Collaborative robots can perform simple and repetitive tasks that save the worker time and are also performed with greater precision. In the furniture industry these tasks are: Artificial vision for recognition and positioning of pieces; furniture resistance tests; manufacture of springs; seat bolting, handling of heavy furniture, bonding of materials, packaging, glueing, palletizing, assembly, painting, welding, and polishing.

Big data and analytics

Deep analysis of huge amounts of data can help understand and even predict customer behaviour. Production machines and systems with sensors that constantly send information (geolocation, habits of consumers, people's health, etc.) are data sources that generate big data scenarios. Some examples of big data applications within the furniture industry can be:

Marketing and sales (customer segmentation)

The data is used to better understand customer preferences and behaviours. In most cases, it is about creating predictive models to know those products that are going to sell better, understand customer preferences and reach them through their preferred channels.

Optimization of business processes

Optimization of stock, supply chain and distribution routes. For instance, based on geographic positioning and radio frequency identification sensors, goods and delivery vehicles can be tracked, optimising routes, and integrating traffic data in real time.

Optimization of the performance of machinery and equipment

Thanks to sensors, machinery and equipment can be more autonomous and intelligent, being able to make decisions on your own.

Finance

Algorithms to decide on the purchase-sale of securities in real time from technical analysis, behaviours of raw materials, company results, news in time real, messages on social networks, forums, statements personalities, etc.

Artificial intelligence

Machine Learning can be defined as a scientific discipline in the field of artificial intelligence that creates systems that learn automatically. Learning, in the field of machine learning, means identifying complex patterns in millions of data. In reality, the "machine" that really learns is an algorithm that reviews the data and is capable of predicting future behaviour. Automatically, also in the context of machine learning, implies that these systems improve autonomously over time, without the need for human intervention. Therefore, machine learning is a type of artificial intelligence aimed at developing techniques so that machines can learn and make decisions by themselves. There are different applications in the furniture industry:

Marketing

Apply artificial intelligence and machine learning to digital advertising to find the best audience or demographic for any ad.

Wizards for users and customer service

People don't like to feel like they're being served by an unintelligent machine, or to have to wait a long time in line to be served, pushing buttons, and being transferred multiple times until they reach the right person. With artificial intelligence it is possible to develop a chatbot system for personalise customer service.

Predictive services for decision making

Predictive services, based on Machine Learning, help improve decision-making, since they allow predicting future behaviour of certain variables. For instance, an app that allows consumers to take photos of furniture they like, either from a catalogue or the actual piece of furniture, and then find matches and determine availability at a variety of retailers

Internet of things

In the industry4.0 era, the internet of things allows sensors to communicate with higher level control systems (i.e., platforms), to send monitoring data. This superior entity is the one that executes algorithms and applications, taking the data received from the sensors as input, to return as output the decision-making about possible changes. This exchange of information must take place in real time to react effectively to, for example, failure situations in an industrial process, or automatic changes in machine configurations, without human intervention. Nowadays there is a huge variety of sensors, and their possible applications are constantly increasing and can be classified depending on if they are implemented in the manufacturing processes or in final furniture products.

Manufacturing processes

There are many applications of the different types of sensors thanks to the implementation of internet of things in the woodworking and furniture manufacturing processes, such as material classification, materials and product handling, sanding, glueing, etc.

Furniture products

Embedded sensors, connected with internet of things with external platforms or data clouds, occupy an important place in the furniture industry, as more and more products require different types of sensors in this field. Mainly humidity, temperature and pressure, weight, occupancy, and force sensors. These sensors can be integrated into the furniture, thus capturing the necessary information about the furniture or the person who uses it. Sensors could monitor health information of the user, to monitor their health status; and user occupation, such as time that a user is sitting on a sofa, to know daily habits and create alerts when something is wrong, especially important for elderly or babies' care.

5.3.2 Maturity of companies in Industry 4.0

A deep analysis of the level of digital maturity on industry4.0 in the furniture industry was done by different Spanish clusters [96]. It was analysed through 5 dimensions, according to HADA tool (Tool for Autodianostic of Digital Maturity): Market and business strategy; Processes; Organisation and staff; Infrastructures; and Products and services.

All dimensions were measured through a series of indicators, classified on different "levers". The different dimensions showed a similar level of digitalisation, around 35%, except product and services dimension, that is far less developed, 13% (Figure 33).

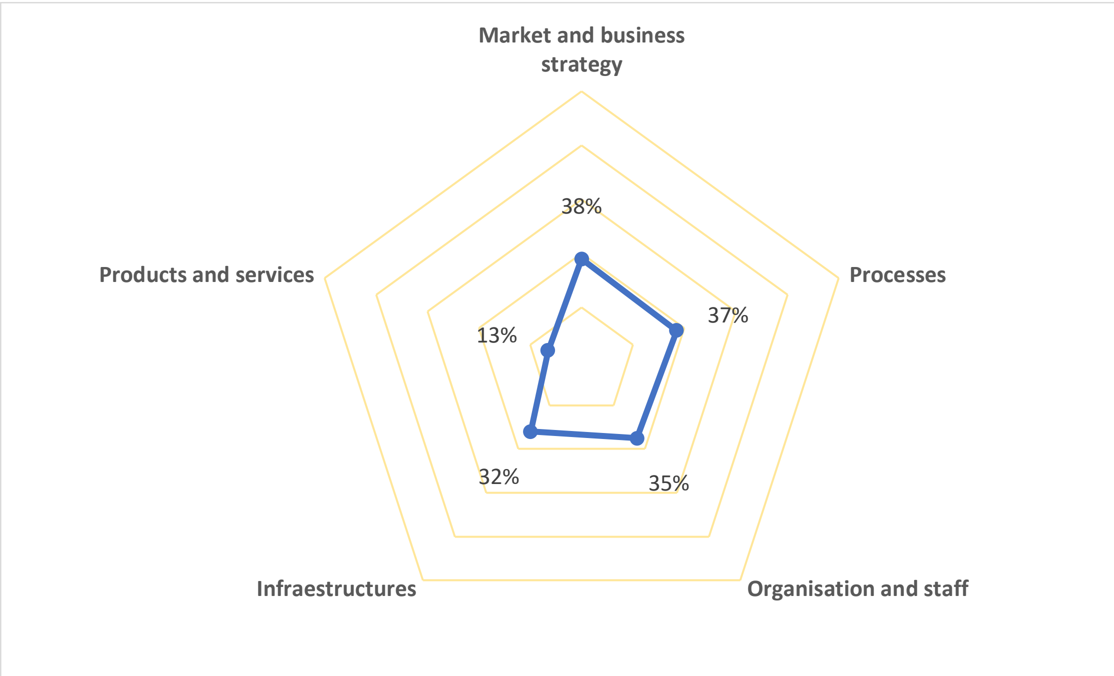

Figure 33: Digital maturity in the furniture sector

Based on previous results, companies have been divided in three different categories: dynamic (6.7%), proficient (23.3%) and conscious (70.0%).

- Dynamic companies: It is in an intermediate state between advanced development and the consolidation of its digital maturity and is characterised by using a 4.0 strategy, monitoring it with the appropriate indicators. In addition, investments are being made in almost all the areas and the process is supported by innovation management. The systems collect vast amounts of data, which is used for continuous improvement using conventional means. Information exchange is also carried out internally and externally. Cybersecurity solutions are used in some departments. The segment is beginning to explore autonomous and self-correcting processes. Instead, here, the dimension of products and services corresponds to a lower level that we could characterise as competent.
- Competent companies: in this segment, which is in a state of development in Industry 4.0, the group incorporates I4.0 initiatives in its strategy. Industry 4.0 investments are being made in several areas. Some data is collected automatically, but its use is limited. There is intra-company information exchange, and, in addition, information is beginning to be integrated with suppliers and customers. Although the fifth dimension, products, and services, is still lagging behind and would correspond to a lower level, being conscious.
- Conscious companies: this segment, in a state of introduction to the digital industry, is involved in Industry 4.0 through pilot initiatives and investments in some areas. Some production processes are supported by systems. System integration and information sharing are limited. However, following the trend of the sample, the fifth dimension would drop to the static level due to the low percentage it possesses.

6. Industry4.0 technologies for a twin transition in the manufacturing sector

Digital technologies, or KETs, are closely linked to sustainability concerns, as they should contribute to solving the environmental and societal challenges of today's society. By applying the sustainable approach at the level of specific industries and companies, the concept of "corporate sustainability" has evolved, and businesses have begun to address how they can implement the new concept of sustainability, including environmental, social, and ethical aspects in their companies [80].

Industry 4.0 technologies have the potential for application in virtually all sectors and industries, including aeronautics, automotive, engineering, chemicals, textiles, space, construction, healthcare, and agriculture. KETs are the 'technology building blocks' behind a wide range of innovations, such as 3D printers, LED lighting, advanced robotics, bio-based products, smart phones, nanodrugs, smart textiles and many more. Products strongly dependent on KETs-components represent 19% of all EU 28 production, and KETs account for 3.3 million jobs in 2013. KETs drive both the development of entirely new industries and the transformation of the existing industrial base in Europe.

In this context, industry 4.0 technologies have the potential to modernise manufacturing processes while having a direct impact on the adoption of sustainability practices, related with the circular economy model, and enabling the twin green and digital transition [8] [17] [18]. The nations and regions mastering KETs will be at the forefront of managing the shift to a sustainable knowledge-based economy. To this end, in 2012, the European Commission adopted a strategy to boost the industrial uptake of KETs in Europe [97].

Digital technologies can enable several functionalities, from data collection and integration. Their role as facilitators of the circular economy transition have been analysed by different scientific papers, but there is still lacking research on their integration.

The following section describes the eight most used industry4.0 technologies with sustainability purposes, according to the scientific literature [84] [98] [99] [100], and how they could act as facilitators of circular economy practices.

Internet of things

Considered the most integrated digital technology for Circular Economy, IoT is useful to collect data during the product life cycle, tracking product flows from the design to the end of use, that can be applied for a better use of resources (product design) and the optimization of disassembly processes. In addition, during the manufacturing phase, it is also possible to monitor data about the process and get more sustainable operations, for instance, by reducing scrap rates, equipment wears and tear, or monitoring energy consumption. Finally, the IoT facilitates the provision of product-as-a-service circular business models, such as sharing or pay per use.

Big data & analytics

Big data and analytics, closely linked to IoT, serve the circular economy through their potential to optimise processes and enhance decision-making, using the data collected from the IoT to improve resource management across the entire product life cycle. Big data and analytics could act as facilitators to close the material loops, for instance by improving product ecodesign while enabling recycling strategies. Moreover, big data and analytics could be useful to identify patterns, related with consumer usage and how to improve product design for circularity.

Simulation

Simulation can be exploited to virtualize/optimise different processes, such as disassembly processes, before replicating them in the real world. Thus, it is possible to analyse how some processes could be implemented and their respective level of sustainability. Moreover, Digital Twin (DT) represents the virtual twin of a physical system. Although originally born in the aerospace industry, DT has great potential to be adopted also in manufacturing industries, to facilitate product design and disassembly or recycling processes.

Robotics

Robots are becoming autonomous, flexible, and cooperative. The implementation of robotics in manufacturing industries allow to employ robots in an increasing number of applications that could be aligned with CE practices, such as facilitating waste sorting and disassembly and remanufacturing processes.

Additive manufacturing

Additive manufacturing allows for circular design, introducing new ecomaterials (including recycled materials) and designs that facilitate product repair. Due to the additive process, it contributes to waste reduction, reduction of handling and transportation activities, and lower energy consumption. In addition, additive manufacturing contributes to mass personalization, boosting local manufacturing while avoiding unnecessary stocks. Finally, additive manufacturing facilitates the production of spare parts for repair purposes, leading to an extension of product´s lifetime, and the improvement of the design phase.

Augmented and virtual reality

Augmented and virtual reality act as virtualization tools, that facilitate the redesign of more repairable and modular products thanks to the simulation of alternative concepts. Besides that, augmented and virtual reality systems can provide people and workers remote assistance, allowing more flexible work processes in service and maintenance activities, and therefore reducing transportation needs.

System integration

Cyber-physical systems could contribute to the internet of things, as the continuous real-time exchange of data via virtual network, allows the use of resources (material and/or energy) in a more efficient way. Thus, it is possible to inform customers about the different components of a product in order to ease their disassembly or recycling.

Artificial intelligence

Artificial intelligence can enable circular economy innovation across industries fostering circular design, through iterative machine-learning-assisted design processes that allow for rapid prototyping and testing. Moreover, artificial intelligence can also support the implementation of new circular business models, such as product-as-a-service and leasing, by combining real-time and historical data from products and users. Finally, artificial intelligence can improve the reverse logistics tools necessary to close the loop of materials by boosting sort and disassemble, remanufacture, and recycle processes.

Table 5 below provides a summary of KET and their usefulness in the different product life cycle phases.

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Table 5: The role of digital technologies in the smart circular economy paradigm [99]

DIGITAL TECHNOLOGY	PRODUCT LIFE-CYCLE PHASE				
	Design	Manufacturing	Distribution	Usage	End Use
Internet of Things		Monitoring of data to achieve operational excellence by reducing scraps and equipment wear and tear.	Enabling the provision of circular product-as-a-service business models (pay per use, sharing).		Tracking products to increase collection rate.
Big Data and Analytics	Transforming product-in-use data into valuable information to improve product design for circularity.			Enabling the provision of preventive and predictive maintenance.	Informing better decision-making for reuse, remanufacturing, and recycling.
3D Printing	Increasing the use of recycled materials (recycled plastic polymers or metal powders). Increasing product personalization to avoid the early retirement of products.	Minimising material losses, scraps, and waste (additive, not subtractive process). Reducing the need to hold large inventories.	Reducing the need for transportation.	Enabling the local and on-demand production of spare parts for repair and upgrades.	

Blockchain		Ensuring trust, transparency, traceability, security, and reliability in the value chain to drive green consumer choices and prevent greenwashing.	Allowing automated transactions (e.g., smart contracts), leading to greater efficiency.	Financial incentivization to drive users' behaviour towards increased recycling.
Augmented and Virtual Reality	Facilitating the redesign of products to improve circularity.		Providing remote assistance and guidance for maintenance activities.	

6.1 Barriers to achieve a twin transition

The twin transition is to take place in a society with a pre-existing economic model and already established work dynamics. To achieve a circular economy as much as to follow through the digital agenda, barriers will be faced [101] as summarised in table 6 and 7.

Table 6: Barriers to achieving a circular economy.

Economic barriers	Lack of intention towards secondary raw materials	EU current waste management	Information flow problems
· The existing economic model does not value natural capital or reward social or environmental impacts · The global market and value chains complicate policy steering at an EU level	· The lack of incentives from company to design with secondary raw materials (or more circular products) · The insufficient quality criteria for secondary raw materials · The lack of demand for secondary raw and recycled materials	· The products, materials and substances on the EU market that contain banned substances of concern, either because they were introduced before being banned or due to the lack of enforcement of REACH · The misalignments in EU chemicals, product and waste legislation, and the presence of certain chemicals, hampering efforts to recycle and re-use products [13] · The illegal waste burning or shipments · The different levels of ambition across the EU in reducing landfills and meeting the agreed recycling targets · The overall underdeveloped waste management infrastructure	· The information which does not travel with products and materials, hampering circular practices like maintenance, reuse, repair, and recycling · The overload or lack of information on products, complicating consumers' ability to make sustainable choices · The lack of common definitions for waste, and hazardous waste hinder shipments of waste across member states

Table 7: Barriers to achieving a digital transition [101]

Development speed differences between sectors	Lack of standardisation across EU	Societal barriers	Barriers related to the use of blockchains
· The inadequate digital infrastructure in EU for connectivity, Internet coverage and cybersecurity (if the EU fails to invest in this basic infrastructure, other related developments will come to a halt) [102] · The slow development and deployment of emerging technologies due to a lack of investments, innovation, and digital skills [103]	· The non-standardisation of data. They are not always comparable nor digital. Different data formats or low-quality data lead to poor outputs. · The lack of clarity on data ownership, degrees of freedom on data flow, and the continuous search for a balance between information sharing and protection of citizens' and businesses' sensitive data impact data economy developments. · The lack of interoperability between systems and data can impair data flows and analysis. ·Difficulties to update old hardware with new software spurs faster turnover of hardware · The barriers to digital services such as geo-blocking, procurement rules and the difference in fees for services and products	· The private and public sectors', and citizens' concerns on the privacy, security and trust related to the use of data can limit access and its usage. · The public sector's capacity to apply digitally enabled solutions that is a hindrance to societal developments. · The lack of basic digital skills and e-literacy in over a third of Europeans in the active labour force. · The lack of IT and AI professionals	· The doubts about the scalability and efficiency of these solutions. · The fact that companies would still need to be incentivised to share their data · The signification amount of energy required of the current 'generation' of blockchain [103] · The fact that the initial information uploaded on a blockchain must be accurate, as the quality of the initial input cannot be addressed by the blockchain itself · The problems that may cause sharing data via blockchain in terms of data privacy, liability, and competition · The lack of international standards and a common understanding of blockchain development

6.2 Risks and contradictions in the twin transition

Digital technologies can contribute to mitigation of climate change and the achievement of several SDGs. For example, sensors, internet of things, robotics, and artificial intelligence can improve energy management in all sectors, increase energy efficiency, and promote the adoption of many low-emission technologies, including decentralised renewable energy, while creating economic opportunities.

However, some of these climate change mitigation gains can be reduced or counterbalanced by growth in demand for goods and services due to the use of digital devices. Digitalization can involve trade-offs across several SDGs, for example, increasing electronic waste, negative impacts on labour markets, and exacerbating the existing digital divide. Digital technology supports decarbonization only if appropriately governed [105].

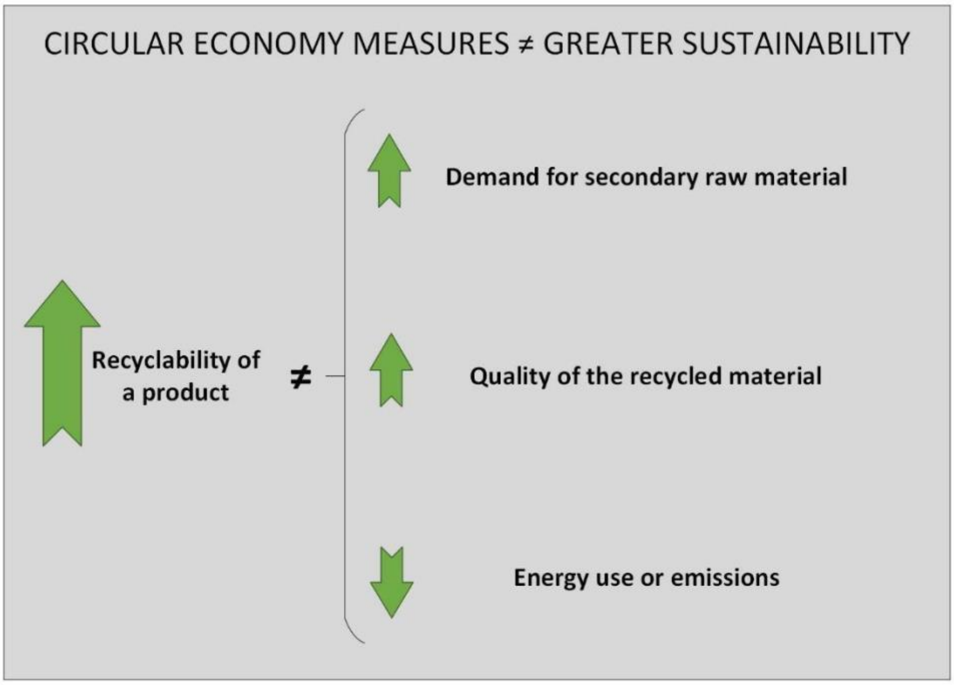

Figure 34: Greater sustainability measures" don't induce a greater sustainability

Some potential contradictions of the twin digital and green transition have already identified by researchers:

1. The first contradiction is that some **"greater sustainability measures" don't induce a greater sustainability**. For instance, increasing recycling alone does

not ensure the quality of recycled materials or demand for secondary raw materials. Product features like greater durability or recyclability do not automatically lead to lower energy use or emissions.

A good example of this can be the implementation of tethered bottle caps. This innovation makes them easier to recycle, however it also increases the use of plastic per bottle and the complexity of the manufacturing process which therefore requires more energy. Those factors result in an increase of GHG emissions [101].

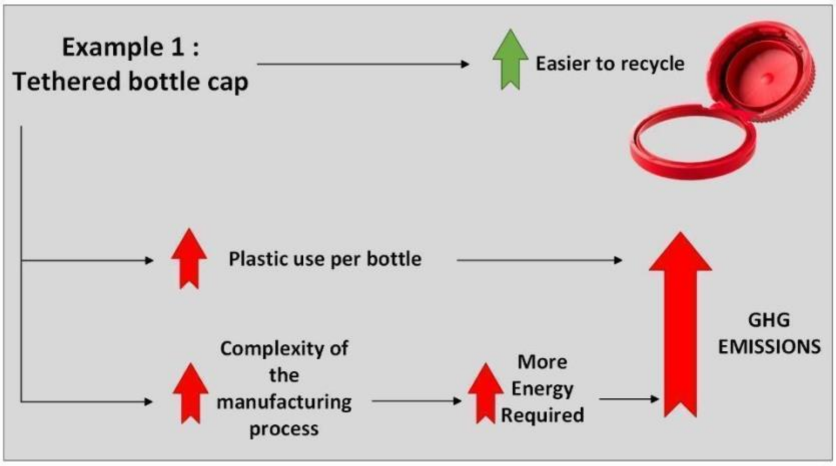

Figure 35: Implementation of tethered bottle caps example

2. **Circular behaviours from the consumer can also have a downside**. For example, keeping old electrical appliances instead of buying new ones will increase their life cycle and decrease the production of e-waste [101]. However, as these appliances get older, the technology becomes more obsolete, and becomes less energy efficient than the more modern product. As they use more energy, they also increase the emission of GHG.

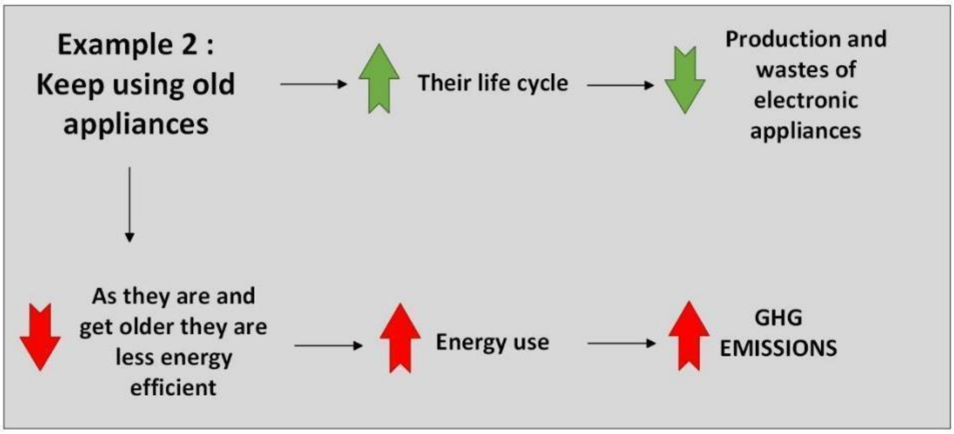

Figure 36: Example of circular behaviour with a downside

3. While **digitalization** can be seen as a powerful tool to boost circular practices, **it can also be a driver to unsustainable** ones, as the use and expansion of digital services can lead to unsustainable consumption, especially with e-commerce.

The increase of importation it generates can increase global transport flow and GHG emissions. Plus, if the product/material is not imported from the EU, the risk of importing some that is not permitted in the EU increases. This can lead to a reduction of global recycling and increased landfilling.

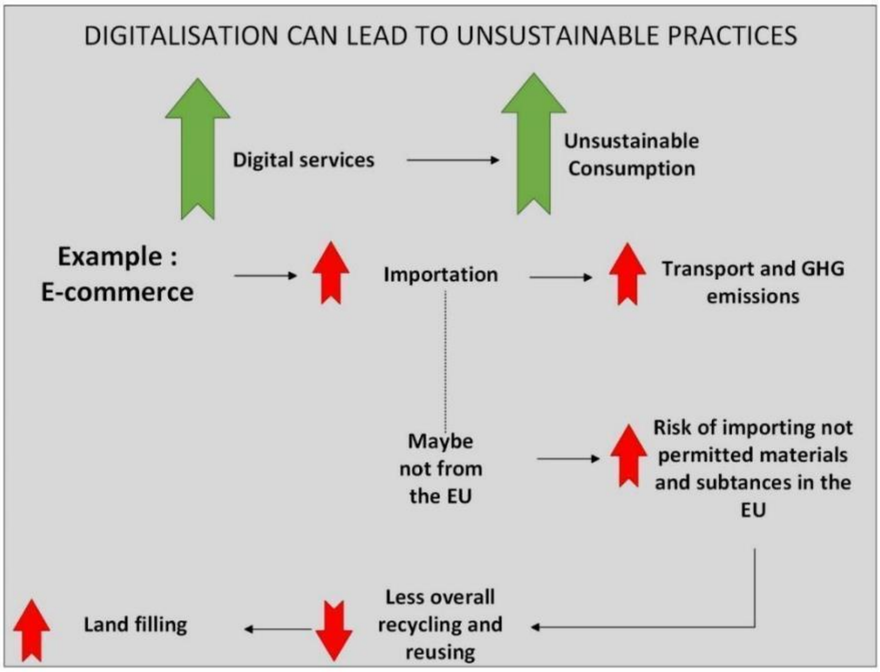

Figure 37: Diagram of digitalisation leading unsustainable practices [101] [106]

4. The rapid technological development and increase of data center demand will lead to a **raise in the requirement of digitally enhanced materials**, which is already often critical [101] [107]. This will result in an **increase of e-Waste and landfilling**, which leads to health and pollution issues (cf. Risks of an economic and societal digital transformation).

Energy wise, the information and communication technologies are responsible for 5 to 9 percent of the global electricity demand. As an increase in demand for data centres, cloud computing and intensive energy technologies is foreseen, this part of global electricity demand could go up to 20% in 2030 [101] [108].

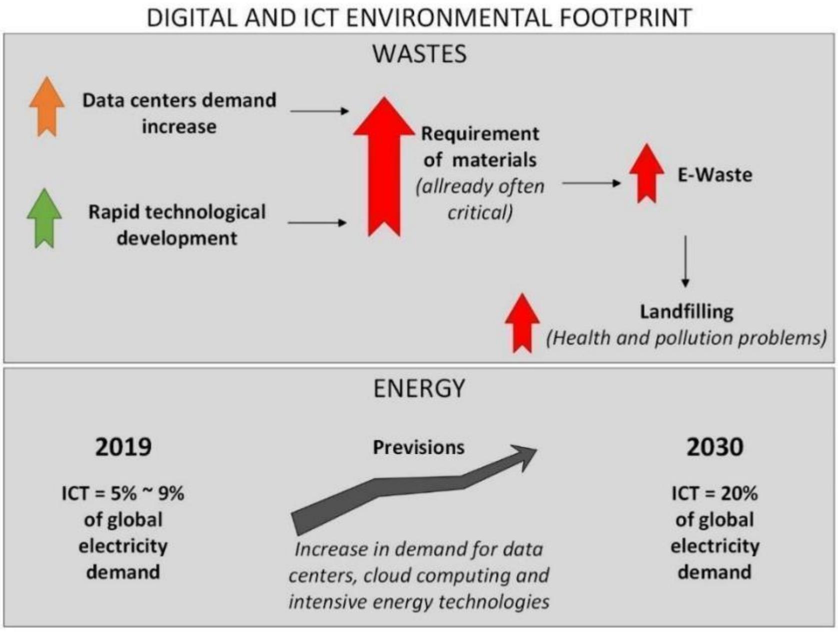

Figure 38: Diagram of digital and ICT environmental footprint wastes

5. **Health issues**, induced by what has been shown in previous points, can be caused by landfilling, radiations, or hazardous substances in the ground. But with the increase of data flow and digitally enhanced material, an **increase in cyberattacks and data stealing** can also be foreseen [108].

Socially, the **digital divide** should be in the centre of the preoccupations towards a digital transition. In the worst case, only the wealthy could access and utilise available technologies. However, there is already a growing gap between highly skilled specialists who can use complex technologies and low skilled workers who might get unemployed because of automation. Moreover, the gap between large companies and smaller ones can increase, as the latter might not have the necessary resources for reskilling programs or the adoption of new technologies [105].

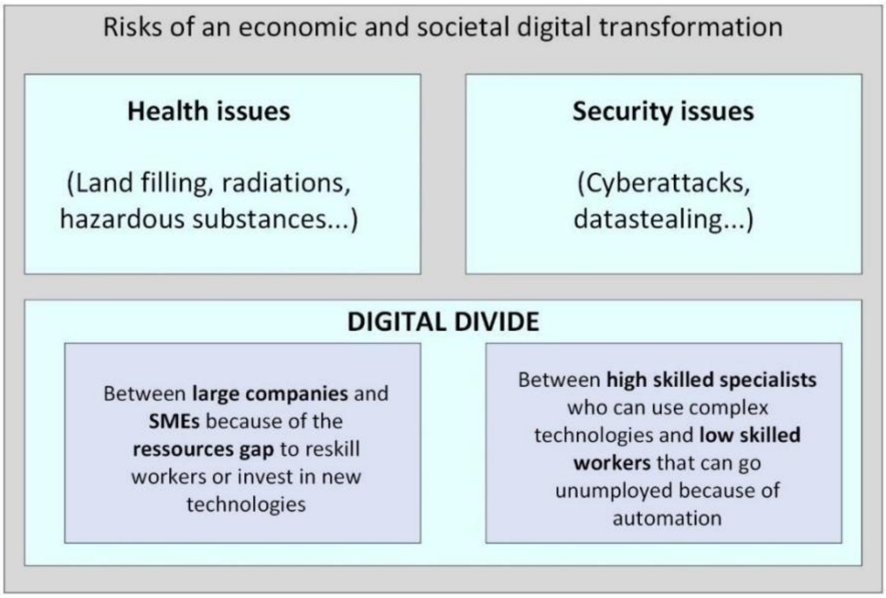

Figure 39: Risks of an economic and societal digital transformation

7. Policy landscape on twin transition

On the 2nd of May 2022, the 8th Environment Action Program (EAP) entered into force in the EU [109]. The 8th EAP calls for active engagement of all stakeholders at all levels of governance, to ensure that EU climate and environment laws are effectively implemented. These engagements are coupled with the Digital Europe Programme that aims to boost digital capacities and contribute to the digital deployment in Europe.

Thus, the framework of the Circular Economy Action Plan and the Digital agenda reflect and are part of the EU policies and efforts toward the twin transition.

7.1 Circular economy action plan

The EU Action Plan for the Circular Economy, also known as the Circular Economy Package, adopted by the European Commission in 2015, provides an outline of policy and legislative measures for improving production, consumption, waste management, markets for secondary raw materials, innovation, investments, and monitoring.

Although the action plan is complex and thoroughgoing, the importance of product design, as a key to a CE, shall be highlighted. To persuade companies to design with circularity in mind, different media can be used, such as taxation rules or Extended Producer Responsibility (ERP).

ERP is a policy approach which assigns producers responsibility for their products, even past the consumption stage which can be used to incentivise producers to design more sustainable products or to use more secondary raw materials. The possibility to use data and digitally enabled solutions to improve the functioning of the EPR (for example by enabling more efficient information sharing between producers and recyclers) should be further explored.

However, give responsibility of the waste management to the producer would be unavailing without implementing a more functional waste management policy. By modernising the waste infrastructures, facilitate legal shipment and ending the illegal one, the EU intend to become a global leader in waste management advanced solution. All that by keeping modern and digital solutions at the centre of these processes.

The consumer and their choices are also actors of a sustainable CE. By implementing Ecolabels and giving digital-enabled solution (like QR codes) to better and more easily understand the environmental footprint of a product, the consumer is given better tools to choose sustainable and ecological options when choosing a product.

Despite the complexity of monitoring a CE, the European commission has set ten indicators of a CE achievement.

Figure 40: Circular economy monitoring Framework [13]

Climate action and the wider sustainability agenda

In 2015 [101], world leaders committed to the UN's 2030 Agenda for Sustainable Development and Paris Agreement in which were stated the objectives of climate neutral Europe by 2050 and a reflection on a sustainable Europe by 2030. Therefore, digitalisation and data collection will help to support new economic and system thinking by capturing social needs and environmental values. The EU Product Environmental Footprint can be set as a good example as it integrates data on all relevant environmental impacts to better understand them.

Information and Data sharing via harnessing the potential of digitalisation is at the centre of the 8th EAP. To boost sustainable finance and transition, economic and tax incentives (as seen before) can be used. For example, to implement a better secondary raw material market, taxation rules (like decrease the VAT on those materials) could be used to increase demand for those materials. That same demand would be answered by implementing digitally enabled solution such as online platform to improve sharing data on and trading those valuable wastes.

Data and material flows can be deceptive if their provenance is not ensured, which is why collaboration from the onset with international partnership such as the UN, World Trade Organization (WTO) or Group of Seven (G7) could be engaged or reinforced to ensure the reliability and safety of different materials and data from outside Europe.

7.2 Digital agenda

EU has promoted a digital agenda for more than a decade and is as inclined as ever to use it as a driver for the CE. However, aligning digital initiatives with a sustainable, climate-neutral, and circular economy would require a twofold approach:

- Guiding and incentivising the digital/Information and Communication Technologies (ICT) industry to become more sustainable, climate-friendly and energy efficient
- Using data and digitally enabled solutions to benefit a more sustainable, circular economy.

Thus, 15% of the budget for the 2021-2027 Multiannual Financial Framework has been allocated to:

- The single market
- Innovation
- The digital sector

Those two last sections could use this budget to contribute to a digital transition to a CE. For example, by funding the Digital Europe programme that aims to boost digital capacities and contribute to the deployment of digital technologies in Europe.

This last programme is focused on five keys area:

- Supercomputers
- Artificial Intelligence (AI)
- Cybersecurity and trust
- Digital skills
- Ensuring the deployment and the uptake of digital technologies

This would bring a great opportunity for a CE that, as we saw before, would truly benefit from a more "open data economy". However, rules such as General Data Protection Regulation (GDPR), Copyright Directive or proposed EPrivacy Regulation may add unnecessary restrictions. Thus, they shall be reviewed from a CE perspective, as well as for the Open Data and Public Sector Information Directive and the free flow of non-personal data.

Although EU is lagging in AI in global comparison, it is stronger in blockchain. They could play a prominent role in enabling the sharing of data on substances, materials, and products in a secure environment and across value chains. Furthermore, in 2019, the Commission also facilitated the creation of the International Association of Trusted Blockchain Applications, a forum bringing together developers, users, and regulators to steer further development of distributed ledgers. This could enable the exploration of ways to turn blockchain into a driver of sustainability and CE.

Framework conditions for the industry

Public procurement (the process by which public authorities, such as government departments or local authorities, purchase work, goods, or services from companies) accounts for 14% of European Gross Domestic Product (Around 2€ Trillions per Year) on the purchase of work, services, and supplies. The procurers have the expertise to consider not just the price, but also the life-cycle costs and environmental and social sustainability when allocating contracts. Thus, could introduce a **"Circular Public Procurement"** [110] and contribute to a closed energy and material loop within supply chains. Digitalising the procurement to facilitate it and provide a political mandate to use procurement as an investment tool for a CE could stimulate the development of a market for valuable solutions.

Implementing standards for products, systems and services are powerful tools in promoting innovation, fostering competition and in guaranteeing consumer safety in the single market. However only 2% of those standards are for services. Developing standards for services and new coming technologies, while keeping a CE and digitally enabled aim could help EU become a global standard setter on an ecological and innovative level.

Encouraging collaboration and innovation

The **EU's Important Projects of Common European Interest (IPCEI) framework** allows member states to support and fund innovative projects in compliance with the EU's state aid rules and initiatives are currently developed for example on batteries, high-performance computing, and automated vehicles. It makes sense to use the current momentum to push for new areas for collaboration, including aligning digitalisation efforts with a CE. **European Investment Bank** (EIB) financing, **Emissions Trading System** (ETS) **Innovation**

Fund and Invest EU Programme should also be used to leverage public and private funding in order to support innovative solutions for a sustainable CE.

The European structural and investment funds (ESIF) and especially the Cohesion Fund, the European Regional Development Fund, the European Social Fund and Erasmus+ (possibly around €400 billion in 2021- 2027) can contribute to economic and societal transition by supporting research and innovation, SMEs, digital technologies, low-carbon economy, and sustainable management of natural resources. For example, the Smart Specialisation Platform supports member states and regions with smart specialisation strategies and could be used to increase their awareness on the linkages between a CE and digitalisation, and their capacities to implement innovative, sustainable, and circular solutions.

Empowering people and society

The European commission intend to empower costumer by teaching them how to make sustainable and optimal decisions. Taking the increasing information overload (which is a downside of digitalisation), consumers need guidance on contributing to a more sustainable economy. The extent to which digitally enabled solutions (such as online platforms, chatbots, games, apps) could be used to inform consumers better and incentivise sustainable behaviour should be explored.

However, looking ahead, ensuring people's trust in digitally enabled solutions, and avoiding a digital divide are keys. Initiatives on EPrivacy and cybersecurity and the eventual GDPR review should ensure that data is collected, processed, and shared in a trustworthy and secure environment, and thus help ensure social trust in the new digital environment. Investing in people skills by teaching them how to use these tools and to make them as intuitive as possible is mandatory to avoid a digital divide in which part of the population couldn't rely on those digital enhanced technologies.

7.3 Legislative instruments

In the framework of the Circular Economy Action Plan (table 8) and the Digital Agenda (table 9) different EU legislative instruments (policy frameworks, directives, and regulations) have been released in the last years. Following tables classify the different legislative instruments by processes where they have a direct impact.

Table 8: European legislative instruments for the circular economy action plan

Process	Policy framework	Directive	Regulation
Product design	· Incentivise producers to design more sustainable products · Accentuate demand for secondary raw material	· Implement taxation rules on secondary raw and sustainable materials · Develop the Extended Producer Responsibility · Use data to share info between producer and recycler Develop standards in European products	· Supress TAV on secondary raw materials
Waste managemen t	· Modernise waste management infrastructures · Make the EU a global leader in waste management modern solutions	· Develop valuable waste management and trading online platforms · Facilitate legal shipment of waste and end the illegal one	
Wider sustainability	· Make the consumer an actor of sustainability · Harness the potential of digitalisation · Ensure international partnership (UN, WTO, G7...) · Monitor the Circular Economy development	· Make the product's sustainability easier to comprehend · Ensure provenance, safety, and reliability of imported products - Monitor waste management, production, consumption, and the use of secondary raw materials	· Implement more Eco-labels · Use digitally enable solutions (QR code) to facilitate the comprehension of a product's environmental footprint

Table 9: European legislative instruments for the digital agenda

Process	Policy framework	Directive	Regulation
Use the digital agenda as a driver of circular economy	· Turn the ICT industry more sustainable, climate friendly and energy efficient · Use data and digitally enabled solutions to benefit a sustainable economy	· Allocate 15% of the budget for the 2021-2027 Multiannual Financial Framework to the Single market, innovation, and the digital sector. · Allocate with the ESIF up to €400 billion for 2021-2027 in the sectors of research and innovation, SMEs, digital technologies, low-carbon economy, and sustainable management of natural resources · Fund the digital Europe programme to boost digital capacity · Use the blockchain capital of the EU to share data or substances	
Implement a more open data economy	· Revise the flow of non-personal data in Europe if it can benefit a CE	· Review the GDPR, the Copyright Directive or the proposed EPrivacy Regulation with a CE perspective	
Enable a circular public procurement	· Consider the life-cycle costs and environmental and social sustainability when allocating contracts · Use Public Procurement to stimulate the development of a market for sustainable solutions	· Digitalise the procurements to facilitate them	· Provide a political mandate to use procurement as an investment tool for a CE
Empower and protect the people	· Incentivise sustainable behaviours to consumers · Avoid digital divide so everyone can rely on those digital enhanced technologies · Ensure that data is collected and shared in a secure environment	· Use digitally enabled solutions (such as online platforms, chatbots, games, apps) · Invest in people skills - Make the digital enhanced tools as intuitive as possible	

8. VET programmes on twin transition

Several educational programmes in Europe have touched upon specific dimensions of the TWIN REVOLUTION upcoming training curriculum. The sections below describe existing programmes that will be used as starting point to develop an integrated learning pathway aiming at developing the skills and knowledge relevant to upskill textile and furniture workforce.

8.1 Twin transition learning in the textile industry

TECOFASH. Strategic Partnership Promoting Education for the Transition of the Fashion Sector Towards Digital and Sustainable Business Models

Programme: Erasmus+ 2021-1-PL01-KA220-VET-000034636

Coordinator: Regionalna Izba Gospodarcza w Katowicach

Start: 01-11-2021- End: 31-10-2023

Abstract: The main objective of TECOFASH is to support a performant, competitive and sustainable European fashion industry, focusing on increasing the capacity of professionals from SMEs and start-up to turn their business toward circular business models and environmental and sustainable innovation thanks to transnational and intergenerational cooperation and training. The training proposal will focus on two pillars:

- Sustainable and digital production processes, addressing the technical and operational aspects linked to the design, production, and distribution of fashion products, for instance how to reduce water consumption or taking care of the raw materials used.
- Sustainable and digital management of a fashion company, that will explore how to turn the entire management system in a circular and responsible loop, including for instance cooperative management systems based on human and social responsibility.

SKILLS4SMART TCLF 2030

Programme: Erasmus+ 591986-EPP-1-2017-1-BE-EPPKA2-SSA-B

Coordinator: European Apparel and Textile Confederation

Start: 01-01-2018- **End**: 30-06-2022

Abstract: The project aims to enhance the modernisation and competitiveness of the EU Textile, Clothing, Leather, and Footwear (TCLF) sectors through the development of a sustainable upskilling and reskilling strategy, which is supported by a communication campaign to attract social, economic, and political actors.

8.2 Digital transition learning in textile industry

TEXMODA. Advanced Technologies for Textile and Fashion Industry

Programme: Erasmus+ 2017-1-LT01-KA203-035160

Coordinator: Kauno Technologijos Universitetas

Start: 01-10-2017- **End**: 31-10-2019

Abstract: The main aim of the project TEXMODA was to develop a massive open on-line course (MOOC) "Advanced Technologies for Textile and Fashion Industry" with corresponding Competence profile, Curriculum, Learning materials, which is open to every interested person, however the target audiences of the MOOC are students at higher education in clothing, textile and fashion departments and recent graduates; SME's employees working in textile and fashion industry; VET graduates of clothing, textile and fashion that want to upgrade their skills and competences.

SKILLS4SMARTEX. Smart textiles for STEM training

Programme: Erasmus+ 2018-1-RO01-KA202-049110

Coordinator: Institutul National de Cercetare-Dezvolatare Pentru Textile si Pielarie

Start: 01-10-2018- **End**: 31-12-2020

Abstract: The Skills4Smartex project was centred on improving knowledge, skills and employability of VET students in the STEM related fields, by providing adequate training instruments to understand multidisciplinary working on the textile sector.

8.3 Green transition learning in textile industry

DESIGN4CIRLE. Innovative design practices for achieving a new textile circular sector

Programme: Erasmus+ 2018-1-LV01-KA202-046977

Coordinator: Rigas Tehniska Universitate

Start: 01-12-2018- **End**: 28-02-2021

Abstract: The objective of Design4Circle is to create an innovative learning curriculum in line with the needs of designers of the textile and fashion industry towards a circular business model, being the main target group current and future fashion designers of the textile industry. Design4Circle will allow designers from the textile sector to reduce environmental impact during the product's life cycle, and to develop new and innovative businesses within the principles of circular economy.

CIRCUTEXT. Circular economy in fibrous composites and technical textiles through the use of virtual laboratories

Programme: Erasmus+ 2021-1-ES01-KA220-HED-000032075

Coordinator: Universitat Politecnica de Valencia

Start: 28-02-2022- **End**: 27-02-2024

Abstract: The project aims at offering an online course on circular economy for fibrous composites and technical textiles, which will help students, who are enrolled in relevant fields in their universities to upskill their sustainability competences and raise their awareness on how to reduce the effect that fibrous composites and technical textiles have on the climate change. The course will be enhanced with the creation of a virtual laboratory, which will help students get a real feel as if they were present in a laboratory

ECOMODA. Upskilling clothing and textile SMEs for sustainable and ethical growth

Programme: Erasmus+ 2021-2-PL01-KA220-VET-000048919

Coordinator: Lodzka Izba Przemyslowo-Handlowa

Start: 01-03-2022- **End**: 29-02-2024

Abstract: The main objective of ECOMODA is to raise awareness on the importance of sustainable and ethical development in the textile and apparel sector with special focus on Small and Medium sized enterprises, through the design and pilot a high-quality e-learning course.

8.4 Twin transition learning in furniture industry

WOODIGITAL. Dual Learning for Improving Digital Skills of Young Woodworkers

Programme: Erasmus+ 2020-1-FR01-KA202-080104

Coordinator: INTERPROFESSIONNELLE AUVERGNE RHÔNE ALPES (France)

Start: 01-10-2020- **End**: 30-09-2022

Abstract: The Woodigital project aims to develop a digital training course to reduce the gap in digital skills specific to the **wooden furniture sector**, which is still very high in European countries today. Training courses will be developed that address the needs identified by companies in the sector, such as:

- **Circular economy** and sustainability.
- **Digitization of processes and new technologies.**
- Understanding of new lifestyles.
- Globalisation.
- New market trends and personalised customer orientation.

WOODigital will first identify the digital skills and competencies needed by young people who work or are interested in working in the wood and furniture sector.

INTRIDE. Soft, Digital and Green Skills for Smart Designers: Designers as Innovative TRIggers for SMEs in the manufacturing sector

Programme: Erasmus+ 612622-EPP-1-2019-1-IT-EPPKA2-KA

Coordinator: UNIVERSITA DEGLI STUDI DI FIRENZE (Italy)

Start: 01-01-2020- End: 31-12-2022

Abstract: INTRIDE aims at developing new innovative and multidisciplinary approaches and tackling future skills mismatches. In terms of specific results INTRIDE aims at:

- developing a Joint master's degree Curriculum for Smart Designers with added competences related to Soft, **Digital and Green Skills** that will become the future innovation triggers for SMEs in the **traditional manufacturing sector**
- building a co-creation structure under a HE-industry community platform which is supposed to be a virtual place for activation and monitoring of innovation, technological transfer, R&D processes under the cooperation between enterprises, HEIs and technical centres.

The project is oriented towards traditional manufacturing sectors, but two of its partners are entities related to the **furniture sector.**

SAWYER project: identifying skills and safety needs for the furniture sector's circular transition

Programme: European Commission call: Support for Social Dialogue VP/2018/001

Coordinator: CENFIM (Spain)

Start: 02/2020 - **End**: 03/2021

Abstract: The SAWYER project aims to facilitate the transition of European **furniture companies** to a more circular economy. The project ran from February 2020 to March 2021, studying the main legislative and voluntary instruments that can facilitate this **circular economy transition**. It also analysed how these instruments are expected to impact and transform the European **furniture sector** by 2030, alongside the **digital transformation ("twin transition").** Lastly, SAWYER will study how this transition can affect existing jobs, workers' health and safety risks, and their new training needs. The final report will be available in 10 languages.

The main results are:

- Mapping the state of play of circular economy legislative and voluntary instruments in the European furniture sector
- Identifying how the circular economy and digitalisation ("twin transition") could affect jobs and tasks
- Preparing recommendations for legislators and regulators, as well as Vocational Education and Training providers.

EQ-WOOD. Quality Qualifications for the European Woodworking and Furniture Industry

Programme: Erasmus+ 591939-EPP-1-2017-1-IT-EPPKA2-SSA

Coordinator: UNIVERSITA DEGLI STUDI DI FIRENZE (Italy)

Start: 01-01-2020- **End**: 31-12-2022

Abstract: The project EQ-Wood tackles innovation capacity and competitiveness of **EU wood and furniture industry** by designing and delivering the curriculum of Innovation Advisor in the Wood and Furniture Industry. It helps managing innovation by merging **green, digital and marketing skills** and provide learners with specific competences required by the sector evolution in Europe.

FUNES. Furniture New European Skills 2020

Programme: Erasmus + 2014-1-ES01-KA202-004883

Coordinator: Aidimme (Spain)

Start: 09/2014 - **End:** 08/2017

Abstract: FUNES will generate a interrelationship among various the new skills demanded in the **furniture sector in** the future years, a system to evaluate whether a worker of this sector has the **future skills,** and a specific training material that will be generated in order to facilitate the acquisition of these specific skills, **recommending about the soft skills needed** by the current and future workers for this sector. The training material generated will be in e-learning format to facilitate the training at workplace or in a VET centre.

As a result of conducted work, new skills and competences were selected like environmental awareness; applying **the environmental and sustainability concepts** (incl. ecological concepts in the design of products and 'zero waste' design) or the use of computers and the rapid development of **digital technology** and robotics.

8.5 Digital transition learning in furniture industry

DITRAMA – Digital Transformation Manager

Programme: Erasmus+ 601011-EPP-1-2018-1-ES-EPPKA2-SSA

Coordinator: CENFIM (Spain)

Start: 01/01/2019 - **End**: 31/12/2021

Abstract: leading companies in Furniture value chain to implement their digital transformation strategy DITRAMA aims to provide an innovative MOOC for training managers (Digital Transformation Managers) to successfully lead and implement the digital transformation in furniture companies along the whole value chain

Digifind - Enhance Adult Learners Digital Skills for Furniture Industry

Programme: Erasmus+ 2018-1-BG01-KA204-047923

Coordinator: UNIVERSITY OF NATIONAL AND WORLD ECONOMY (Belgium)

Start: 01/09/2018 - End: 31/08/2021

Abstract: The project aims to support adult trainers in acquiring the necessary competences for teaching digital skills and Industry 4.0 to low-skilled adults in Furniture industry, in order to guarantee the future furniture sector sustainable development and to foster their employability, socio-educational and professional development. The objectives include developing a training program for trainers, educational materials, and innovative instruments for supporting the training on digital skills for low-skilled adult employees in Furniture sector.

IN4WOOD – Industry 4.0 for Wood and Furniture Manufactures.

Programme: Erasmus+ 575853-EPP-1-2016-ES-EPPKA2-SSA

Coordinator: CETEM (Spain)

Start: 01/11/2016 - End: 31/10/2019

Abstract: IN4WOOD's objective is to modernise vocational training by focusing on ICT skills needs to increase the competitiveness of the wood and furniture industry. This Alliance, composed of VET technology providers, VET authorities and wood and furniture experts from 4 EU countries, has strengthened the exchange of knowledge and practices between them and the labour market and will increase the recognition of qualifications at EU level in production managers and the target industry.

It delivered a specific on-line training course in these topics. No copyright issues are foreseen for the project outputs use.

MAKING 4.0 – Improving Malaysian HE Knowledge towards a Wood and Furniture Industry 4.0.

Programme: Erasmus+ 598783-EPP-1-2018-1-ES-EPPKA2-CBHE-JP

Coordinator: UPCT (Spain)

Start: 01/11/2018 - End: 31/08/2022

Abstract: The aim is to improve the sustainability of the industry in Malaysia and to strengthen collaboration and development between European and Asian universities. As a result, Malaysian and European partner universities should be able to offer high-level training on Industry 4.0-related trends and technological developments for their students, representatives of the participating Malaysian wood and furniture industry and other stakeholders.

8.6 Green transition learning in furniture industry

FURN360. Novel training approach for circular business model innovation in the furniture and woodworking sectors.

Programme: Erasmus+ 2017-1-BE01-KA202-024752

Coordinator: ECORES (Belgium)

Start: 01/12/2017 - End: 31/08/2020

Abstract: The aim of FURN360 is to create an Innovative didactic content to promote the integration of the Circular Economy Principles within the furniture and woodworking sectors. It comprises a joint curriculum, didactic materials, and a collaborative platform in line with the needs of the different target users identified.

ECO4VET - Improvement of Vocational Education and Training related to Ecodesign in the Furniture Sector

Programme: LEONARDO 539774-LLP-1-2013-1-ES-LEONARDO-LMP

Coordinator: CENFIM (Spain)

Start: 01/12/2013 - End: 31/03/2016

Abstract: The lack of an official curriculum on ecodesign and sustainable production directly affects the traditional manufacturing furniture industry, which is dominated by microenterprises (86% of EU enterprises have less than 10 workers) as their designers, production, purchasing and logistics staff, managers and responsible of management systems are not fully supported with these skills. The size and structure of these EU furniture companies do not help adapting the workers to these new requirements (legislation, environmental, market). Furthermore, taking into account the recent consolidation of **ISO 14006 regarding ecodesign**, it is necessary to address the training needs of the different enterprises that want to implement it.

ECO4VET aims at addressing the identified **educational gap in the furniture sector** developing tools and methods for **training workers in "Ecodesign and Sustainable Production".**

9. Learning outcomes for a twin revolution

According to the Recommendation on the European Qualifications Framework (EQF), learning outcomes are statements of what a learner knows, understands and is able to do upon completion of a learning process.

Based on the main findings of this blueprint, the project consortium has identified a set of key learning outcomes following the Knowledge, Skills, and Competences framework from the Council Recommendation on the European Qualification Framework for lifelong learning and the CEDEFOP handbook on defining, writing, and applying learning outcomes (CEDEFOP, 2017).

- **Knowledge** means the outcome of the assimilation of information through learning. Knowledge is the body of facts, principles, theories, and practices that is related to a field of work or study. In the context of the EQF, knowledge is described as theoretical and/or factual.
- **Skills** means the ability to apply knowledge and use know-how to complete tasks and solve problems. In the context of the EQF, skills are described as cognitive (involving the use of logical, intuitive, and creative thinking) or practical (involving manual dexterity and the use of methods, materials, tools, and instruments).
- **Competences** mean the proven ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development.

The key learning outcomes for a Twin Revolution are outlined below. Identified skills part of the ESCO database connected with these learning outcomes are inter-linked.

Knowledge

- Describe the concept of Circular Economy and its current status
- Describe the concept of Industry 4.0 and its current status
- Describe the current state of the furniture and textile sectors regarding digital transition
- Describe the current state of furniture and textile sectors regarding green transition
- Describe the interconnections between green and digital transition for the manufacturing industry
- Describe Key Enabling Technologies (KETs) supporting circularity in the textile and furniture industry
- Describe the policy landscape at EU level supporting the twin transition of the manufacturing sector
- Be aware of companies' best practices regarding green and digital transition of the manufacturing sector

Skills

- Identify and recognize key circular strategies, tools and processes relevant for the textile and furniture industry
- Identify relevant Key Enabling Technologies (KETs) of the Industry 4.0 relevant for the textile and furniture industry
- Identify material, product, processes, business models and ecosystem innovations supporting a twin transition in the textile and furniture industry

Competences

- Analyse, compare and select circular strategies relevant for the textile and furniture industry
- Analyse, compare and select relevant KETs supporting a twin transition

10. Recommendations for the VET system: Towards an integrated green and digital curriculum development approach

As highlighted in the blueprint, the Twin Transition of the manufacturing industry creates a demand for new specific competences and skills of the workforce. Anticipating and building future-fit skills is essential in this rapidly changing labour market. Despite an emerging offer of training programs focusing on digital and green skills (see previous section), the current supply of skills often does not match this demand for new and adapted skills. There is a clear gap between the skills needed by the Twin Transition of the manufacturing sector and the current educational offer.

The following recommendations are based on the analysis on the current VET programs in textile and furniture sectors and the input of studies on future skills and competences [111] [112]

- **Systematically review existing curricula with circular and digital dimensions**

The adaptation or modification of existing curricula should respond to or even anticipate the changing skill needs for the Twin Transition. The modification of courses and learning outcomes in curricula that are set up in a modular way or based upon workplace-based training makes it very flexible to integrate the new skills.

- **Create new future-fit curricula integrating inputs from digital and circular pioneer companies**

Beyond adapting existing curricula, new integrated trainings should be developed taking the twin transition as a starting point. These new curricula should be codesigned locally with sector councils and take into account the emerging practices from representatives of (green) industry and digital champions.

- **Close the gap between new theories and concrete implementation**

Many courses and programs are already being modified to integrate (some) aspects of circular economy and/or of digitalization. But this is too often only 'sideways' and too limited. For example, using wood or textile from sustainable sources is often only taught in theoretical lessons, but not included in the procurement of the used resources in the workshops. Similarly, digitalization is taught as a concept, but often not integrated in the machine-workshops, where the computers are outdated and unsuited for demanding VR/AR applications.

- **Increase collaboration between training institutions and the industry**

In order to introduce circular & digital economy in the curricula of VET schools, local businesses should be used as learning cases for students to redesign their products in a circular economy perspective.

- **Offer reskilling programmes for the existing workforce**

Besides the adaptation or design of curricula for students, there is a growing need to develop adapted training paths for the 'upskilling' and 'reskilling' of the existing workforce to match the requirements of the twin transition following a continuous learning mindset.

- **Diversify training delivery methods**

Integrated curricula should be delivered taking a portfolio approach: modular, workplace-based, web-based learning, hybrid learning methods, off-campus training… can be used to offer on-demand and personalised training pathways for anyone interested. Methods should be adapted to the specific target groups and focus on changing the mindset, rather than addressing purely technical issues.

- **Promote circular and digital literacy through stakeholders' collaboration**

Effective methods to anticipate future skill needs include sustained dialogue between employers and employees, companies and trainers, coordination across governmental institutions, labour market information systems, employment agencies… Collaboration and cooperation at all stages is needed. All stakeholders - training providers, social partners (firms, employers' and employees' organisations and federations), universities and academic world, sectoral organisations, public employment services and all the relevant governmental partners (ministries of education, work, environment, digitalization…) need to be included.

- **Combine technical and soft skills for the twin transition**

The Twin transition relies on the integration of technical digital skills with a strong understanding of sustainability and circularity principles. In that context, soft skills should not be neglected (systems thinking, collaborative thinking, multidisciplinary).

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