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CIRCULAR ECONOMY THROUGH 4.0 TECHNOLOGIES: THE CASE OF EYEWEAR

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Sommario

Introduction

Sustainability concept has been gaining importance in the last years. The plastic crisis we are experiencing and the general increase in pollution and social discrimination are raising awareness amongst a big share of industries' actors and customers.

Manufacturing for apparel and accessory is one of the industries which have the higher environmental footprint, due to the increasing consumerism lead by a raise in the disposable income and the fast-changing trends of the fashion industry. The industry is working for reducing the impact of its products on the environment, also thanks to the increasingly awareness of consumers about environmental issues, that pushes fashion actors to search for greener materials and production processes.

For reducing this impact, a solution could be found in the adoption of a circular system of economy, for the sustainable design and recycle of products.

The evolution of technologies has brought an important support in improving the companies' environmental performances without sacrificing their economic ones, fostering the adoption of circular economy. Disruptive technologies introduced by the 4.0 industry revolution could support the transition to sustainable production increasing efficiency and improving the services a company can offer to the market.

The thesis is organised as follows.

In chapter one will be introduced the concept of sustainability in all economic, social and environmental needs. We will see which is the situation today and how Governments are promoting sustainability in their policies. In particular, the concept of Circular Economy will be explained, showing which are the environmental and economic benefits that this production system could bring if businesses choose to grow through the adoption of a circular business model.

In chapter two we will go deeper in the fashion industry's environmental impacts, analysing which have been the trends that lead to the consumerism levels we are experiencing today. The transformations that fashion industry has gone through and the role of customers in these changes will be analysed. It will be seen if fashion can be considered sustainable and which are the circular economy practices that are being adopted for trying to reduce the industry's footprint, especially from luxury segment's brands.

In chapter three will be introduced the fourth industrial revolution and the impact that 4.0 technologies have on industries. We will see which are the main 4.0 technologies and how they can help in greening the production processes and enabling the circular economy, playing therefore a role in the sustainability of manufacturing activities. It will be seen how these technologies could help enabling a circular economy and which are the benefits of adopting a 4.0 supply chain.

In chapter four we will see how the concepts of circular system and industry 4.0 are applied in the eyewear sector, with particular focus on the 3D printing technology. It will be analysed how actors in the eyewear sector exploit digital technologies as well as try to become more sustainable through materials' innovation. 3D printing can bring to a shift in the business model adopted by companies towards a more service-oriented, but it will emerge how the limits imposed by this technology cause different adoptions of between small producers/ retailers, and big leaders of the design, production and distribution of the eyewear sector.

1. Sustainable development and the concept of circular economy

The increasing concern about the environment's problems in the last years has increased the importance of the concept of sustainability, and in particular has shown the necessity to persuade a sustainable development. Environmental issues are mainly the effects of the human activity, but how can we try to reduce this impact? Which are the strategies or models that business can adopt in order to reduce the footprint that their activities have on the environment?

1.1 Sustainability and sustainable development

The concept of sustainability has its origin in the Brundtland Report of 1987[1], in which sustainability has been defined as the balance between the aim of reaching an even better life and the limitations deriving by the nature. Since then, the concept has shifted in meaning but the focus of the debate remains the regenerative capacity of the environment and the substitution potential in the economy.

Sustainability and economics are strictly corelated due to the social and economic consequences it brings. When attempting to change development patterns, the social, cultural, health and financial aspects must be taken into account. Nowadays, differences between North and South of the world are undeniable: the number of inhabitants in developing countries is growing and their individuals aim at reaching western lifestyle, characterized by high consumptions, while in developed countries the number of inhabitants' growth is slow, but the level of consumptions is unbearable. The objective of sustainability is to manage this gap between the two countries without deteriorating even more the environmental resources. This can be possible using strategies and technologies which increase the efficiency of the processes and at the same time reduce the exploitation of resources above a critical threshold. Growing through sustainability can have a positive impact on costs reduction, on the increase of market share (due to the public image that the company will benefit of) and on the creation of new employment. Instead, growing overexploiting the environment can lead to an antieconomic growth, reducing the lifestyle of individuals[2].

[1] World Commission on Environment and Development (1987).

[2] Daly (1999) defines the antieconomic growth as the "*growth that, at the margin, increases environmental and social costs by more than it increases production benefits. […] When growth becomes uneconomic, we must find new answers to the problems of overpopulation, unjust distribution and unemployment*."

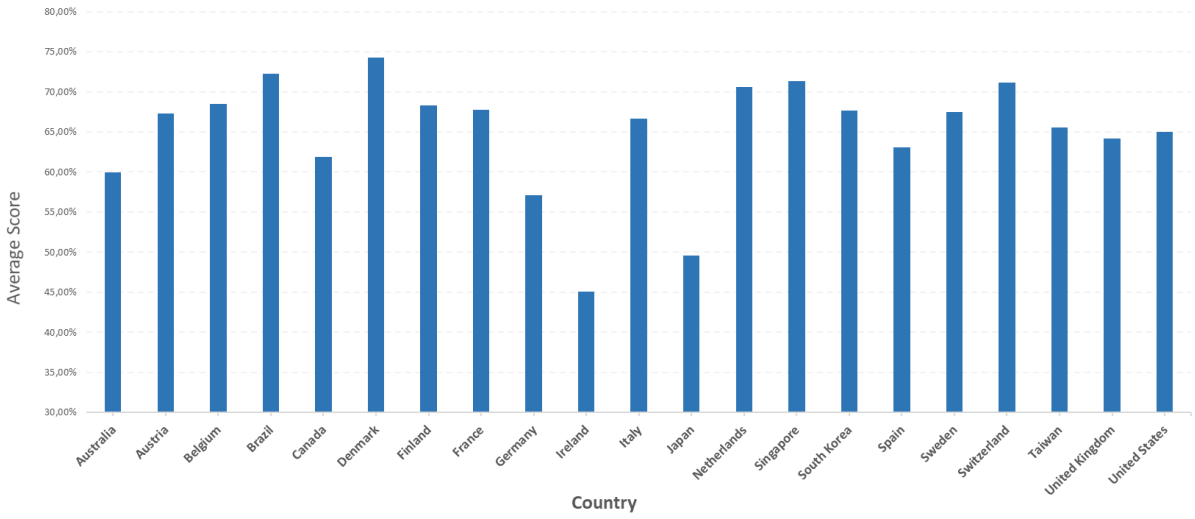
Businesses are being asked to adopt long-term practices more sustainable and at the same time this means that they need to improve profitability for funding innovation on new technologies. Sustainability encourages companies to set decisions based on long-terms perspectives, considering factors besides the usual profit-loss balance. But why not all companies decide to set sustainable goals? For embracing a sustainable production, long term investments in efficiency and renewable resources are needed, and this usually led to a more modest earnings result in the short-term. From this perspective, investors must adjust their expectations for returns when a company decides to shift to a greener process.[3]

Despite the "financial sacrifice" required for embracing a greener business, an ever-increasing number of companies takes this decision. Each year companies are ranked after being evaluated on a vast range of fixed parameters, which go from productivity under different aspects (energy, waste, water, particular matter,…), to the innovation capacity, to the women's employment in executive roles, taking into account also the suppliers' sustainability score. In *Appendix 1* we can find this year ranked proposed by *Corporate Knights* agency[4] for the year 2019 Global 100 most sustainable corporations in the World. As we can see in *Graph 1*, the 100 corporations are spread in 20 countries, the most of which are European. The country where the average sustainable score is higher is Denmark (74,26%), which is also the country of origin of the first ranked company: Chr. Hansen A/S, a bioscience company that develops natural solutions for food, beverage, nutritional and pharmaceutical industries. The second-best performing country is Brazil, one of the five major emerging national economies[5]. Amongst the 100 companies of the rank, four are Brazilian companies, three of which are within the 20th position. This positive presence indicates how, even if sustainability needs primarily economic funds, also developing countries are making changes for trying to get along with the environment needs. Clearly, the efforts required from these countries are greater given the generally higher social problems (amongst which corruption) and a less instable income, education and health, which deviate the worries from the environment.

Looking at the industries in which these companies operates (*Graph 2*), the highest score is achieved in the Petroleum Refineries industry, with Nested Corporation, a Finnish oil refining and marketing company, ranked as second in the Global classification.

[3] https://www.investopedia.com/terms/s/sustainability.asp. The article also outlines how investors are discouraged by the lack of transparency of companies' earnings result.
[4] https://www.corporateknights.com
[5] Brazil is one of the BRICS countries, along with Russia, India, China and South Africa. These nations are considered to have strong developing economies, rich strategic natural resources and an important growth of gross GDP.

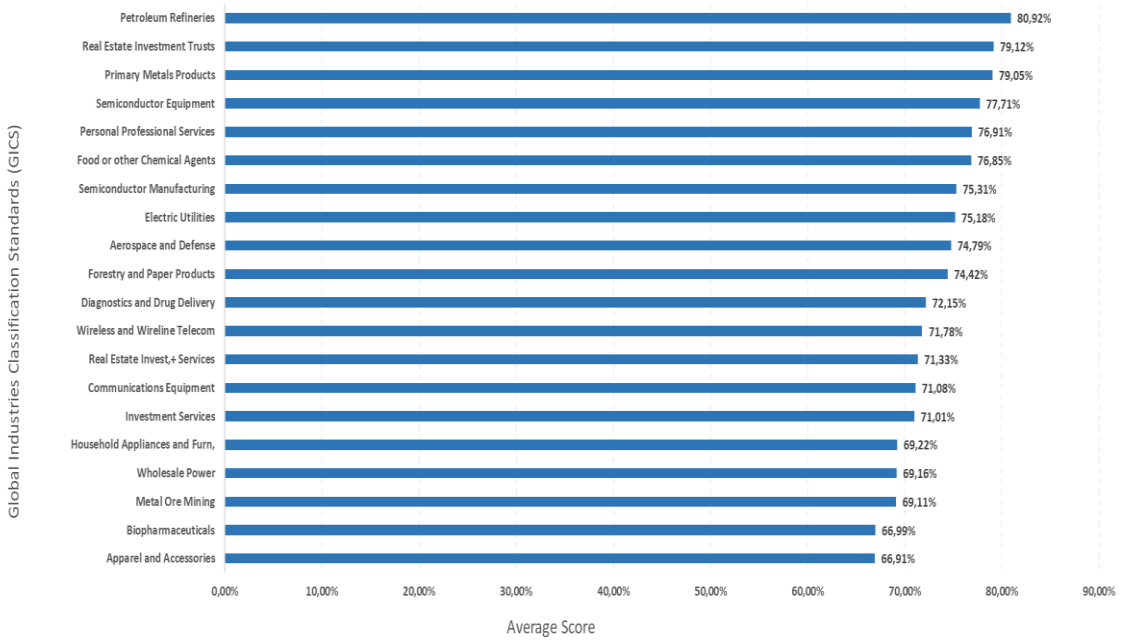
Country of origin of the 100 most sustainable firms



Graph 1: Country of origin of the 100 most sustainable firms

Source: Author's elaboration from Corporate Knights data, 2019

First 20 industries in which the top 100 most sustainable companies operate



Graph 2: First 20 industries in which the top 100 most sustainable companies operate

Source: Author's elaboration from Corporate Knights data, 2019

1.1.1 The three dimensions of corporate sustainability

Sustainability involves the simultaneous pursuit of three components: economic growth, social inclusion and environmental balance. Only if all these three dimensions are in equilibrium, then we can reach sustainability. In the case of Italy, the Great Recession of 2008 showed that weaknesses in other pillars can directly weaken the environmental one: during deficits, environmental problems get less attention since the priority becomes the economic regression.

The environmental component is the one that tends to get more attention in normal times. Companies focus on reducing the impact due to their activity: cut down waste in general, water usage and their carbon footprint, as well as considering the environmental consequence of their product over the life cycle. Reducing impact on the environment can also have a positive financial impact: less raw material they use more they can recycle, and less they have to spend for those materials.

Economic sustainability consists of the capacity of a business to generate and maintain over time capital[6] and employment keeping under control the use of disposable resources. This reasonable management allows the business to keep its market position in the long term, and lead to good financial and sustainable results. One of the main aspects that need to be kept in consideration is the innovation and technology effort: investments in R&D are fundamental for a business to reduce environmental impacts and at the same time increase the efficiency of the processes and final products. For being able of plenty shift the activity to a greener solution the selections alongside the supply chain should reflect the intentions of the company to reduce its environmental impact, and relationships with suppliers have then to focus on sustainability too.

The social dimension of an organization is defined as the consciousness of responsibility for its own actions, that should have the support and approval of employees and stakeholders[7]. Companies have to maintain and secure this support through many factors[8], both internal (corporate governance, motivation and incentives, health and safety, human capital development) and external (ethical behaviour and human rights, no controversial activities, no corruption and cartel, corporate citizenship). On a global scale, social awareness by the business is also through how the supply chain is being filled: child labour, underpayment and safety of work environment.

[6] Three types of capital must be managed: financial, tangible and intangible (Tenuta, 2009).

[7] This support appears from the Social License to Operate (SLO), a dynamic and non-permanent social contract granted by the community, through which a project has the approval within the local community and other stakeholders, or ongoing acceptance. The SLO is rooted in beliefs, perceptions and opinions about the project (https://socialicense.com/definition.html).

[8] Baumgartner and Ebner (2010).

In the years, different attempts to describe this relation through the use of images and graphical representations has been made, but none of them has been able to fully represent the link between the three components without drawbacks.

The Venn Diagram (*Figure 1*) represents one circle for each sustainability's dimension. Where two circles overlap we are in a situation in which we reach a semi-equilibrium, but the third dimension is missing so we will reach just a partial integration. Only where all three circles overlap we reach sustainability (yellow area).

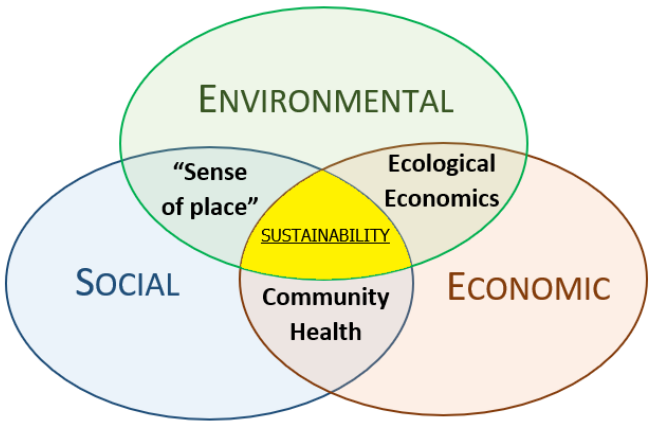


Figure 1: Venn Diagram for sustainability
Source: Adaptation from Todorov and Marinova (2009)

Even though this model is widely used and is of simply understanding for the relationship of these three dimensions, more scholars[9] pointed out lacks and issues associated with this representation of sustainability. A first problem is the lack of dynamism: this image represents only a moment in time and does not follow the dynamic processes of change that occur over time. Moreover, the three dimensions are not of equal importance, the perception could change based on individuals. Some advocates of sustainability tend to prioritize the environmental component, as we said at the beginning, while a sectorial approach to sustainability with the specialization on the study of complex phenomena encourages the prioritization of the environmental and economic dimensions not considering the social issues that can derive from this categorization.

Another attempt of representing the relation between the three dimensions of sustainability has been made with the Nested Circle Model (*Figure 2*). In this representation the inner circle represents the economic aspect, which is a subset of the social aspect and both are inside the environmental dimension. In this integrational perspective, economic and social components

[9] Giddings, Hopwood and O'Brien (2002); Lozano (2008); Moir and Carter (2012).

depend upon the natural environment, meaning that environment could exists also if society is no longer present and, to a certain extent, society can exist also without economy. However, this model does not reflect the inter-connections that are present amongst the three dimensions[10] and, as for the Venn diagram, time dynamism is not taken into account.

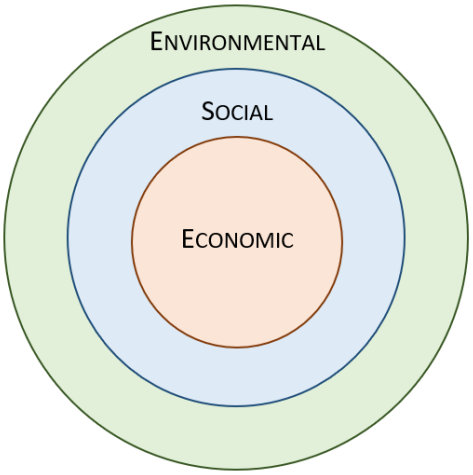


Figure 2: Nested Circles Model for sustainability
Source: Adaptation from Moir and Carter (2012)

What this approaches lack are the interconnection amongst the dimensions and the dynamism for both short- and long-term prospects. Lozano (2008) tried to propose a new model where both intergenerational overview and dynamic dimension were present. The result is a 3D form where:

- dynamism is represented by the First Tier Sustainability Equilibrium (FTSE) in which economic, social and environmental dimensions end up overlapping and rotate for representing the continuous contact between the three components (*Figure 3a*);
- a cylinder represents the overtime equilibrium, where no deviations are considered. Otherwise, the form will take the shape of a cone in two types: a wider side on the left end if too emphasis is put on the present or, on the contrary, a wider side on the opposite end when too emphasis is put on the future limiting today needs' satisfaction (*Figure 3b*).

Putting together these two improvements, we will reach doughnut shaped 3D form where the time cylinder is converted into the Two-Tiered Sustainability Equilibria and where all the aspects, including time, interrelate (*Figure 3c*).

[10] Humans could invade natural reserves for obtaining short-term resources. In this case, resources would be taken directly from the environment passing over the social dimension (Hart, 1997).

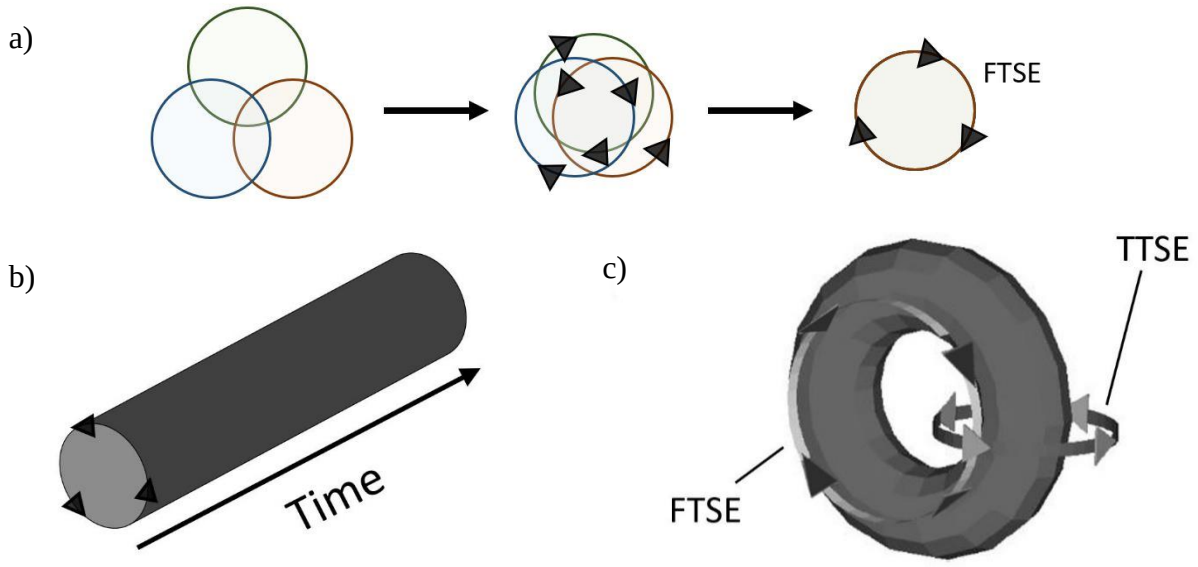


Figure 3: Phases through the 3D model of sustainability
Source: Adaptation form Lozano (2008)

There is a fourth dimension of sustainability that can be considered along with economic, social and environmental ones: cultural sustainability[11]. Culture is usually taken as part of the social dimension but, notwithstanding the increasing importance that it is being given which started to differentiate the two components, not much studies seem to actually consider culture as the fourth dimension of sustainability. Cultural sustainability has been defined in 1998 by the Sustainable Development Research Institute as "*the ability to retain cultural identity, and to allow change to be guided in ways that are consistent with the cultural values of a people*". The reason for including culture sustainability was given by the United Cities and Global Government assembly of 2010 for which they state that "*culture ultimately shapes what we mean by development and determines how people act in the world*". This would imply that the circular model (*Figure* 2) should provide another ring for the Cultural dimension but, as now, no graphical representation of this type has been considered.

1.1.3 Sustainable development

The guidance principle of sustainability is the *sustainable development*. Its concept originated primarily in economics as solution for the man-environment relationship, with the growing necessity of conciliate economic growth and equal distribution of resources.

[11] Duxbury, Gillette (2007). United Cities and Local Governments (2010).

In 1983, the General Assembly of the United Nations established a special commission which aim is to address growing concern about the accelerating deterioration of the human environment and natural resources, and the consequences of that deterioration for economic and social development: the World Commission on Environment and Development (WCED). The WCED in a 1987 assembly drafted a report called "*Our Commune Future*"[12], which defined the concept of sustainable development incorporating humanity's role:

> *"27. Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits […] imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. But technology and social organization can be both managed and improved to make way for a new era of economic growth. [..]"* (Brundtland Report, 1987)

In this report the commission pointed out also the negative impact of poverty on sustainability: poverty reduces sustainability and accelerates the environmental pressure. Poor often depend heavily on natural resources for their livelihoods and survival and so are the most vulnerable to environmental change[13]. Reduce sustainability is in fact one of the goals of sustainable development (see *1.1.4 Goals of sustainable development*). Essentially, sustainable development is a solution in a long-term perspective for planning humans' unlimited progress, cutting down the environmental impact so as to ensure a living environment for next generations.

1.1.4 Goals of sustainable development

In 1992, the Earth Summit reunited in Rio De Janeiro elaborated the "*Agenda 21*", an action plan adopted by more than 178 Governments and which aim is to achieve global sustainable development, to be taken both globally and locally by Organizations and Major Groups. The action program was composed of 40 articles divided into 4 parts: **Social and economic dimension**, **Conservation and management of resources for development**, **Strengthening the role of major groups** and **Means of implementation**. The program also defined some key concepts, and one of those was the *co-responsibilization* of all the environmental stakeholders,

[12] Also known as Brundtland Report in recognition of Gro Harlem Brundtland, former Norwegian Prime Minister and Chairperson of the WCED commission.
[13] https://www.unicef-irc.org

who must be sensitized on their strategic role for a sustainable development; there is a need for a synergy between policies, manufacturing and single behaviour.

Since the 1992 summit, other meetings characterized the subsequent years[14] and in 2015 the Sustainable Development Summit drafted the Sustainable Development Goals (SDGs).

SDGs are a set of 17 goals established by the United Nations Organization and aimed at reducing the problems regarding the economic and social development[15]. This set of goals is also known as Agenda 2030, deriving form the name of the document drafted in 2015 and in which they are listed.

Figure 4. List of the 17 Sustainable Development Goals of the Agenda 2030

Source: Adaptation from the SDGs United Nations' website

The goals established in the program relate to many different fields in the economic, social and environmental sphere. From an economic point of view, there are targets established in more goals and part of them requires an action directly from the single individual instead of from Government's policies only. The targets of the "Decent work and economic growth" goals include: the reduction of the imbalance between gender salary and the end of modern slavery and child labour, the promotion of youth employment and minorities protection; the

[14] Development and evolution of the *Agenda 21*: - 1997: *Rio+5*, for evaluating the status of the Agenda 21 objectives – 2002: *Rio+10* and *Agenda 21 for Culture* – 2012: *Rio+20*, where the attending members reaffirmed their commitment to *Agenda 21* – 2015: Sustainable Development Summit.

[15] https://sustainabledevelopment.un.org/?menu=1300

achievement of higher levels of productivity through diversification, technological upgrading and innovation; the promotion of development-oriented policies that support productive activities, entrepreneurship , creativity and innovation; the progressive improvement of global resources efficiency in consumption and production. This goal goes together with the one regarding "Industry, innovation and Infrastructure". From the SDGs website progress' page of 2019 we can read that, even though impressive progress has been made in infrastructures, there is a lack in investments in scientific research and innovation. This suggest how firms do not invest enough on new technologies for creating a more sustainable industrialization, even if they could benefit from this investment as well: the use of new technologies and techniques can help reduce costs and increase the efficiency of the production process. The investment in new technology and the greenery of processes is one common point of more targets of this goal: promote inclusive and sustainable industrialization, upgrade infrastructure and retrofit industries to make them sustainable also with an increase in resource-use efficiency and a greater adoption of clean and environmentally sound technologies and industrial processes, enhance scientific research and upgrade the technological capabilities of industrial sectors.

The achievement of these sustainable goals requires both responsible production and responsible consumption, through the use of more environmentally friendly methods. During the years, different strategies had come up in order to accomplish this requirement. Industrial Ecology[16] and Industrial Symbioses[17] are two examples of greening ways but, as pointed out by Stahel (2019), the aim of these two concepts is not on maximise the use of physical assets but on resources' use only, by reusing wastes in what is considered a linear industrial economy. What they are missing is a circular loop in where they take into account also the lifecycle of their final products.

1.2 A help to sustainability: the role of Circular Economy

For a long time, Governments did not consider the production, management and disposal of the wastes[18] of the economy, and how much they weigh on social and environmental wellness.

[16] Science that studies the material and energy flows through industrial systems, for understanding how these systems interact with the environment. This science's concern is to shift from a liner system to a closed one where wastes can become new inputs (https://en.wikipedia.org/wiki/Industrial_ecology).

[17] "Association between two or more companies where the wastes or by-products of one become the raw materials for another, in a linear cascading approach" (Stahel, 2019)

[18] E-waste is also considered: used electrical or electronic devices which have been discarded. Of this type of waste, in Europe only one third is correctly recycled while the rest is illegally disposed (mainly in Africa, but also inside Europe) with negative consequences for both environment and economy (https://www.greenideatech.com/e-waste-perche-e-importante-riciclare-1/).

From a similar point of view, waste can be considered an economic inefficiency, raising a cultural issue and increase the concern from countries where production efficiency is source of pride.

As stated in the first law of conservation of matter, whatever human does in the planet stays in the planet but degraded, and in order to use this matter we have to use more and more energy to transform it again and again[19]. In this view, circular economy (CE) is seen as a guideline for sustainable development given its capacity in helping to reduce the development and environmental issues coming from the overconsumption of resources. Since the industrial revolution technological progress has evolved, and innovations provide us with continuous improved products; but the current system is no longer sustainable for business, people or the environment. We make products, use them and throw them away: this take-make-waste linear economy is unsustainable for the resources we exploit. Circular economy is basically a system where products are designed for continuously regenerate themselves.

One of the biggest promoters of CE is the Ellen MacArthur Foundation, a private foundation launched in 2010 with the aim to accelerate the transition to a circular economy, which defines circular economy as an economy "*based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems*"[20]. In this view, what the world will reach is an economy with zero waste. Actually, the concept of CE started to emerge at the end of the 70s and from then different schools of thought arose, amongst which the one that is now one of the bases of circular economy: the regenerative design, that is the study of a complete productive system able to regenerate products and resources.

700 Million USD annual material **COST SAVING IN THE FAST-MOVING** consumer goods industry	***48%*** **REDUCTION** of **CARBON DIOXIDE** emissions by 2030	***550 Billion USD*** **REDUCTION** in **HEALTH CARE COSTS** associated with the food sector
3000€ **INCREASE IN DISPOSABLE INCOME** per annum for EU households	***70 Trillion CNY*** **SAVINGS** for **BUSINESSES AND HOUSEHOLDS** in China by 2040	***47%*** **REDUCTION** in **TRAFFIC CONGESTION** in China's cities

Table 1: Some numbers about the benefits of a circular system

Source: Ellen MacArthur Foundation

[19] First law of conservation of matter states that nothing is destroyed, only transformed. This is combined with the laws of thermodynamic which say that whenever the matter is transformed, it degrades.

[20] https://www.ellenmacarthurfoundation.org/

1.2.1 Form a linear model to a circular model

The system that has characterized the economy until these days is what has been defined "linear model" (*Figure 5*), also described as take-make-waste approach: resources are taken from the ground to make products which are used, and when final products are no longer needed or wanted they are discarded. This mindset was based on the idea that resources were unlimitedly available, and companies were motivated to design life-limited products due to the fact that this would result in an increase in sales: linear model was based on the cost-efficient production[21]. This approach is also defined **cradle-to-grave**: products are designed just for their function, without taking into account their utility at the end of their life. In this sense, products take life and then "die" without any foreseen usefulness.

Figure 5: Linear Model

Source: Adaptation from Stahel (2019)

The ever-growing demand, and the consequent volumes required, started to put into discussion the linear approach: the limits of the resources used appear in an increasingly marked manner. One of the first signal of this realization of non-limitless of resources reflected on prices: according to Iraldo and Bruschi (2015), the cost of goods that were traditionally considered commodities increased of nearly 150% between 2002 and 2010, and this is destined to become even higher given the prevision on consumers' increase by 2030.

This trend pushed companies to be more aware about their production process and start to shift to an industrial model where less resources are wasted. As we can see in *Figure* 6, the circular model has the aim to implement an economy (as much as possible) independent from the use of raw materials. In a circular economy, biological cycle and technical cycle overlap and through recycling, reuse and refurbishment, it reduces the generation of waste and the necessity of extraction of raw materials. According to the Ellen MacArthur Foundation, the three macro-bases of the new circular model are:

- the design of waste and pollution. Waste and pollution are the consequence of the way things are designed. Starting from the design phase, it is possible to consistently reduce them;

[21] The main drivers of this models was substantially the (presumed) abundant availability of relatively cheap natural resources and energy, and technological and social innovations. (EEA Report, 2017)

- keep products and materials in use. Even designing reusable, repairable and re-manufacturable products, there still are products that cannot last forever. In this case the solution is to be able to get the materials back for not throwing them away in the wrong way;
- regenerate natural systems. Give back to the soil the nutrients that the economic activity removes is what closes the loop: everything is food for something else.

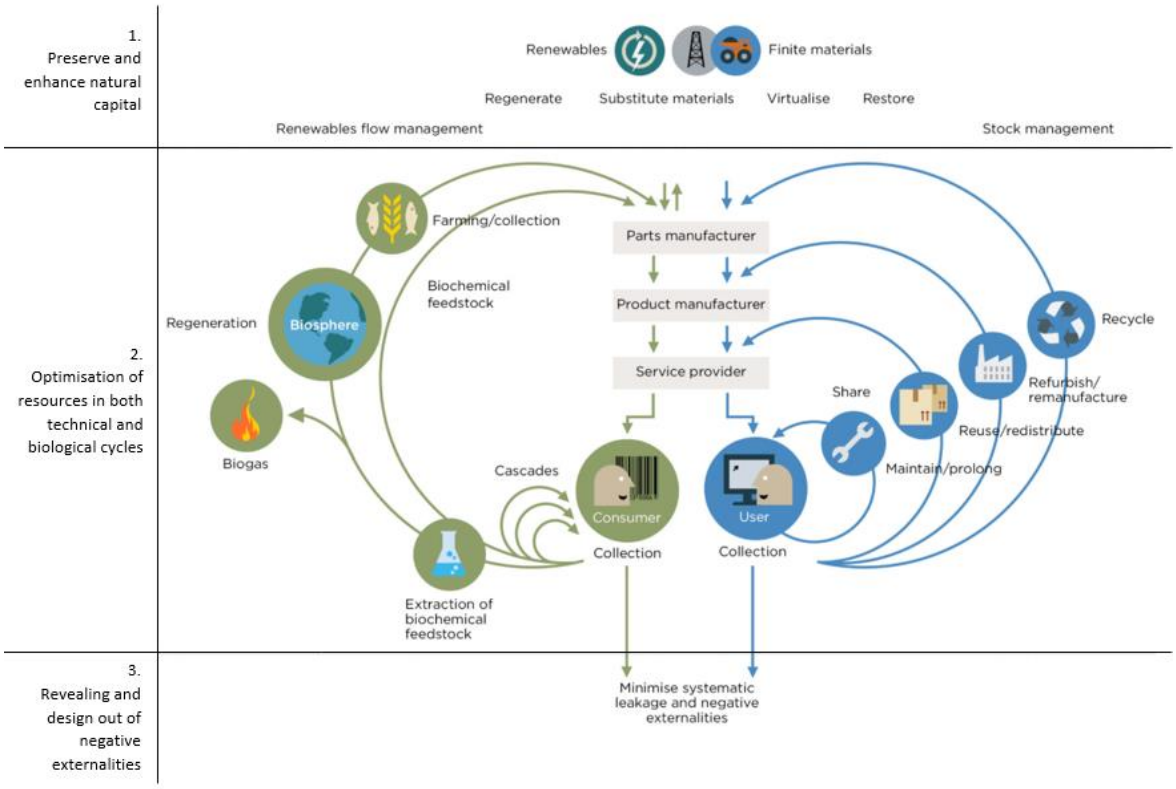


Figure 6: Outline of a Circular Economy

Source: Ellen MacArthur Foundation

This system has not a single author, indeed during years different schools of thought has raised, depending on the academics' view and focus of importance.

Braungart and McDonough (2010) developed the ***Cradle-to-Cradle*** concept, encouraging the eco-effectiveness over the eco-efficiency. Their theory is based on the idea that reduce, reuse and recycle is only a delay strategy instead of a solution, and the aim of the concept is to have a positive impact on the environment (not less of a negative): produce goods without harmful waste produced at all, thinking to their end-of-life use from the beginning (design phase).

Stahel (2010) proposed an interpretation of circular economy where the focus is not on the flows of materials or energy, but on the servitization: the target is on the maintenance and

exploitation of capital, and revenues are obtained from providing services rather than selling goods. As pointed out by Stahel and Clift (2016), this model fits best economies where the quantity of new goods entering the cycle is complementary to the quantity of goods scrapped at the end of their life, meaning economies close to saturation.

Natural capitalism concept described by Hawken, Lovins and Lovins (1997) describes an economy where business and environmental interests coincide, and an "ecological living" does not imply a loss of economic growth. Four are the principles at the bases of natural capitalism: increase the productivity of natural resources through changes in design and technology, promote the use of biological materials and production models, move to a "service-and-flow" business model[22] and reinvest in natural capital.

Despite the different view of these concepts, the focus remains the need and how to embrace a circular model. Three joining links to circular economy have been defined from the OECD[23]:

- the closure of resources' flow, where the management of wastes is important as well as the reuse and re-manufacturing of products;
- the extension of the life cycle of products and the contrast to the programmed obsolescence;
- the increase in the efficiency of the resources used, reducing the wastefulness and for being able to produce more with the same quantity.

1.2.2 Principles of circular economy

The adoption of a circular model requires the adaptation of all the phases during the production process: from the design, to the production, distribution, consumption, collection[24] and to recycling. In the ideal model, all these phases are "pure" from wasted, but in a more realistic scenario each phase leaves behind a percentage of waste. What is needed to embrace a circular model is the capability to limit the use of materials and energy at the top of the process and minimise their exit during the process, reducing negative environmental externalities. For a best adoption of circular economy, the Ellen MacArthur Foundation identified five fundamental principles for any economic activity to follow.

[22] This principle is strictly correlated with the Stahel (2010) interpretation of circular economy: value should be provided to customers by offering continuous services rather than rely on the pure sale-of-goods mindset.
[23] Organization for Economic Co-operation and Development.
[24] Phase in which the products at their end of life, or not wanted anymore from consumers, came back to the company for being given a second life utility. foreseen

1. SYSTEMIC APPROACH. Take into account the reciprocal relations and how the parts are affected each other. Understand underlying relationships is fundamental when we want to improve a system to avoid a worsen situation.

2. ECOLOGICAL DESIGN. Design products considering from the beginning their utility at the end of life. Forecasting the use of every single material used for assembling a product lead to an easily, and more efficient, reuse and recycle.

3. USE OF RENEWABLE RESOURCES.

4. "WASTE IS FOOD". Zero waste objective: scraps are designed with the aim of being reused inside the cycle, where can dissembled and reassembled over time. Biological wastes are compostable, while technical ones are reused with the minimum energy use.

5. ADAPTABILITY AND VERSATILITY. Products should be designed for upgradability and easy repair. Making it easy to remove only parts of a product help to easily disassemble, lowering the costs of switching components when damaged. Modular products are easier to customise and innovate based on market demand.

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1.2.3 How does Circular Economy creates value?

Circular economy allows to reach a series of benefits like the increase of energy efficiency, the extension of products, materials and components lifecycle allowing also to gain value at what, in a linear model, would have been considered their end of life.

Bressanelli et al. (2018) identified three ways through which circular economy can create value: increase in the utilization index of products and their general efficiency, extension of the life cycle and gain from the residual value. The increase in the utilization index is mainly with a shift in the focus from consumption to use, through models as sharing and pay-per-use. These three benefits can greatly improve the impact on the economy, environment and social spheres, the three components that must be balanced to reach sustainability.

In addition to the benefits outlined above, other positive impacts deriving from the adoption of a circular model include:

- a substantial resource savings: if raw materials are recycled, less expenses are needed for buying them. In 2019, only 9% of raw materials are from a circular system, and this data is even less from the 2018 result[25];
- economic growth and the growth of employment: the birth of new circular activities to sustain the system will likely require the introduction of specialized workforce in charge of the development, production and maintenance of the products. This increase in high specialized job is opposed to the decrease in less specialized job, with the consequent increase in labour's value. Models which combine specialized knowledge and cross-sector collaboration are more likely favoured by market forces, given their adaptation and innovation ability;
- innovation: circularity requires a continuous optimization of process and technologies, which will stimulate innovation for always reaching a higher level of energy, material and labour efficiency[26].

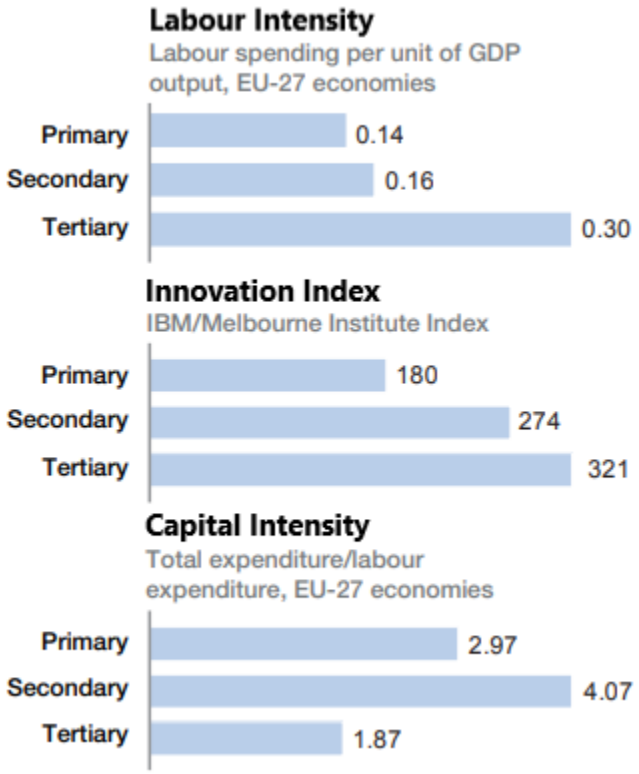


Figure 7: Impact of labour intensity, innovation index* and capital intensity on the primary sector (extraction), secondary sector (manufacturing) and tertiary sector (services).

Source: WE Forum (2017)

* Index include: R&D intensity; patents, trademarks and design intensity; organizational/managerial innovation and productivity

[25] https://www.circularity-gap.world/

[26] Source: WE Forum (2017).

1.2.4 Barriers and best practices

Despite the benefits it can bring, the circular model is not free from inefficiencies. The Green Economy Observatory (GEO) in 2015 identified these inefficiencies as a consequence of the centrifugal force which characterizes the circular model: as we can see in *Figure 8*, the flow of raw materials entering the circle goes gradually diminishing due to the wastes that exit the circle because are not recyclable.

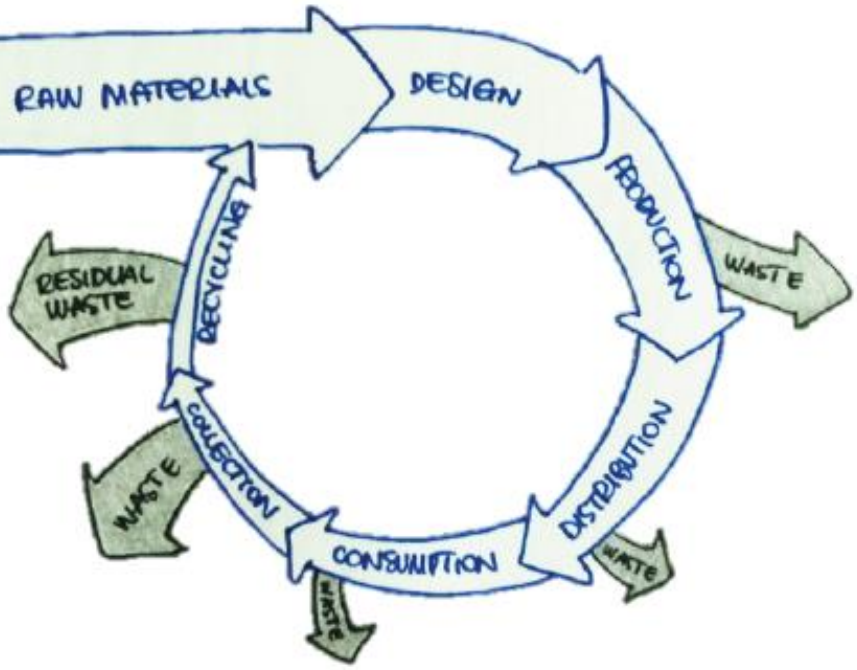


Figure 8: Efficiency lost in a more realistic circular economy model
Source: The Green Economy Observatory (2015)

This loss of efficiency can be attributed to different causes. One of the main elements is the geographic dispersion: the supplier network for producing a good can likely be spread all around the world. When this is the case, it is difficult to not loose waste along the value chain. Globalization also limits what is called *reverse logistic*, which implies a "backward management" along the supply chain. Geographic dispersion increases also other factors which can cause inefficiencies to the model, like habits and culture, and regulations. In many markets, recycled products are limited by consumers' mentality, who consider second life-goods having a lower efficiency compared to "pure" ones. Moreover, different regulations between countries can limit the closure of the circular processes. In addition to these, the non-consciousness of producers about their products impact and the sadly pursuit of personal interests above global ones increase the ineffectiveness of the implementation of a circular model.

Economy is locked-in to the linear system, and there are a lot of challenges that need to be accepted by businesses. The choose of short-term solution does not fit with the adoption of a new production system: incentives must be aligned for all players all over the supply chain in order to be able to close the loop.

Solutions for overcome these limitations need efforts but a global strategy must be implemented and, according to Geng, Sarkis and Bleischwitz (2019), it should include:

- a global database for collecting information about resources' use, with indicators on global flows, production costs and market trends;
- a global platform composed by experts and organizations aimed at collaborating for generating and sharing the green knowledge;
- the creation of international alliances for implementing large-scale experimentation on innovations;
- a list of standards for performance measurement, reporting and accounting, with the purpose of reducing gaps between sustainability strategies;
- the introduction of sanctions on an international scale, with a reputational risk for businesses that will motivate their commitment to the circular model.

1.2.5 Circular Economy around the world

Despite the challenges that Circular Economy requires, an increasing number of businesses and countries are starting to understand the importance of shifting from a waste-intensive linear model to a more sustainable circular model.

In 2015, the European Commission adopted a new plan for stimulating the European transition to a circular model, with the aim of promoting a sustainable economic growth and create new jobs. The plan provided for 54 measures to follow for adopting a more circular system. Netherlands is considered one of the most advanced country in this topic with the goal of shifting to a circular system by 2050. Belgium and Finland as well have set up programs to stimulate local economies to become more sustainable. Purposes are to help reduce costs, increase innovation and contribute to create local jobs.

The Ellen MacArthur Foundation calculated that, at European level, savings on materials' cost can be up to 630 million of Dollars per year (23% of the actual cost), and in 2018 with the World Economic Forum, the World Resource Institute, Philips, the United Environment Programme and over 40 other partners, launched the Platform for Accelerating the Circular

Economy, a platform which support partners projects to scale-up circular economy action on electronics, plastics, food & bio-economy and business models and markets[27].

Outside Europe, countries adopt different strategies for enabling circular economy. Geng, Sarkis and Bleischwitz (2019) identified how China, Japan and South Korea have national "top down" strategies, while Brazil, India and US adopt a "bottom-up" approach. China began adopting circular economy from the initial 2000s with emphasis on the three Rs: reduce, reuse and recycle. From 2017 it started looking at eco-design and extended producer responsibility[28]: the growing economy and the ever-increasing level of innovation is what facilitated the transition. While Chinese transition started from policies deriving from the top, Brazil approach started from consumers' initiatives. An example is Rede Asta, a platform created in co-operation by a network of more than 60 women's groups across ten Brazilian states, which aim is to support artisans who recover materials from corporate and urban waste.

In 2018, the Chilean Production Development Corporation launched the first program for circular economy. The aim was to support excellent companies that contribute to the Chilean circular economy, and support them in their activity, as well as establish a technology centre for circular economy.

Conclusions

The aim of this chapter was to make an overview on sustainability and the sustainable development that companies should embrace. The increasing concern about environmental problems has lighted the weak points of what for years has been considered the most efficient system for our economy, and the realization of the existing limits of resources used put under discussion the linear model. The solution has been found in a circular model where the logic of take-make-use-dispose are put aside in favour of a model based on the idea of making economic growth independent from the use of raw materials, with a regenerative process where end-of-life products become input materials for the circular making process. Circular economy is then at the base of a sustainable development, where companies creates new value respecting the environment and reducing their footprint.

For the adoption on a circular model, businesses must rethink at their processes starting from the beginning: design phase is in fact the most important one, where products are thought and

[27] https://www.acceleratecirculareconomy.org/
[28] https://kenniskaarten.hetgroenebrein.nl/en/knowledge-map-circular-economy/circulair-countries/

designed for creating an added value at their end of life. Circular economy, however, requires companies to reconsider all their global value chain for aligning their green processes to the ones of suppliers and partners.

As we saw, circular economy is not free from inefficiencies but is a starting point for companies for approaching sustainable development. Moreover, it could require a big amount of investments for companies, especially for innovations and new technologies. Despite the financial requirement, businesses should consider also the long-term benefits of sustainable activities which, beyond environmental ones, are also of economic and competitive nature.

2. Sustainability in the fashion industry

Consumerism is burning resources in an unsustainable way causing an ever-growing waste pollution, and the fashion industry is one of the industries where consumerism is more rooted. Textile production has one of the biggest environmental footprints of all industries: it pollutes around 200 tons of water per ton of fabric, using dangerous chemicals and consuming a huge amount of energy and water. The industry is working for reducing the impact of its products on the environment, but consumption levels remain high and a big market share still continuously demand for new products in faster times. Despite this, fashion industry is being positively influenced by the increasingly awareness of consumers about environmental issues, pushing it to search for greener materials and production processes. The aim of a sustainable fashion is to spread a new consumption's culture against uncontrolled consumerism and create a new industry view where environmental footprint is the focus of the decision-making processes.

2.1 The fashion industry

Fashion industry can be defined as a globalized sector that acts in order to meet the market demand for apparel and accessories and dictates the trends for what should be worn. This sector is divided in five levels:

- *Haute couture*
- Luxury wear
- Affordable luxury wear
- Mainstream clothing
- Discount clothing

Haute couture is a term born in the French high fashion sector in the mid-1800s, precisely in Pairs, which means "high dressmaking". Initially, the term referred only to custom-made garment produced by one of the members of the *Chambre Syndicale de la Haute Couture*[29]. As today, the term *Haute Couture* is used to refer to the custom-making of garments by high-end designers based in Paris, while outside France it is used to refer in general to extremely expensive fashionable garment no matter if it has been custom fitted or not. The price of these products are commonly high given the segment long-term tradition, materials and work that

[29] As of 2019, amongst the over one hundred members we can find: Alexandre Vauthier, Balenciaga, Balmain, Chanel, Dior, Giorgio Armani, Givenchy, Louis Vuitton, Valentino and Versace (https://fhcm.paris/en/members/)

goes into each of them; pieces can be considered unique since they are fitted for a specific client and materials used are of high quality: there is no price limit and each design is done by hand and might take months of labour.

The second and third level, Luxury wear and Affordable luxury wear, developed from *Haute Couture* with the difference that are designed for mass-marketing and not as unique creations. These two categories still have prices which are higher than ready-to-wear ones and are more commonly sold in boutiques and luxury department stores.

Mainstream clothing has a low-price range and is marketed to the masses are ready-to-wear garments with a lower quality respect to luxury categories. The lowest-price level is discount clothing where the quality is low-end, and the offer will often include knock-out apparel copied from luxury and designer wear but with a much lower quality both for materials and production.

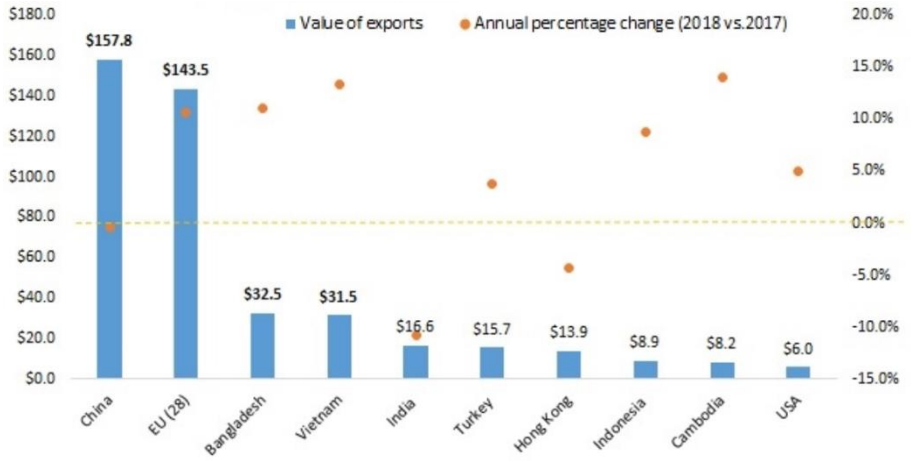
2.1.1 Product segments and principal actors in the fashion industry

Inside fashion industry we can recognize several different product segments: Textile and Apparel (which represents the major share), Apparel's accessories, Footwear, Jewellery, Lens and Eyewear, Leather goods and Fur products.

The volume of world merchandising trade, measured by the average of exports and imports, is constantly growing and new countries have jointed the market during years. Even if in 2018 China was the world's leading clothes trader (especially of fast fashion) accounting for 30% of world apparel exports, recently its attractiveness as exporter has decreased due to the rising labour costs and political tensions deriving from increasing tariffs. Despite this decrease in China's leadership, no single country has emerged to take its place.

Graph 3: Top Ten exporters of TEXTILE in 2018 ($Billion USD)

Source: WTO Reports World Textile and Apparel Trade in 2018 (Sheng, L.)



Graph 4: Top Ten exporters of CLOTHING in 2018

Source: WTO Reports World Textile and Apparel Trade in 2018 (Sheng, L.)

As we can see from *Graph 3* and *4*, China and European Union are at the top of both textile and clothes rank in 2018. For the textile, together with India they accounted for 66,9% of world textile export. Moreover, their growth in respect of the year 2017 has been two of the biggest (7,9% and 6,9%) after the Vietnamese one of more or less 12%. In clothing sector instead, together with Bangladesh and Vietnam, China and the European Union are the top four larger exporters accounting for almost 72% of world market shares. This lower result respect to 2017 (~76%) and 2016 (~74%) is due mainly to Chinese decline as exporter, but capacity limits encountered by other countries resulted in no country emerging to take the place of China; instead, China's lost market share were fulfilled by small different countries.

Global trade consists of intermediate products which are mostly exchanged worldwide within Global Value Chains. Becoming part of these GVCs is an opportunity for developing countries to grow their economy. Anyway, when choosing clothing manufacturer from developing countries, attention must be paid because workers' conditions are generally worse: underpaid and not environmentally friendly. Despite this common trend, in developing countries wages for garment workers vary significantly but in Asia they are growing. As usual, there are trade-offs to take into account for the activity: if the brand wants to be known as sustainable and socially responsible, drive the choice to a developing country or not as a partner could be fundamental for the external aspects. Also developing countries are going through a continuous increase of the cost: the combination of demand market price pressure, the increasing labour cost and an increasing requirement on speed are the three main causes. Based on these three factors, the Production Cost Index (PCI) rose through years across all main sourcing markets (see *Figure 9*). This increase did not affect only China, but also other low-cost sourcing regions

which affected also the cost of labour and the strengthen of local currencies (versus USD and Euro). The higher labour cost drove in turn an increase in minimum wages, in competition for skilled workers and a growing alternative on work offers.

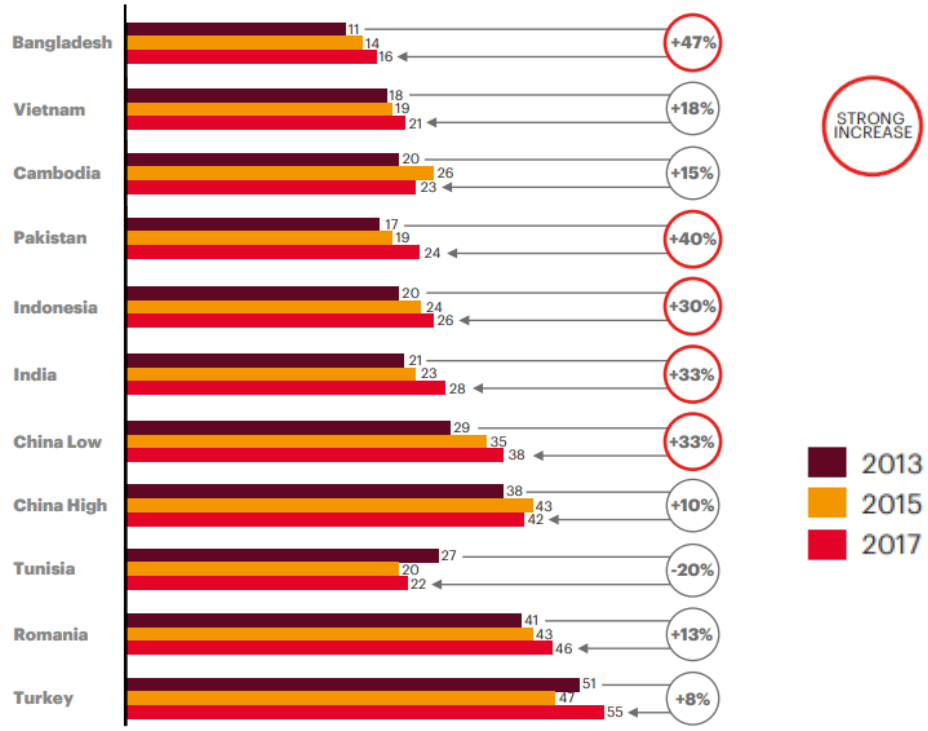


Figure 9: PCI Developments 2013-2017

Source: Adaptation from Salmon (2017)

For comparing sourcing destinations there are six main factors on which companies base their supply selection: Speed to market (the logistic lead time over which the good transit from the supplier factory to the buyer-company location. China and Vietnam usually offer shorter lead time thanks to their more advanced textile and apparel industries which allow them to increase the efficiency of their supply chain management, Sustainability concerns, Reliability, Sourcing cost (most competitive cost is offered by Bangladesh, followed by Vietnam and Asian countries, even if the last ones are becoming weaken given the rise in income levels), Flexibility and Operational Risk.

2.1.2 The research of the Made In

Also developed countries have been affected from sourcing market changes and had to adapt. From the 2019 annual Fashion Industry Benchmarking Study of the United States Fashion

Industry Association (USFIA)[30] it emerged how American companies are concerned about the impact of trade wars and trade policies in general (especially on imports from China[31]), and the increasing production and sourcing costs linked to tariffs primarily on Chinese importation. Costs in China are increasing as well as costs to source in the main alternative markets. Despite the introduction of tariffs and the threat of new ones, the return of the Made-in-USA production (or near the West) plods along; instead, Asian suppliers (out of China) are the real beneficiaries.

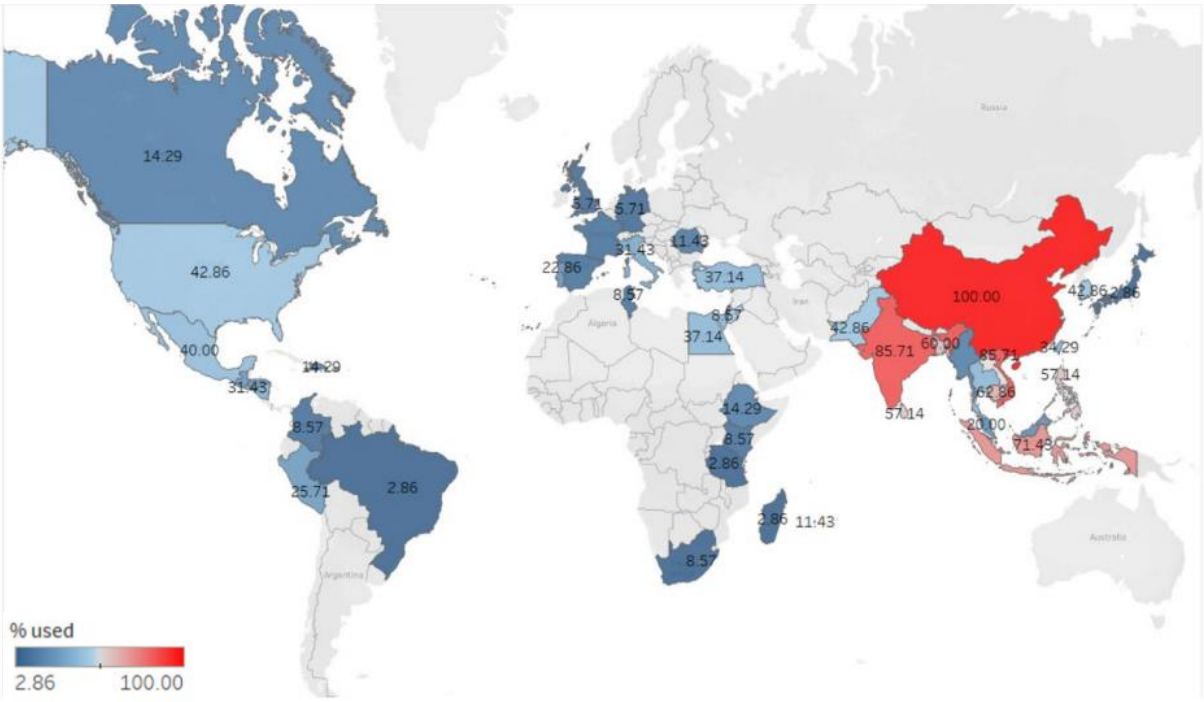


Figure 10: Utilization rate of sourcing destinations used by American companies.
Source: Lu (2019) in collaboration with USFIA.

Under Italian law, a product can be defined "Made in Italy" only when it has been entirely produced in Italy or when it has been substantially finished in Italy. It is recognized worldwide as representing high quality fashionable products. For the Made in Italy latest trends have been more than positive. In the third trimester of 2018, Italian export of finished products for individuals has reached a new peak with a growth of 3,6% respect to the previous year, of which apparel and accessories, leather goods and footwear are the drivers. The main European markets of the Italian exports are Switzerland, United Kingdom, France and Germany. Outside Europe, China, United States and South Kores contribute as well to increase the export of Made in Italy.

[30]The organization represents American based brands, retailers, importers and wholesalers doing business globally. This year scope of the survey was on business outlook, sourcing practices, Free Trade Agreements utilization and views on trade policies. (https://www.usfashionindustry.com/)

[31] China is the country mainly impacted due to the potential *Section 301* punitive tariff which provides an increase on tariffs of nearly 25% on a series of selected product imported from China.

This trademark is well exported also through ecommerce channels: beyond the nearest European countries, Italian-made products are shipped worldwide with China as one of the major digital markets for luxury apparels.

2.1.3 The evolution of the fashion industry

What differentiates apparel from fashion is the subjective-view part: while apparel is a basic need for individuals, fashion incorporates the prejudices of style, individual taste and cultural evolution.

In the first post-war period, society was still clearly divided between high society and working-class, and so was consumptions: clothing was a way for showing off the higher status, comparing to lower classes which were characterized by ordinary clothes.

This started to change in the '60s with two simultaneous events: youth role in the Protests of 1968[32] and women's emancipation. Youth started to feel different from the adult world, and their desire to differentiate themselves gave life to a new dressing market. These was the years of the economic boom of the second post-war period, and an increasing number of individuals was able to access to consumptions. Moreover, women started increase their importance, shifting their role from the quiet housewife to a more high-employment position, adapting their dressing habit to the new role. The increase in consumptions spread also to lower-middle classes and lead to a new concept of fashion: industrialized and with high differentiation and segmentation inside the industry. Brands started to differentiate their production for satisfying the increasing demand, adapting their products to different price range in order to be able to reach all classes. This development of the industry continued in the subsequent years, giving life to the consumerism that we are facing also now.

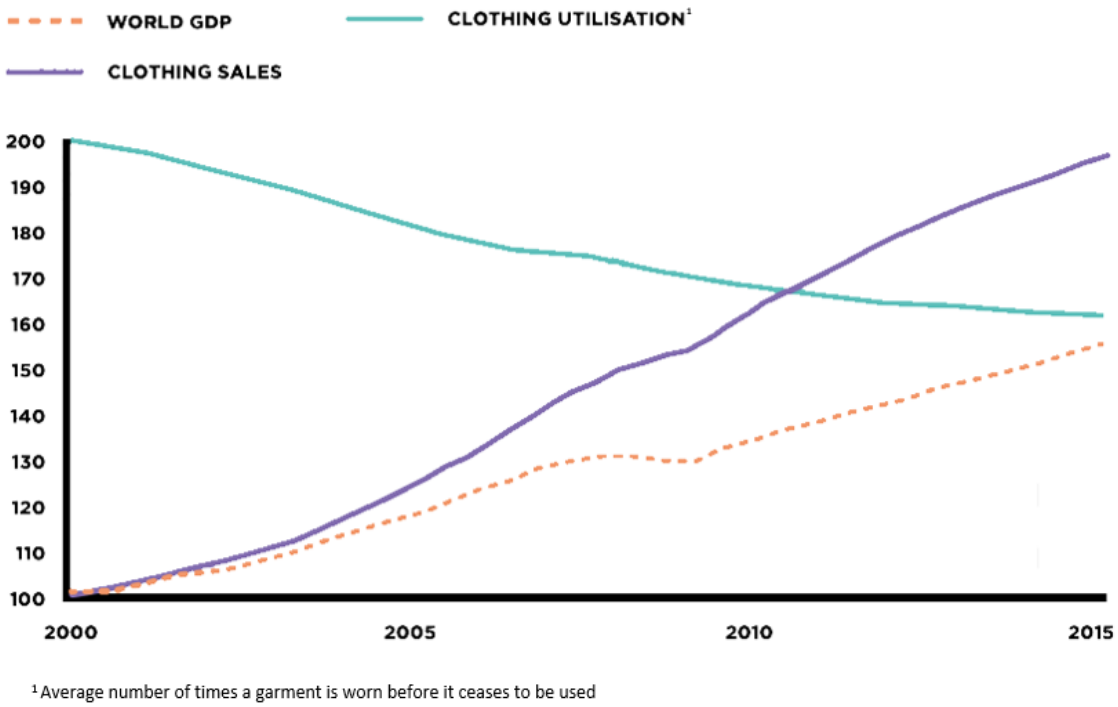
In the last years, fashion industry become an integrated system involving more sectors: marketing, art, music, technology. Fashion marketing made space for itself in the business: to survive, companies need to know the different styles, stay in line with the continuous evolution and an must implement an always increasing interaction with the customer. Globalization is a key element, as well as customer satisfaction and the quality and efficiency of the distribution

[32] The Protests of 1968 was a series of socio-cultural events characterized by groups of action against the elites. These movements characterized almost all the Countries in the World, as a way of challenge the social and political structure (https://it.wikipedia.org/wiki/Sessantotto).

network. Firms must be able to anticipate the wants of consumers, but styles and demand are always changing, and a constant adaptation is needed both in design and materials[33].

2.2 The shift thorough a more sustainable fashion

Since years 2000s clothing production has more than doubled, due also to globalization and the increase in middle class consumptions, and at the same time the average number of times clothes are used before being thrown away has decreased of nearly 40% (*Graph 5*). Both trends are mainly due to the birth of the fast fashion. Fast fashion is a productive model where there is a quick renewal of the collection at lower prices, for pushing consumers to continuously purchase. Examples of brands which adopt this model are H&M and Zara, which production and selling strategy is also deeply based on social networks. This production model requires a high level of resources and raw material, and the recycling possibilities are very low. Fast fashion is one of the main causes of social and environmental issues[34].



Graph 5: Growth of clothing sales and decline in clothing utilisation

Source: Ellen MacArthur Foundation

[33] Wilson (n.d.) and D'Amato (2018)

[34] Social issues are mainly represented by developing countries' labour exploitation, where individuals work for poor wages and in environmental working conditions where too often they risk their life, with no insurances and security provisions.

As highlighted by the Ellen MacArthur Foundation, textile industry is mainly based on non-renewable resources: oil to produce synthetic cloths, fertilisers to grow cotton, chemicals. The low rate of use and levels of recycling are part of this linear system, which highly worsen the industry's footprint. With the adoption of a circular system, fashion industry could access USD 560 Billion of economic benefits. In this view, materials keep an high value during production process as well as during recycling and reuse processes, never being wasted. The idea is to have a cycle that includes the safety and renewability of the inputs, solution for gar to be turned into new and a new business model that incentives reused garments.

From matching a sample of 180 High Sustainability companies and Low Sustainability companies, it has been found out that High Sustainability group outperformed the Low sustainability group by 4.8%[35].

2.2.1 The role of consumers and the concept of political consumerism

Many firms are shifting to a greener strategy due to the increasing environmental awareness of consumers, especially younger generations. An ever-increasing number of customers drives its choices in a brand on factors like its green practices and the sustainability of its products, considering both the materials used and the end-of-life utility. Consumers expect brands to be concerned about sustainability issues and to act for the environment, but these are seen as prerequisite rather than a driver purchasing decision. What moves consumers towards a more sustainable lifestyle are also emotional factors: be a role more for those around, feeling less guilty, pay it forward. Investors can have a key role in influencing brands as well if they prioritise sustainability when deciding on investments.

A research of the Boston Consulting Group of 2019[36] found that more than a third of surveyed consumers have shifted from the preferred brand to another due to its responsible practices. 75% of surveyed individuals see sustainability as a very important matter, and more than 50% plans to switch brand in the future if another one acts in a more environmentally way. They also found out that consumers acquire information about environmental-related issues mostly through online research (35%), social media (31%) and other non-digital media (29%). Nonetheless the increasing concerning about sustainability processes, the latter do not influence enough individuals in their purchasing behaviours: sustainability is the key purchasing driver

[35] CFDA Guide to Sustainable Strategies
[36] https://www.bcg.com/

for only 7% of consumers. Responsible practice will soon become a driver for purchasing decision, but customers need to stop buying from brands that do not act responsibly. However, industry cannot wait for customers to ask for sustainable production, it is up to fashion leaders to influence their perceptions and to lead the transition to a more sustainable fashion industry.

In all this process, consumers must incorporate an ethical-critical role, where it could be able to influence companies to shift to an environmentally sound management of their activities. At the same time, Government must support this role imposing to companies energetic and environmental standards, in order to align the products offered to collective consumers and private ones. These roles have been expresses with the concept of *political consumerism*. Under this concept the idea is that consumption decisions are political or ethical statements, and consumers can collectively influence the world through their decision. Micheletti (2003) defined political consumerism as representing "*actions by people who make choices amongst producers and products with the goal of changing objectionable institutional or market practices. Their choices are based on attitudes and values regarding issues of justice, fairness, or noneconomic issues that concern personal and family well-being and ethical or political assessment of favourable and unfavourable business and government practice*".

Political consumerism can have three basic forms:

- Negative political consumerism: consumer boycotts. Boycotts encourage individuals to disengage irresponsible companies by not buying their products. The aim of this action is to make the company change its policy and behaviour, which will be forced in order to avoid both an economic and reputational damage.
- Positive political consumerism: consumer buycotts. Contrary to boycotts, buycotts scheme is to signal the positive businesses, more sustainable ones and/or with eco-friendly processes. Examples of this type of political consumerism are certifications, eco-labels and fair-trade labels. It's a reward for the good behaviour and policies of a company.
- Discursive political consumerism is the political ideologization of the industry by giving importance to exchange of opinions about corporate policy and communicative efforts directed to the mass and institutions. This can be a way to involve individuals in a dialogue about the corporate strategy.

While the first two forms of political consumerism, negative and positive, are aimed at directly influence companies (since actions are based on making choices about their products), discursive political consumerism does not imply monetary repercussions. Sustainability could

increase the brand value only if they build credibility over time, following the People-Planet-Profit approach[37].

2.3 What is sustainable fashion and the birth of green marketing

Hopefully, the fashion industry will show progress towards better social and environmental footprint. Companies that want to stay on track with changes in consumptions started to show and grant sustainability of their products to the market, adopting an integrated production chain and continuous improvement. Starting from the 90s, a movement promoting the change of fashion products towards a more ecological impact arises. Northern countries like Scandinavia, Canada and Germany have been in first line for sustainability, but their concept of fashion sustainability was aesthetically poor and about "less is best", as if individuals need to renounce to something in order to be sustainable. The revolution came with the pulse of the *aesthetic sustainability*.

As Freeman et al. (2006) stated, sustainability can be considered the result of the consideration of all stakeholders who participate in the design, manufacturing and selling of a product. This means that companies should change towards a strategy based on the exchange of information and cooperation in order to choose suppliers which respect the consumers' expectations on the brand. For this process to be possible to implement, stakeholders should work with the company for an open and transparent communication. This concept can be integrated under the Corporate Social Responsibility (CSR). CSR is defined as the internal and external management of externalities in the company's strategy, which expresses the will of the firm of considering the environmental, social and economic externalities of its activity.

Today, 90% of clothing is thrown away before it needs to be and less than 1% is recycled[38]. Sustainable fashion aims to create a circular process in which apparel can be recycled by before giving it the maximum value possible, in order to be ready to re-enter the market. *Circular.fashion*[39] is a system which focus is to assist suppliers, brands and recyclers in innovating their products and systems for building a circular economy in fashion and textiles. It makes available a digital platform for users which provides information on materials and guidelines for a circular design. It also provides consultancy and training for brands which want

[37] This approach, also called *3P concept* was firstly used by John Elkington in 1994, and indicates the three dimensions of sustainability: social (People), environmental (Planet) and economic (Profit).
[38] Ellen MacArthur Foundation (2017).
[39] https://circular.fashion/

to transit to a circular process, with the focus on innovation: solutions for creating new offerings for customers, while at the same time gaining financial and creative value from circularity.

Figure 11: Lifecycle of a garment

Source: https://www.encircled.ca/pages/end-of-life-cycle

Sustainable fashion has developed some aspects which become key for the environmentally sound management of the industry, but anyway alone do not are sufficient for being sustainable:

- takes into account the quality and eco-compatibility of raw materials, being informed on the security and footprint when choosing a material over another one;
- controls the supply chain and the environmental aspects in all processes, with the eco-design and the prevention of negative environmental impact in all forms (energy, water, emissions, transportation, end of life disposal), as well as being informed about the management of its supplier's processes;
- manages the relations with local communities for sustain an economic and social development of the territory;
- gives value to qualifications and work of the employees because, as seen, one of the consequences of consumerism was the reduction in prices, which required a reduction in the labour cost and a consequent devaluation of humans' work and value.

Fashion industry faces an ever-reduction in the disposal of resources. For this reason, sustainable fashion relies on strategies for reuse, recycle and refurbishment. Used apparels, when they are not wanted anymore, can enter in a new creative process of design as vintage or second-hand shops, which means finding new markets and new users. Cloths from production waste, or end-of-life waste, can be put together and recycled in order to become a new product and enter in the market for being sold and used. Sustainable fashion considers the impact its activities have in all the production process phases, identifying in all of them areas of improvement on which develop a solution:

Raw materials	• Low environmental impact or from biologic farming • Fairtrade market • From recycling and renewable sources
Productive chain	• Reduction in energetic consume, and adoption of renewable sources of energy • Reuse of water from the production process and depuration of waste • Adoption of innovative eco-technologies • Recycle of waste • Elimination of chemical and toxic substances with the research for alternative solutions
Logistics	• Packaging reduction • Choice of suppliers based on the means of transport
Advertising	• Environmentally friendly equipment and lighting • Communication form with lower environmental impact
Use	• Conditions of maintenance for long lasting durability (washing, drying and ironing)
End-of-life	• Reuse and recycle • Biodegradability level

Table 2: improvement sustainable fashion adopts in each phase of the production process

Source: Adaptation from Tartaglione, Gallante, Guazzo (2013)

Each actor in the fashion industry can emphasize a different sustainable way of applying sustainable fashion: producing in a more environmentally friendly manner, promoting second-hand and vintage apparels, renting or borrowing instead of purchasing. Collecting all, we can highlight how the path of an apparel should be: manufactured on demand or custom-made,

produced in high-quality and in an environmental friendly (and ethic) manner, used for a long time and being cared about and, when no longer wanted, should be given to second-hand or vintage shops for a second market, or its materials' recycled if not in the conditions to be used[40].

2.3.1 Green marketing and its role in sustainable fashion

Being sustainable requires a continuous innovation for companies. Brands must continuously develop new products and solutions, which requires a deep research for revolutionary eco-friendly strategies. For this reason, the concept of green marketing started to arise, in sustain of profits.

Green marketing can be defined as the marketing of products that are presumed to be environmentally safe[41]. It is a concept in which sustainability and marketing live together for sensitise responsible purchases; and represents a link between business and environment: it creates a relation in which the brand cooperates with the customer for the development of new ideas. Strategies for a green marketing include a green design, green positioning (a company should promote its green performance, and activities must reflect its sustainability values), green pricing, green logistics and green disposal. All these strategies reflect what are the basis for a sustainable circular business process and its supply chain.

For being effective, there are five characteristics to adopt, also called the "*Five I of Green Marketing*" (Grant, 2009):

1. **Intuitive**. Alternatives proposed to consumers should be of easy understanding for avoiding them to perceive they are forced to change their habits.
2. **Integrated**. Must combine all three dimensions of sustainability (economic, social and environmental) plus the technological aspect, that for long has been considered only as having a negative interference for the environment.
3. **Informed**. Must create knowledge and awareness in customers' minds, for training them to become examples for others and for future generations.
4. **Innovative**. The implementation of online platforms and dedicated green e-commerce (*g-commerce*) has been fundamental for sharing knowledge and strategies between all actors.
5. **Inviting**. People must want to embrace a greener lifestyle, and not feel forced to.

[40] http://www.greenstrategy.se/sustainable-fashion/seven-forms-of-sustainable-fashion/
[41] https://en.wikipedia.org/wiki/Green_marketing

2.3.2 The Global Fashion Agenda and its Copenhagen fashion summit

Each year, numerous are the meetings and conferences organized in all the world with focus on sustainable fashion, for sharing news and debate on the latest innovations in the transition to a greener fashion industry.

Green Fashion Week[42] (GFW) is a non-profit international event where fashion designers and companies promote sustainability through their collections and products. It first was presented in Abu Dhabi, then Milan, Los Angeles, Las Vegas, Dubai, Switzerland and lastly, this year in April, Hungary.

Above all, the largest business event on sustainability in fashion is the Copenhagen Fashion Summit, hosted by the Global Fashion Agenda every year since 2009. With strategic partners like Asos, H&M Group, Kering and Nike, this event summons lots of pioneers of sustainable fashion industry as well as new entrants who want to get closer to the topic. The Copenhagen Fashion Summit is a two-day industry-led event that focuses on sustainability issues in fashion. The event is enriched by keynotes, dialogues, discussions and presentations and, in last editions, an innovation lab which showcased emerging textile solutions. The focus is on sharing knowledge and sustainable solutions for the fashion industry, and for this reason also the environment of the summit is sustainable as well: everything, from exhibition stands, water bottles and nametags are designed and produced to be fully sustainable and recyclable. Partners chosen for the event are strictly selected by the Global Fashion Agenda organization based on their green offer: catering, spatial design, furniture and even hangers' suppliers for hanging up guests' clothes. All is thought responsibly. This year Summit discussed about how lots of individuals are still convinced that pursuing ethical and sustainable solutions will negatively impact their profits, while one of the solutions is to produce less fighting fast fashion and overconsumption: give the right price to the final good from a company side and reduce purchasing of new products in favour of reused ones from a customer side.

In addition to the Copenhagen Fashion Summit, the global Fashion Agenda is promoter of other global events and systems, all focused on sustainability[43]. The *CEO Agenda* is an annual guide for CEO in fashion to follow for moving from words to actions, with seven key points to implement: sustainable material mix, circular fashion system, promotion of better wage systems, supply chain traceability, combating climate change, efficient use of energy and chemicals and respectful and secure work environments. The *2020 Circular Fashion System*

[42] https://www.greenfashionweek.org/
[43] https://www.globalfashionagenda.com/

Commitment, which is a jointed industry initiative on circularity launched during the 2017 Copenhagen Fashion Summit and signed by fashion companies which represent almost the 13% of the fashion market. Another initiative, co-authored together with the Boston Consulting Group and the Sustainable Apparel Coalition, is the *Pulse of the Fashion Industry*, a deep evaluation of the fashion industry's green performances. This tool gives a score[44] out of 100 to the sector, that from the 32 points of 2017 (first edition) improve to what is today, 42 points: a sign that awareness in increasing, but there still is a long road ahead. As we can see in *Figure 12,* the Pulse Score for the apparel and footwear industry of 2019 is growing but at a lower rate than from 2017 to 2018, and with a projection of an increase in industry size growth rate of 10% the gap between the two variables will continuously increase if industries do not speed up on finding and developing new strategies to improve their footprint.

Beyond all these events for brands and companies, the Global Fashion Agenda has established the Youth Fashion Summit, an educational program and idea generator dedicated to students engaged in sustainability and fashion. It is structured as a two-year sustainability program for 100 selected students in the fashion industry, whose objective is to outline an idea path on how to reach two of the SDGs. The 2018-2019 selected SDGs was "Good health and well-being" and "Gender equality". Participants of the Youth Fashion Summit were given a space also during the Copenhagen Fashion Summit, giving them opportunity to interact with experts and enrich their knowledge.

Figure 12: Relation between Pulse Score and industry size

Source: https://www.globalfashionagenda.com/pulse-2019-update/#

[44] Pulse Score: is based on the Sustainable Apparel Coalition's proprietary Higg Index, which is the most extensive and representative existing transparency measurement tool of the industry (*see 2.3.3*) (https://www.globalfashionagenda.com/)

2.3.3 Measuring corporate sustainability performance

Measuring the sustainable performance of a company is often expensive in both time and financial terms. Moreover, the reading of results can be not easy to understand. That is why for comparing performance of different companies, common policies on measurement are defined; in order to grant objectivity, measurement is performed by external organizations.

Sustainability performance can be defined as *the performance of a company in all dimensions and for all drivers of corporate sustainability*[45].

Two are the main measurement used at international level:

- the *Higg Materials Sustainability Index (MSI)*[46].

  The MSI is a globally trusted industry standard for measuring (and improving) sustainability. This index provides information on the impact of each material used in the production of a good. The website of the MSI[47] acts as library for all materials searched. It helps companies to compare materials, makes environmental data available to all and can be used by production teams during material selection to help them make a more sustainable choice. MSI track materials' impacts during all their making: from the impact of extraction/production, to the manufacturing and end-life utility. Examples of companies that already use this tool are Patagonia, Kathmandu, University of Delaware (it uses the MSI in its fashion programs, for training students – future employees of the apparel industry) and The North Face. More companies access the portal, and more information about materials will be available and easier it will be to compare materials.
- the *Product Carbon Footprint (PCF).*

  The PCF is the sum of all emissions, expressed in CO_2 terms, produced by a good during all its life, from the extraction of the materials needed, to the end of its life[48]. All phases are not always considered: the calculation of the carbon footprint of a product can be difficult due to the different actors that take part in the process, so most measurements consider just the phase in which the individual actually contributed in the production process. In 2013, a new certification was introduced at international level, the ISO/TS 14067, which describes the principles, requisites and modalities for the measurement.

[45] Schaltegger and Wagner, 2006.
[46] Shanthi, 2015 and Youdina, 2017.
[47] https://msi.higg.org/page/msi-home
[48] https://it.wikipedia.org/wiki/Carbon_footprint

Measure sustainable performance is not easy, and tools must be continuously improved in order to fairly represents the commitment of companies.

2.4 The role of luxury fashion in a sustainable industry

Luxury identifies a specific share of the general fashion industry. Luxury products are seen as expensive good-quality goods, not essential for individuals. Customers of luxury brands are those who wants to identify themselves in a specific social niche status that is difficult to reach, and traditionally are seen as superficial. In the last years, this association between luxury and "unnecessary expensive" products got weaker as society realised that brands from luxury business are the ones most aware of their environmental and social impact. It is sufficient to think about the durability of their products to identify one of the biggest problems resolved by luxury: products are designed to last long, end this implies a longer lifecycle for the material used and which will remain in the market for a longer time contrary to fast fashion brands. A long-life approach for its products made the fashion market to rethink about production processes, with the aim of creating an added value for its customers given by its sustainability choices all along the supply chain.

2.4.1 Fashion Weeks becomes sustainable: the Green Carpet Fashion Awards

Fashion weeks are the main runway fashion shows where fashion designers and brands in general present their latest collections to the media, and from these shows upcoming seasons will be influenced. Around the world there are more than 170 fashion weeks, but the most importants are the ones of New York, London, Paris and Milan.

These events are windows for promoting their product but, even if at the beginning this was focused only on this, in latest years designers and brands have started to focus also on the general appearance the show transmits, creating the atmosphere choosing the perfect location and sending a message to audit, customers and media on the values the brand carries. Under this view, brand took the chance to promote their positive social and environmental impacts.

Over the years, an increasing number of fashion weeks started to promote sustainability in their shows and, in some cases, to set sustainable limitation for brands; Helsinki, for example, has been the first event 100% sustainable and also banned leather from its Fashion Week of this year in July.

The representative of Italy in the four most important fashion week, Milan, has been promoter of a more sustainable idea of fashion week, including sustainability in its management (plastic free policies and green mobility for guests' transfers) and rewarding brands who embrace a greener business activity. This year Milan fashion week closure has been with the third edition of the Green Carpet Fashion Awards hosted by the *Camera Nazionale della Moda Italiana*[49], the "Oscars" where actors of sustainable fashion, who took the challenge of creating a fashion which can link aesthetic and ethic, have been awarded for their commitment. Brands, advocates, models, emergent designers have been the main characters of this edition.

Stefano Funari founded in 2013 "I Was a Sari", an Indian social organization born with the aim of improving the conditions of women from economic and social disadvantage and which activity is the upcycle of *sari*. In 2017 also Gucci joined the organization. He won the Responsible Disruption Award for its firm's commitment on the creative reuse and restoration of old *saris*.

The Circular Economy award has been conferred to Healthy Seas, a non-governmental organization funded in 2013 for cleaning seas of marine litter mainly from fishing nets and recycle them creating yarn to be used in fashion and interior industries. SICIT President and CEO, instead, won the award for Technology and Innovation thanks to their green turning point on leather curing.

Thanks to events like this of Milan Fashion Week, environmental issues are put under light and taken under consideration from an increasing number of fashion brands which recognize also the business potential for their marketing of embracing a more sustainable management, increasing their brand value for expanding it also to the most environmental-careful customers.

2.4.2 Luxury brands and their commitment to sustainability

Numerous luxury brands are shifting their activities to a more sustainable activity management. Here are some of the most famous and committed luxury brands.

GUCCI

Founded in Florence in 1921, Gucci is today part of the Kering Group and one of the most famous luxury brands at international level. The brand has always been active for human causes

[49] https://www.cameramoda.it/it/sostenibilita/

with UNICEF, and in 2013 launched an organization for globally sustaining women's empowerment.

Kering Group has been for years pioneer of sustainable fashion, and as today Gucci is one of the best performers of the Group in terms of sustainability. In addition to adopting eco-textiles and green materials, in recent years Gucci change its packaging design substituting the old not environmentally friendly packaging to the new one totally produced by recyclable materials.

The brand implemented also a platform called Gucci Equilibrium[50], where are displayed and continuously updated all the social and environmental policies of the brand. The name, Equilibrium, reflect the focus of the brand on balancing the aesthetic of its products with the ethical values of the brand for meeting customers' expectations. Gucci's objectives include grant traceability for 95% of its raw materials, manage it supply chain in an innovative and responsible way, granting gender quality and promoting diversity and inclusion, and developing new solutions for improving its logistic management through the adoption of innovative technologies.

STELLA MCCARTNEY

Daughter of the former Beatle Paul McCartney, Stella launched her own brand in 2001 in a joint venture with Gucci Group. Since the beginning, also due to parents' influence (her mother was an animal rights activist), Stella McCartney embraced a sustainable attitude in her business model, creating the first vegetarian luxury brand. Every step of the process, from the design to the after-use destiny of the product, is deeply thought because the brand feels responsible for the resources it uses and the impact its activities have on the planet. In fact, responsibility is in the core of the business:

> "*I design clothes that are meant to last. I believe in creating pieces that are not going to get burn, that are not going to landfills and that are not going to damage the environment. For every piece in every collection, I'm always asking what we have done to make this garment more sustainable and what else can we do. It is a constant effort to improve*"
>
> – Stella McCartney (Muthu, 2018)

It has been one of the first luxury brand organized on a circular model for sustainable activity. Recycling is one of the key points of the brand's philosophy, and all its locations have recycling systems. Amongst its products, we can find a lingerie line which uses organic cotton,

[50] http://equilibrium.gucci.com/it/

biodegradable soles and a sustainable eyewear collection made from over 50% of natural and renewable resources.

In 2003 and 2004, Stella McCartney launched a collection with Adidas and H&M respectively, the first for a cruelty-free sportwear using no leather and the second for pieces made from organic cotton. The brand is also active in many social organizations and won numerous prizes for its support to sustainable fashion.

Big part of the brand responsibility is based on social sustainability: the care of people who make clothes, farmers who grow the crops for materials used in the production, employees and customers as well. Along the supply chain, materials are from carefully selected suppliers, 76% of which are form Italy, which are subject to audit activities (also unannounced auditing). Many of the suppliers are small manufacturers and artisans specialized in a particular techniques or phase of the process.

For measuring its impact, Stella McCartney uses the Environmental Profit and Loss[51] (EP&L) decision-making tool developed by Kering, comparable to a natural capital accounting. It measures the environmental footprint of each component in the processes all along the supply chain, and then analyses the environmental outcomes and their impacts on people for being then translated into monetary value, giving a clear understanding of the cost of activity. This tool allows to better understand the impact and choose the best strategic solution for minimising it. In the long-term, it grants better performance because the brand is more aware of problems and can focus on their solution.

Stella McCartney won the Groundbreaker Award at this September's edition of the Green Carpet Fashion Award in Milan, for its commitment to sustainability and for being pioneer of numerous sustainable innovations in her brand's line.

VALENTINO

Valentino is an Italian brand founded in 1960 in Rome by Valentino Garavani, and is now part of the Valentino Fashion Group. In 2013 the brand communicated its commitment to a zero-deforestation policy on leather and packacing procurement promoted by Greenpeace, to remove from its production processes fibre originating from tropical deforestation and leather originating from pastures resulting from tropical deforestation. In the same year, the brand has been nominated as the eco-friendliest luxury fashion house out of 15 luxury brands interviewed

[51] https://www.kering.com/en/sustainability/environmental-profit-loss/what-is-an-ep-l/

in a survey conducted by Greenpeace. The survey focused on three areas of the supply chain: the leather-purchasing policies, the pulp-purchasing policies and the policies on textile production. In each three areas Valentino scored high. For the last area, Valentino commit itself to the Greenpeace campaign "Detox", with the aim of to gradually reduce, and at the end completely eliminate, dangerous chemicals used during painting process in favour of natural colourants.

TIFFANY & CO.

The American brand founded in 1837 is specialized in luxury jewellery. In addition to jewels, it sells fragrances, watches and eyewear accessories as well. In the last 20 years, the focus of Tiffany has been on maximise efficiency reducing its environmental impact.

The brand approach to sustainability is based on a continuous discussion with stakeholders for understanding their priorities: employees, shareholders, ONG, suppliers and consumers. Given the materials used for its products, Tiffany is particularly concerned about employment conditions in its supply chain and the relationships with local territories where it operates. For this reason, the brand collaborates with the Initiative for Responsible Mining Assurance (IRMA) since 2008, for the safeguard of employees and the reduction of the negative environmental impact coming from miners from which Tiffany takes diamonds. In 2009 Tiffany's Council establishes the Committee for the Corporate Social Responsibility.

From 2011 the brand adheres to a long series of initiatives focused on protecting the ecosystem and reducing the environmental impact of its sector. In addition to this, from 2019 the brand launched the Diamond Source Initiative, with the aim of giving transparent information about the origin of each diamond; together with Bvlgari, Tiffany has been certified from the Responsible Jewellery Council

LVMH

LVMH is a French multinational luxury goods conglomerate formed in 1987 from the merger of Louis Vuitton with Moët Hennessy. The company controls around 60 subsidiaries in many different sectors, amongst which: Belvedere and Mercier (Wine and Spirits); Céline, Dior, Emilio Pucci, Fendi and Givenchy (Fashion), Guerlain and Kenzo Parfumes (Perfumes and Cosmetics); Bvlgari (Watches and Jewellery); DFS and Sephora (Selective retailing).

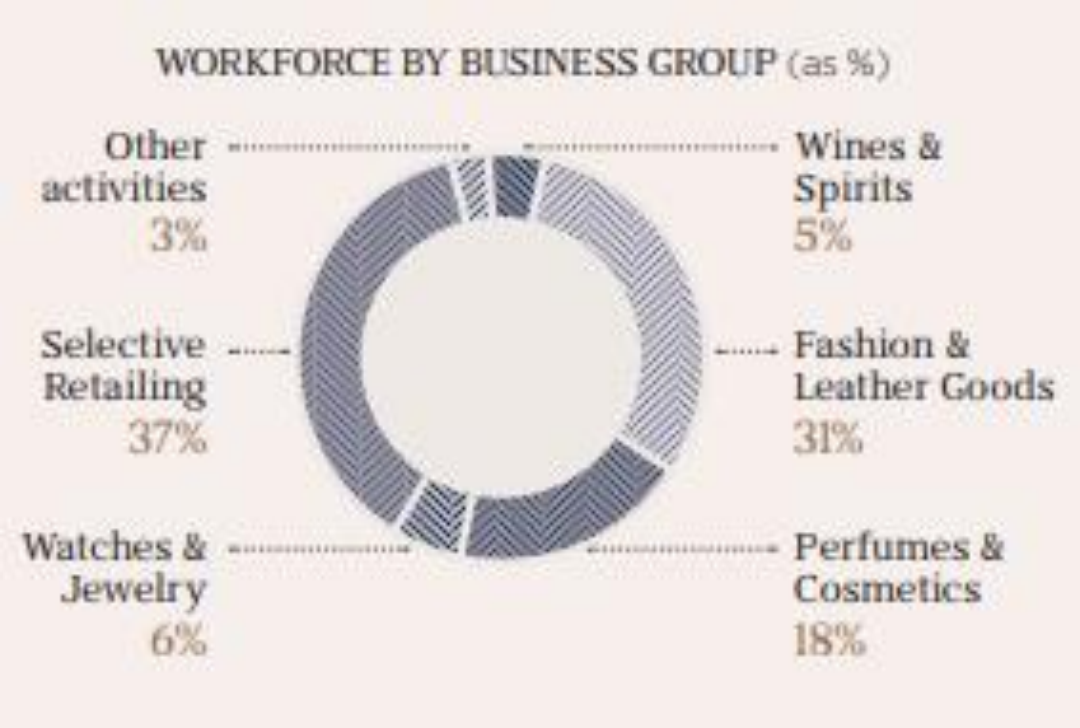


Figure 13: Workforce by business group in LVMH

Source: https://www.lvmh.com

The LVMH Group sees sustainability not only as a duty, but also as a source of competitiveness. The long-term success of the brand relies on the disposability of natural resources used in production, that is why preservation of the environment is a focus for the LVMH Maisons.

The Code of Conduct revised in 2017 by the Group sets the core ethics that its Maisons must share with. Acting responsibly and with social awareness, protecting the environment, winning the trust of customers and shareholders are three of the key principles. Its commitment to social, economic and environmental causes is also showed from the numerous partnerships and organizations of which the LVMH Maisons are partner: disabilities, supporting access to employment and youth employment, and non-discrimination organizations. On the social side, 73% of the Group's total workforce are women, 42% of key positions are held by women as well and 30.6% of employees are under 30; 17% and more purchases are made with companies specifically employing people with disabilities. More than 25% has been invested in improving working conditions. For the economic sustainment commitment, 58.9% of employees have received training and 56% of management positions have been filled internally. For cooperating with local areas and communities, €130million have been invested in R&D, almost 750 ninth-grade student interns have been hosted, 150 of which from disadvantaged schools, and around

4.500 mentoring and sponsorship initiatives[52]. In April 2018, the group announced the creation of *La Maison Du Start-up*, an accelerator program which each year will welcome 50 international start-up for innovations in the industries in which it operates.

Since 2006, Bvlgari has financed a master's program in "Management and Control of the Environment: the Circular Economy and Efficient Use of Resources", where students collaborate with the House for developing new sustainable solutions for reducing environmental impact by innovating its production processes. One of the 2020 goal of the LVMH Group is to improve the environmental performance of all products by 100%, and the biggest concern is the prevention of raw material procurement and the guarantee of their quality and harmlessness. In this sense, as the environmental impact of the Fashion & Leather Goods sector is closely related to the raw materials it uses, the priority will be to develop a sustainable supply chain by relying on certifications[53].

Conclusions

At the beginning of the chapter we saw that fashion industry is divided into more levels, each of which differentiate from the other on quality and market. Above all, the lowest-price levels count for big share and fast fashion is one of the causes of the high levels of pollution produced by the fashion industry. In all this, China during years has emerged as one of the larger exporters in clothes, especially as regards fast fashion, also due to the extremely lower salaries and poor working conditions. The constant growth of the sector, due to the increasing consumerism characterizing these years, attracts new actors to enter the export-import game, and with the increasing labour cost in China countries must rethink where to locate manufacturing. The choose of where locate production for countries must take into consideration all the Global Value Chain actors, and the consequent brand appearance depends also on these choices.

The high levels of consumerism and the non-renewables resources on which textile industry in mainly based on require a shift through a more sustainable fashion industry, with the creation of a cycle that includes safety and renewability of inputs. Big importance for motivating brands in taking this action is given to customers and investors, who through their market chooses can drive brands adoption of greener habits in managing processes; but customers alone are not

[52] Data are taken from the LVMH Social Responsibility Report (2018).
[53] LVMH Environmental Report (2018).

enough, must be sustained by Governments' policies. Along with policies, lot of initiatives arose for promoting the transition of businesses all around the world.

What we can see is that, even if also small businesses are taking the road towards a more sustainable fashion, more results come from luxury brands which want to create a value added for their customers and differentiate themselves from the mass recognizing their brand as sustainable.

3. Sustainability and industry 4.0: enabling Circular Economy through the use of 4.0 technologies

Through the years, continuous changes affected businesses' activities. One of the biggest is about the technologies which help companies to regularly improve their environmental performances without sacrifice their economic ones but, instead, increasing the offer's quality. Digital technologies could support the transition to sustainable production increasing efficiency (type and quantity of materials used, use of resources) and transparency (traceability becomes easier and secure), and allowing the business to change its model for focusing also on the personalisation of customers' demand.

In this chapter, we are going to see what industry 4.0 is and how it can be useful for the adoption of circular economy on a general economic basis, while in chapter four we will go more in deep with an analysis on the role of 4.0 technologies in the eyewear.

3.1 Industry revolutions in history

We can identify different industrial revolutions in our history. Industrial revolutions are economic phases characterized by a gradual increase in productivity generated by a radical change in the technologies adopted for the production processes. We can identify four evolution milestones in the industry's history (*Figure 14*).

Industry 1.0 is what is known as the First Industrial Revolution, started in England in the late '700 with the introduction of steam machines and the general mechanization of processes, that led to an increase in production volumes with a lower production time. This has been the most drastic improvement: the adoption of steam machines allowed to increase volumes and the consequent demand for workers, giving birth to proletariat, and deeply changing also the economic and social equilibrium.

In 1870 the Second Revolution, with electricity first and oil then, represents the increase in mechanization levels and marks the beginning of mass production with the adoption of assembly/production lines. Key innovations in this phase are represented by two theories: scientific management, known also as Taylorism after its founder (Frederick Winslow Taylor), and Fordism (from its founder Henry Ford). The first theory was based on the optimization on workflows for increasing labour productivity. Fordism instead forms the basis for the modern

industrialized models for mass production, where standardization of the phases is the key, and gave birth to what is known today as assembly line.

The Third Industry started in the ‘70s and represents the first introduction of Information and Communication Technology (ICT) in the production processes, where IT and electronics increase even more the automation levels in processes.

Last, what we are experiencing now: Industry 4.0. The fourth industrial revolution is a mix of technology and robotics. Production models are automated and interconnected, and internet is a big part of the operations: more information, more integration, more interconnection and more efficiency. This last industry is highly based on the integration of different technologies, where people and machines are connected and must find a way for communicate each other.

The main upgrade from the preceding revolutions is that, while Industry 3.0 focused on the automation of the single machine and process, Industry 4.0 aim to the complete digitalization of all physical assets and all along the entire supply chain.

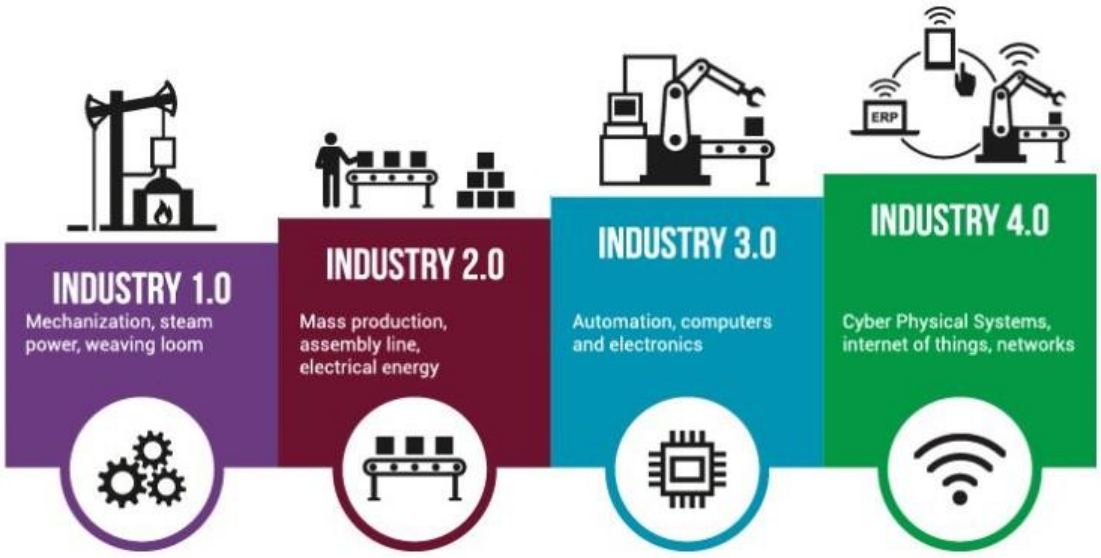


Figure 14: The evolution of Industry

Source: Durand (2018)

This new revolution, as all the previous ones, has raised the concern of workers who are wondered they could be replaced by machines and lose their job. Despite the aim of 4.0 technologies to increase job’s speed of production, this advent brought the need of new skilled professional roles as well, for developing, maintaining and managing these new technologies. Machines will never be able to substitute individual’s creativity, but they will need to develop new skills and upgrade their capabilities.

From a research of the McKinsey Global Institute conducted in 2017, it emerged how around 15% of global workforce (about 400 million workers) could be displaced by automation in the next 13-14 years but also how, in the same time, jobs will also be created, with a scenario of additional labour demand up to 33% of the global workforce[54].

3.2 The fourth industrial Revolution: 4.0 Technologies

Used for the first time in 2011 at the *Hannover Messe*, a German exhibition on industrial technologies, the term Industry 4.0 indicates a business' management with the tendency to industrial automation, which integrates new productive technologies for improving work conditions, creating new business models and increasing the productivity and the quality of the activities. 4.0 technologies include 3D printing, programmed robots, in-cloud management of data and data analysis for identifying weaknesses and strong points of production processes. Since 2011, most Governments have incentivized the adoption of smart technologies through financial incentives and financings.

As industrial systems are moving towards a circular model where resources' optimisation is improved and recovery of materials from waste is maximised, industry 4.0 could potentially help in renovating the process of products' monitoring during all their life.

Every manufacturing company who wants to adopt 4.0 technologies has to consider a set of dimensions that this new production management brings[55]:

- new strategies and business models, required for ensuring a continuous improvement for achieving enterprise value at scale;
- improved technologies and systems, where to invest the capital for better delivering the new strategy;
- a shift in the governance and in the management of risk. The adoption of 4.0 technologies requires big investments from companies, which sometimes are more focused on the adoption per se than on the costs associated with this decision. For this, a strong governance is required in order to keep under control the risk and ensure a profitable ROI;
- people, key components of the business: new competencies are required, and individuals must upgrade their knowledge and develop their skills, for adapting to the new jobs created from the adoption of 4.0 technologies;

[54] Manyika et al. (2017)
[55] KPMG (https://home.kpmg/xx/en/home.html)

- operational performances are affected by the possibility of integrating the supply chain in the business, creating a substantial competitive advantage;
- customer experience, which is one of the most valuable sources of strategic advantage for companies. The adoption of smart technologies can greatly help the business in building a stronger connection with its customers and change their behaviour.

Entering in the industry 4.0 requires investments by the companies, but benefits can be much greater than the costs. Businesses must be able to carefully study all the common dimensions and identify which are the key points where they can take advantage from. These technologies are not just about adding smart devices into existing products, but also creating value for both the company and the end user; this requires specific teams aimed at analysing data coming from the devices and translate them into products or processes improvements.

The major benefits expected from these technologies are multiple for a business activity. First, the increase in the quality of the production and services offered and the reduction of waste thanks to digital sensors that can monitor production in real time and adjust the process based on data collected. This is directly related to an improvement in productivity, due to the reduction in production times for identification (and reduction) of errors, machines' downtime and set-up. Another benefit is represented by an increase in speed between the phases of prototyping and mass production, as well as in the flexibility of the production processes. All these benefits lead to an increase in the competitiveness of the products and services offered thanks to the value-added deriving from the advanced technologies they are equipped with[56].

3.2.1 Key enabling technologies

KETs (Key Enabling Technologies) are defined by the European Commission as "*knowledge intensive and associated with high R&D intensity, rapid innovation cycles, high capital expenditure and highly-skilled employment. They enable process, goods and service innovation throughout the economy and are of systemic relevance. They are multidisciplinary, cutting across many technology areas with a trend towards convergence and integration. KETs can assist technology leaders in other fields to capitalise on their research efforts*"[57].

These technologies are at the basis of the innovation and provide interconnection amongst different fields of research, connecting sectors and machines. Thanks to the improvements they

[56] Ministero dello sviluppo economico (2016)
[57] Innovation Union (2014)

bring in the production processes, products and services carry a value added when offered in the market.

Research on 4.0 technologies is in continuous evolution, therefore the NETs are too. As of today, we can identify nine key technologies (*Figure 15*).

Figure 15: Nine Key Enabling Technologies
Source: adaptation from Ministero dello Sviluppo Economico (2016)

Additive manufacturing

Additive manufacturing describes a production process where, starting from a digital scratch of the output, the product is obtained by adding material layer over layer.

The potential of this technology is represented by the possibility of creating customised shapes while at the same time almost delating the costs related to waste management. Moreover, the fact that the idea is digitally transmitted to the machines reduces the need for intermediate remanufacturing, opening the possibility for the adoption of new business models based on the personalisation of the product.

Despite this potential, additive manufacturing suffers of costs and volumes' limits due to the long production lead time, making it quite impossible for this technology, as of today, to reach mass production.

Fields of application of additive manufacturing go from medical care, infrastructures, aerospace as well as food industry.

Augmented reality

Augmented reality (AR) is defined by Azuma et al. (2001) as a system that combines real and virtual objects in a real environment, running interactively and in real time, that applies to all senses. AR is then a fusion of digital and physical environments at the same time in visual/graphic, text, audio and video overlays, which can be constructive (if additive to natural environment) or destructive (if hiding the natural environment).

It is important not to confuse augmented reality with virtual reality. In the latter, individual's perception is based exclusively on visual information, while AR integrates virtual data with the real environment.

AR is used through different devices. The most common are displays, eyeglasses (kind of visors), HUD[58] and contact lenses. Field of application of this technology include gaming, military training, medical care, navigation apps, advertising and promotions.

AR devices are continuously improved, making them as much adaptable as possible to humans' body in order to maximise the extra-dimension experience. A challenge for this technology is represented by the need of normalize the communication between the virtual and the real: how AR responds and adapts to real time changes in the external environment.

Autonomous robots

In manufacturing, robots cooperating with humans in production processes are already popular, but in future they will become even more fundamental. A big improvement given to robots during years has been the ability of interacting each other as well as with the operator in real time, while executing tasks, allowing to maximise efficiency of production process and increase competitiveness amongst companies.

[58] Head-up-display: transparent display that presents data without requiring the user to look away from his viewpoint. Are commonly used in military aviation, aircraft and automobiles. (https://en.wikipedia.org/wiki/Head-up_display)

Autonomous robots are widely used in industries for production and logistic, but also (in a lower complexity scale) for domestic use like floors' cleaning robots. However, robotics is not just limited to robots: self-driving cars are a form of autonomous robot as well, and the research on this way in continuously improving.

Big Data Analytics

Big Data are the collection of massive, complex and variable data deriving from technologies which are organized, grouped based on a common "area" and archived. When needed, these data are extracted from the archive and analysed in order to be elaborated under what is defined as Big Data Analytics.

What differentiate Big Data from the archive that every single machine connected to the Cloud have is that, while the latter collects data only from that specific technology, Big Data collect information from all the machines connected to the cloud as well as from the network (market conditions, clients' behaviours), grouping all together and classifying them, allowing a predictive analysis on the business.

Main objectives of this technology are the minimisation of costs (especially for the management of big volumes of information), the speed of analysis and the precision of results thanks to the bigger amount of data on which predictions are based [59]. The results are better services to customers, minimisation of the time-to-market, increase of sales and offer.

Cloud computing

The term cloud computing is strictly correlated with Big Data technology. It indicates the on-demand availability of resources saved on the devices' network connection, without a direct management by the operator. The cloud is a data centre which can be accessed by many users through Internet connection from all geographies, allowing then remote interaction.

Through Cloud computing, Big Data are achieved, elaborated and shared amongst the network, which can be public (if available to multiple organizations) or private (if the cloud infrastructure is in operation for one single company).

[59] Raguseo (2018)

Cyber-security

With the introduction of 4.0 technologies the amount of information exchanged through the Internet has intensely increased. Businesses keep their real time data collected from machines in the network for sharing them with all devices. The increasing connection between machines for the collection, elaboration and achievement of data requires to be adequately protected from avoiding damages to production, intellectual property, business' image or stakeholders.

Every device is an access point for a possible informatic attack: hackers find the weakest device and use it as a "bridge" for reaching all the others linked in the same network.

There are specific tests for establishing if a system is threatened or not, but for preventing damages companies should be adopting cyber-security from the beginning, avoiding the risk of losing important information like its specific know-how, which could be the key for the competitive advantage the company benefits of.

Horizontal and vertical system integration

4.0 technologies allow to digitally integrate information systems amongst the supply chain: with customers and suppliers (vertical integration) as well as in the production process (horizontal integration).

This integration is mainly based on shared platforms or management software like PLM (Product Life Management). The aim of this software is to group all the information on development, changes and products/services' pick-up from the market, such that from everywhere and anytime operators can access these data[60].

This technology allows to maximise the coordination between activities along the supply chain, reducing the costs related to warehousing.

Internet of Things

Internet of Things describes systems where the digitally integrated device is combined with a software and recognises communication inputs deriving from the external environment. External data are then transformed and shared through the internet. Machines can be equipped with this technology also later in time, allowing to easily adapt to changes and to integrate different machines also located in different plants.

[60] Assolombarda (2016)

Internet of Things application is common in numerous fields given that every existing object which can be connected to the Internet can be equipped with this technology: ovens, fridges and electrical appliances in general, eyeglasses, automobiles, railway tracks, bridges, farming applications and medical resources. In all these field, the aim is to collect data on the interaction of the product with the environment for improving its performances, utility, efficiency and safety.

Simulation

Simulation is a math model which aim is to digitally describe a process, product or service in order to analyse and test all possible scenarios. It could allow to reduce production costs and waste, as well as maximising quality and reduce the time-to-market.

This technology has been an important application in manufacturing. It can be used as predictive tool for the performances evaluation or for comparing alternative solutions before the real application in the production processes.

Simulation is widely used also in scientific and technological areas where experimentation is an important initial stage. Fields of application are for example aviation, for testing flights with specific environmental conditions and pilot's reactivity, and automobile, for testing the safety of the vehicle during car crashes.

3.3 Industry 4.0 and Circular Economy

From when the two concepts started to become popular, numerous researches have been made in the area of both Circular Economy and Industry 4.0. Despite this huge scientific work, as of today researches on the combination of the two concepts are not much: less evidences on the possible link between Circular Economy and 4.0 technologies have been proposed. The key question is whether emerging technologies can provide opportunities for sustainability enhancement and drive the evolution of a new generation of Circular Economy initiatives.

On one side, circular economy is designed for regenerating itself (biological materials are reintegrated in the process while technical ones should be revalued for new use). On the other side, Industry 4.0 can increase competitiveness and efficiency, as well as promote the introduction of new business models through which produce value, innovation and employment. The interconnection generated by 4.0 technologies allows to better design the production cycle of a product together with its use cycle and end-of-life utility. In this way the

use of resources is optimized and waste is minimised, two of the bases of a sustainable economic model.

Technological advancement has speed up the development and implementation of circular business models, creating new processes, channels and operational efficiencies. New technologies are key for the transformation the economy is undergoing, from the linear to the circular model. A circular system requires deep studies on materials and processes to adopt; 4.0 technologies can, in this sense, help tracking the flows all along the supply chain and increase the dynamism. What is needed for Industry 4.0 to work are the integration and networking capabilities, data exchange for tracking performances and results of the processes used, security and privacy of data collected, interoperability and self-organization capabilities especially for the intercommunication of connected devices. Among all these key features, Big Data analytics is required for properly elaborate, analyse and benchmark data collected for improving Industry 4.0 utility and performance. Industry 4.0 integrates human-robot collaboration and transform manufacturing in digital processes where heterogenous data are shared and elaborated between different environments.

3.3.1 Enablers for the adoption of 4.0 technologies in circular economy

From a study of Rajput and Singh (2019), it emerges how 4.0 technologies have the possibility to better support supply chains based on circular economy, as they ease with visibility of the entire supply chain, traceability and efficiency. In this support, three are the enablers which emerged as the most effective. Circular economy per se is key for reduce the business' footprint and maximise the efficiency coming from resources. Together with circular economy, key enabler is Artificial intelligence, that becomes mandatory when automation is introduced in the supply chain, as it manages the technological aspects relating to automized processes. With artificial intelligence it is possible to collect, analyse and apply data through smart interfaces that provide the needed flexibility to the processes, and maintain this information on products and processes all along the supply chain as an archive. Lastly, service and policy frameworks for establishing regulation on materials' disposal and for creating standards to follow in the management of waste and resources, are fundamental for the aim of providing greener products and solutions to customers. This would allow to reduce the impact of both production and consumption, especially if integrated with a predictive maintenance activity for promptly detect changes in system's conditions to improve the process, reducing errors and waste.

3.3.2 Challenges for the adoption of 4.0 technologies in circular economy

In the same way, the authors identified which are the challenges in implementing Industry 4.0 for a circular economy-based supply chain. The first obstacle is represented by the need to integrate cyber-physical systems, since they use different computing models and collect heterogeneous data which must then be analysed together. Along with digital obstacles, other barriers relate to design, compatibility and infrastructure standardization needed for the application of smart devices and the integration of the systems and processes. The geographical location of the production site can be challenging for the device integration given the added technologies they require as cloud storage, computational activities, compatibility between the systems, and privacy and security support, which must be as much improved as possible for correctly interact remotely.

First common barrier identified for the integration between Industry 4.0 and circular economy is the interface design, mainly for the difficulties of integrating automated systems required by circular economy without scarifying the flexibility required for example in smart factories, designing functional CPS systems. The second common challenge is identified in automated synergy, which requires a centralized model of evaluation for collecting data, standardize and analyse them accurately for minimising errors and increase efficiency in the processes. Both these technological barriers are of primary importance to overcome since the human-machine interaction and the ability to manage automated systems which offer real-time solutions on operational processes are two key points in the integration of disruptive technologies in sustainable supply chains for reaching a circular system.

3.3.4 Industry 4.0 in a circular system

4.0 technologies have the ability to support the monitoring, analysis and control of products and processes' data in order to assist in goods' lifecycle and their management at the end of their utility. Information flow along the supply chain requires a continuous exchange of data among all the actors in the network. This can be facilitated with the use of Big Data under the ReSOLVE[61] framework, which support the circular economy transition, and the IoT system for allowing system optimization models, real-time measurement, big-data analysis, smart integration[62]. To these digital technologies, technological improvements as additive

[61] Big Data have four main characteristics: volume, velocity, variety and veracity. These characteristics are applicable to the ReSOLVE process which states for Regenerate, Share, Optimise, Loop, Virtualise, Exchange.
[62] Ünal, Urbinati Chiaroni (2018).

manufacturing (fundamental in supporting the design phase and allowing the production of modularized and customized products), cyber-physical systems (CPS) and cloud manufacturing are flanked. CPS integrates computation, networking and physical processes: computers and networks monitor and control the processes, giving real-time feedbacks on issues and improvements; physical processes respond to these feedbacks with adaptation and the loop continues. Cloud manufacturing technology, instead, is based on the creation of a shared network where manufacturing resources and capabilities are collected: is a service-based tool, where suppliers and customers interact exchanging services rather than physical products.

Figure 16 schematizes the relationships between four of the 4.0 technologies mentioned above (CPS, Cloud manufacturing, IoT and Additive manufacturing), and two of the processes embedded in a circular economy system: value creation and value capture. As we can see, in almost all pillars value creation comes from sharing knowledge or data through the creation of a network and collaborations along the value chain. The last pillar, additive manufacturing, is based more on technical aspects than on cloud: focus for creating value is on the physical process' phases and on the sustainability of materials (and resources in general) used in the production cycle.

Value capture, instead, is focused on customers' experience and services their given rather than the good per se. Additive manufacturing aims to engage the customer in a circular economy loop by offering him customized products based on specific requests, increasing the value attributed to the good and providing a service through which the business is also able to reduce costs related to waste. IoT focuses on collecting real-time information and provides feedbacks for maximising the individual experience.

		Circular Economy business model	
		Value Creation	*Value Capture*
Industry 4.0 pillars	*Cyber Physical System*	-Resource, energy and capacity efficiency -Sharing data through partners among supply chain to enhance skills and capabilities	-Supporting the service models for customers through highly integrated physical goods with smart algorithms
	Cloud manufacturing	-Effective collaboration through value chain for design, assembly and manufacturing while capturing new skills	-Enabling active customer engagement in Circular Economy activities -Active e-commerce enabled promotion of circularity
	Internet of Things –IoT	-Better communication and exchange of data through value chain	-Enables the service models through collecting real-time information on location, condition and availability of assets
	Additive manufacturing	-Facilitating the DfX practices for CE (design for disassembly, recycling etc.) -Resource, energy and capacity efficiency -Friendly material usage as a substitution to mainstream toxic ones in the market	- Unique parts-solutions that can't be produced with conventional methods for sale of single products as well as service -Enabling active customer engagement in Circular Economy activities as the parts are tailored for specific customer

Figure 16: Deployment of Industry 4.0 on Circular economy business model

Source: Ünal, Urbinati Chiaroni (2018).

3.4 Supply Chain 4.0

Industry 4.0 introduces disruptive technologies that require companies to rethink the structure of their supply chain. Different trends have pushed this change in the management, starting from the growing customers' expectations on product as well as on services, like customization; this must be added to the increase in online shops' platforms that offer a multitude of always new products worldwide, driving the competition of supply chains and increasing the need of integration between al the stakeholders involved.

Digital supply chains will become:

- Faster. Especially as regards logistics: product distribution will be improved for reducing the delivery time. This will be possible thanks to weekly forecast and predictive analysis.
- More flexible. Production is better scheduled and real-time planning allows to faster changes deriving from customers' behaviour.
- More customer specific. Demand for personalization is increasing, and this requires a more focused micro segmentation for satisfying the demand.
- More accurate. The introduction of sensors and devices in the production processes allows a real time feedback for rapidly identify issues and, where possible, automatically adjust the process. Not only in production processes, IoT can help in collecting all the KPIs information and adjust services based on results, keeping the focus on the target and increasing aspiration levels.
- More efficient. New technologies allow to optimize the use of resources and maximise the adaptation to market requests.

All these improvements can be combined in a circular supply chain.

A circular supply chain provides renewable energy and bio-based or fully recyclable materials as inputs of the process, for enabling a regenerative cycle where resources are used again and again. In addition to inputs' utility maximisation, sustainable supply chain forecasts from the design phase to the end-of-life management of the product, often adopting a business model that gives to customer the service of recalling products taking upon themselves the duty of recycling the good.

Implementing a supply chain of this type can be challenging under different aspects. First of all, the availability of sustainable chain partners is very limited, even if in recent years the number of suppliers who offers greener alternatives is increasing. Despite this, there is also a segment of them that declares to offer sustainable choices even if they are not, increasing the

customers' mistrust. Reliability is an important feature, that is why businesses should rely only on certified suppliers. A solution for this has been found in the concept of traceability of products, a technology with which companies can trace their product all along the supply chain for certify its origins. Other challenges are represented by the uncertainty of the product's return from clients at the end of its utility and the transportation infrastructure, phase which plays a big part in environmental impact. About transportation infrastructures, the main concern is that (in general) products should be send all over the word if required by customers, especially when supply chain is globally spread.

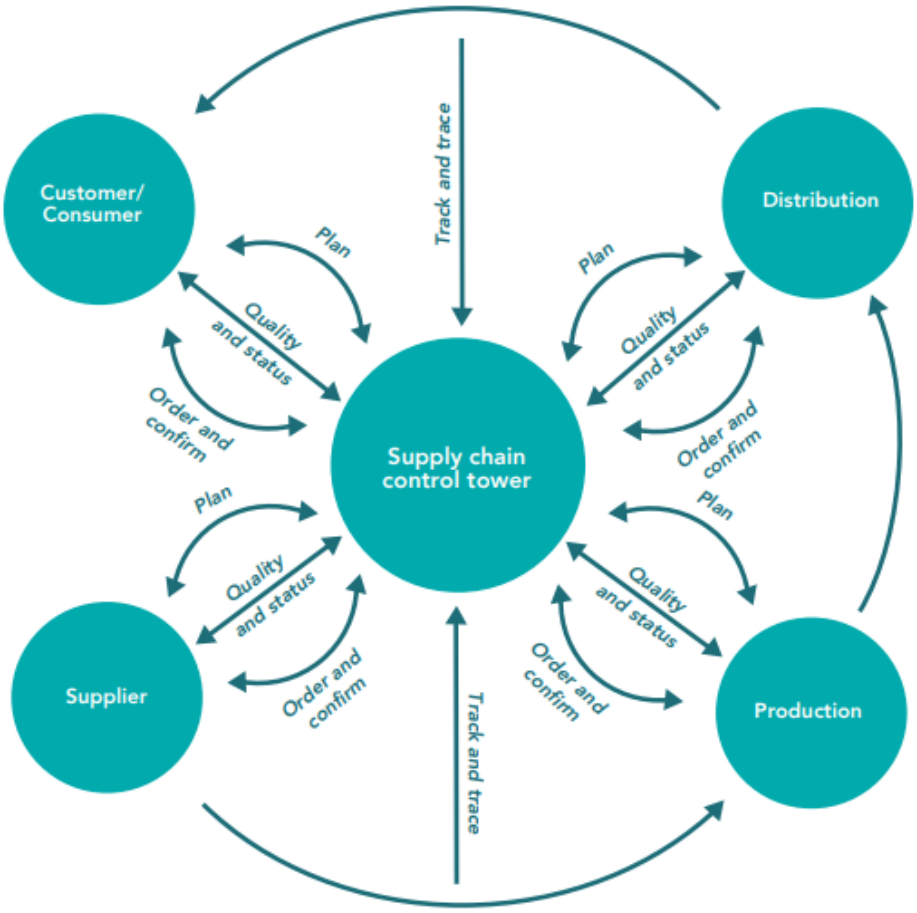


Figure 17: Integrated supply chain ecosystem

Source: Ferrantino and Koten (2019)

3.4.1 Remanufacturing and the role of new technologies

As we said in the first chapter, circular economy is at the base of a system where products at their end of life become new inputs. There are many end-of-life channels (recycling, remanufacturing, reusing, refurbishing) but the most effective in creating value added and preserving the existing quality is remanufacturing, which is the "*process of bringing end-of-life products back to good-as-new status through disassembly, cleaning, inspection/sorting, restoring and reassembly*"[63]. Remanufacturing is a huge opportunity in a circular economy system, but there are many challenges to be overcome for this technique to be effective. First of all, it has to be said that remanufacturing is not always possible but is easier to implement in sectors where products are durable and contain high-value materials, technology cycle is stable and where products could be sold as services. In sectors where carrying out this activity is possible, there are other common challenges that affect the remanufacturing ability of a business: the lack of standards and legislation, the lack of life cycle design awareness[64], lack of market demand and "input products" (due to the negative perception customers have on the quality of remanufactured goods) and the lack in skills and technologies, added to the limited information sharing (remanufacturing is a high-labour intensive activity which requires technically skilled individuals). What can help to overcome these challenges is the advent of 4.0 technologies and their integration in the production process from the beginning to the after end-of-life phases.

In *Figure 18* we can see the three are the area where Industry 4.0 could bring opportunities for remanufacturing, and the technical enablers.

[63] Yang, MR, Kaminski & Pepin (2018)

[64] As said in the first chapter, the design phase is one of the bases for circular economy: designing a product taking into consideration its end-of-life utility is fundamental for the circular system.

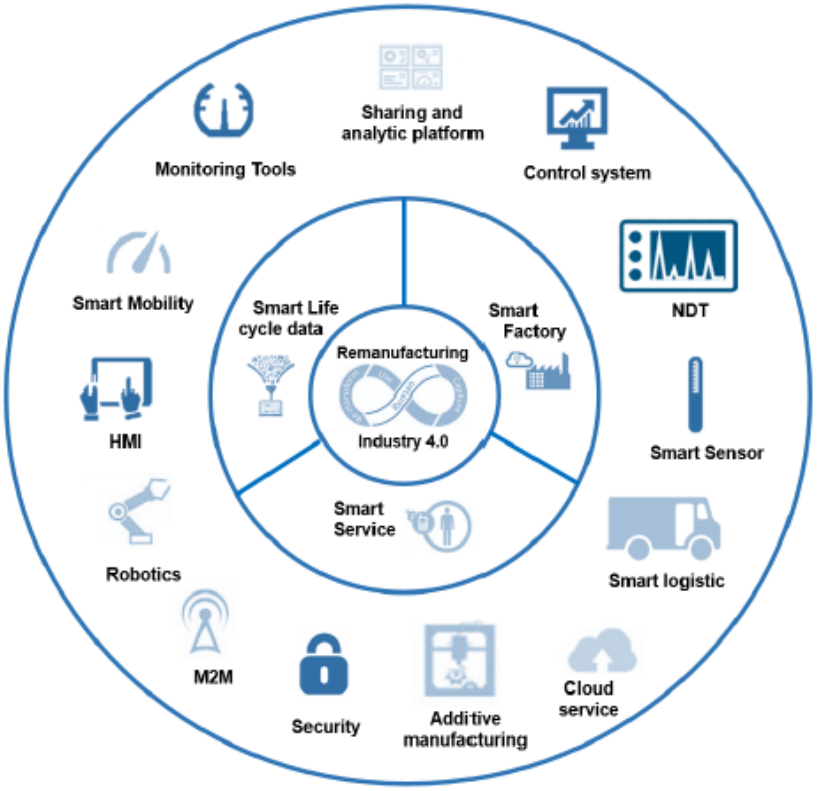


Figure 18: Opportunities from Industry 4.0 for remanufacturing, and its key enablers
Source: Yang, MR, Kaminski & Pepin (2018)

Smart Life Cycle Data

All along the life cycle of a product, information is generated and should be recorded in a product's register. This information should be shared with all the product's stakeholders in order to effectively manage the processes in the future and being able to continuously identify points of improvement. What was missing until the advent of 4.0 technologies was the ability to properly gain and retain information on the product's life cycle from the design phase. With the introduction of Big Data and IoT, and more in general with the digital transformation of the business, this obstacle has been partially overcome thanks to data transferability improvement and the creation of data-sharing platforms.

Smart Factory

Remanufacturing activity requires a high degree of flexibility from the plants in order to quickly adapt to the different product requirements. For this, the help has come through the implementation of Smart Factories, where the smart component is reached using a shared network of resources (RFID tags, barcodes) to allow machines to collaborate together using

shared data analysis. The smartness of factories will continuously improve also thanks to additive manufacturing, automated robots, drones and augmented reality tools which will likely decrease the cost of remanufacturing while at the same time increase the quality and the value added of the product resulting from this process.

Smart Services

One of the challenges to overcome for remanufacturing activity was the lack on the control of the quality and the quantity of products returned to undergo the remanufacturing process. One solution to this problem has been found in a change in the business model adopted by the business: ownership of the product is retained by the producer, while to the customer is offered the service for using the product (so called "Product as a service" business model). This could be a win-win situation: from the manufacturer side, he can monitor the product during its life cycle and forecast the operations needed for when the product will be returned for remanufacturing; from the customer side, he will pay for the service and the usage hour, and will not have to worry about the management of the product at its end of life.

3.4.2 Digital technologies for the support of supply chain's efficiency and transparency

As mentioned at the beginning of this chapter, the introduction of new technologies in the production process have the potential to increase efficiency and transparency all along the supply chain, improving the overall business' performance especially in the long period.

Increase in efficiency reflects both on the supply chain management (quality and quantity of material used, resources management) and on the service quality offered to customers. The combination of multiple new technologies would bring positive results to the company. Amongst all, a key role is played by additive manufacturing. Additive manufacturing (AM) is commonly known as 3D printing, even if the term in general identifies all a series of production technologies where final product is made without the use of stamps or rough mould. The concept of AM is opposite to the traditional subtracting manufacturing. The key difference between the two processes is that in subtractive manufacturing production starts from a block of raw material which is worked through different phases until it reaches the desired shape, leading to a higher volume of waste, created by all the material removed from the block, rather than in additive manufacturing where final object is created depositing material layer over

layer[65]. It can be understood how residual waste deriving from AM is much lower. The most frequently used additive processes of 3D printing are three: selective laser sintering (SLS), fused deposition modelling (FDM) and selective laser melting (SLM).

SLS process works through the fusion of material in the form of powder. The powder is spread on the worktable and a laser sinterings it following the scratch of the model. This works for every layers of the object. The difference between this process and the SLM is that SLS put the powder together by melting an added material which works as glue, while SLM directly melts the particles of the powdered material, creating more resistant and of higher quality products.

The third process if fused deposition modelling. FDM consists of creating layers of materials through a nozzle in the printing head, inside which material is previously melted. This technology usually requires a subsequent rework for finishing the product and removing material's excess.

All three these techniques work through a 3D model created with CAD systems in .SRT file and sent to the printer. The file is worked by a software that divides the CAD sketch in horizontal sections, for being elaborated by the printer as the layers. Therefore, physical machines must be integrated and operate with two different software: the one for creating the initial model as a file, and the one that elaborates the file for giving the input for the 3D printer work. The results obtained largely depend on the material used, since its choice will determine the quality, flexibility and resistance of the printed object[66].

3D printing requires time, but precision is very high. That is why this technique is largely used in sectors as medical and dental care, for the production of small prothesis, or aeronautical sector, where complexity of parts and resistance are fundamental. In addition, AM can be used to support the design for assembly (and re-assembly) by producing modular and customized products, also closed to customers by exploiting localization advantage. Despite the potentials of this technologies, amongst which the reduction of waste and the increased efficiency and quality of products, it is not so popular yet due to its limitations. Production is very long-lasting, and it is unthinkable to reach the volumes and rhythms that mass production has as of today. Moreover, the bigger the object and the more time is required, even if it is not possible to produce big items due to "work-spaces" constraints. That is why 3D printing is mostly adopted

[65] Watson, Taminger (2018)
[66] Bacchetti and Zanardini (2018)

for the production of parts rather than entire objects. In chapter four we will discuss further potentials of additive manufacturing.

Digital technologies can also support the increase in transparency of supply chains. In the mid-80s, traceability arose as a way for reassuring customers about the safety of products, especially for the food sector, increasing the transparency of the steps along the supply chains form producers to consumers. In the fashion industry this safety is intended as informing the customers on the environmental impact of clothing/production and on the labour conditions in production and manufacturing plants.

Customers increasingly demand for assurance of certified and sustainable products and market demand can be influenced through traceability, increasing the demand of responsible made products and decreasing the sales for unethical produced ones. These certifications often lead to a higher cost for consumers since producers will likely transfer the traceability cost on the final product, but customers are willing to pay the extra price if this means to have a product certified as green, for the same reasons explained in chapter two on how customers influence the market with their choice towards more sustainable brand: traceability creates a niche were products are identified for an added value, and customers can differentiate themselves from the mass.

Usually, traceability is expressed through labels that help the customer to understand the characteristics of the product, the environmental impact of its production and where materials are coming from. Along with the benefits for the customers, traceability has utility also for companies. Having a label which record all the information on the industry chain of a product with the overview on the processes it has gone through, allows the company to track down the good along all the supply chain. Moreover, traceability could help in the control of goods for lowering the selling of counterfeiting goods.

In the era of 4.0 technologies, traceability systems are integrated with blockchains technologies. Blockchains are databases where transactions data are verified and recorded, and in supply chain application this database allows to create “information blocks” on the transactions between suppliers and producer on the processes. The information collected is recorded and cannot be modified. In 2017, for the first time an apparel has been tracked with blockchain technology: an alpaca pile. Through an App, a blockchain system has been implemented for following the product all along its production processes from clipping to selling, and all information were available by scanning the QR code on the label. For gaining form companies trusted information on materials, processes and stakeholders behind the production, in 2013 in

London born the start-up *Provenance*, for tracking the supply chain of fashion industry products through blockchain. The brand can enter the website and use the Provenance platform for creating their digital transparent supply chain[67]. Another network where brands can access for creating a transparent and sustainable supply chain is Circularaise.com[68].

Businesses can benefit from blockchains under different aspects. First of all, as said transparency and security of information (data cannot be altered once created) increase customers' trust on the brand. Moreover, the network of information reduces the costs of transactions which becomes also faster since the cost of exchanging information and the time for third-parties involvement is eliminated. Lastly, given the unchangeability, and so the greater importance, of information shared, all stakeholders will be aware of their brand, and will have at disposal all the data they need for taking well-informed decisions.

Conclusions

Revolutions in the industry history have been happening since the '800, but what differentiate Industry 4.0 from the previous ones is the introduction of a series of disruptive technologies in the production processes based on automation and interconnection of machines.

New digital technologies have the ability to interconnect and make resources cooperate from different geographies through remote control. Key enablers technologies for this 4.0 industry are continuously improving. Interconnection and integration allow a level of information exchange which becomes fundamental for the shared improvement of competitiveness and efficiency, as well as creating new business models through which companies can create value, innovation and employment. On the other side, circular economy aims to reach not only economic benefits, but also social and environmental ones. This transition requires big investments because new materials and way of works are needed. Main reasons for which companies should adopt 4.0 technologies are the deriving improvements in services and efficiency, but also the positive impact on environmental impact plays its role. Amongst all, the most adopted technologies in manufacturing are additive manufacturing (especially 3D printing), Big Data (for conducting predictive analysis) and IoT.

[67] Costa (2019) https://www.provenance.org/
[68] https://www.circularise.com/

For this aim, 4.0 technologies can play a key role in enhancing circular economy: connecting products and plants, creating networks of value chains and monitoring the entire lifecycle of a product, from its design to its end-of-life utility, is a big step in reaching economic and environmental sustainability. Waste management, energy and resources optimization, processes improvements are all goals that economic activities could reach.

Even if not much studies have been done until now on the relationship of these two concepts, evidences on the positive correlation between the adoption of 4.0 technologies and the enhancement of circular economy are increasing. There are still challenges that limit the potentials outcomes, as the need for integration between human-machine language for the collection and analysis of data. Despite this, 4.0 technologies play a strategic role in enabling circular economy, representing a key tool for optimizing the use and the management of resources from a productive point of view, but also the consumption of resources from a usage point of view. Their help is fundamental especially for obtaining information on supply chain phases through digitalisation and achievement of data, for allowing real-time control on products and resources status.

Supply chains based on 4.0 technologies can be combined with sustainable systems of circular economy, creating a circular supply chain based on digital innovation. This adoption requires the research for new sustainable suppliers, certified for their bio-based or recyclable materials in order to gain consumers' trust. 4.0 technologies applied in supply chain management allow to maximise efficiency, minimise cost related to waste and reduce the quantity of materials and input used in the production processes: both economic and environmental benefits are reached. In addition to "materials" benefits, the combination of circular economy and industry 4.0 is at the basis of new business models based on services rather than products. Offering services to customers means having more control on all the life cycle of the product, preventing an incorrect management from the costumer when products are not useful anymore, and allowing the business to increase the value added connected to the service offered.

4. Use of 4.0 technologies in the fashion industry: the role of additive manufacturing in the eyewear sector

We have seen in previous chapters the importance of shifting to a greener management of the business activity and, in particular, the benefits deriving from the adoption of a circular model. We highlighted also how the last industry revolution brought disruptive technologies into production processes, and in which way their adoption can have a positive impact on performances and on the vastness of the offer of companies that adopt 4.0 technologies.

In this chapter we are going to see if eyewear industry can be considered sustainable and in which way 4.0 technologies are integrated this sector, in particular regarding the goals companies can reach when adopting additive manufacturing with a focus on 3D printing, and how this technology (as well as others) could shift companies' business models towards a more service-focused one, offering personalization and the customisation of products.

4.1 The evolution of the eyewear sector

Even if there are traces of ancestors of what we know today as eyeglasses, it is only at the end of the 19th century that Angelo Frescura, an optician in the Belluno area, started the industrial production of eyeglasses.

The first models were produced in leather, then wood, natural horn and metal has been introduced. Eyeglasses were considered exclusive goods and were then used mainly from aristocracy and clergy. Plastic materials have been introduced only at the end of the 19th century, opening the opportunity for the development of new models and styles.

The evolution has continued in the years. Eyeglasses and sunglasses are widespread all over the world, becoming a fashion accessory produced by almost all fashion brands in an even more internationalized supply chain.

4.1.1 The quality of the Made in Italy between tradition and innovation

Eyewear sector has developed mainly from the Belluno area since the second half of 1800. During the subsequent years, firms in the area started to agglomerate creating what is known today as the cluster of the eyewear. It was characterised by a high concentration of production

units, the prevalence of small companies and a strong relationship (both competitive and cooperative) between the actors inside the cluster.

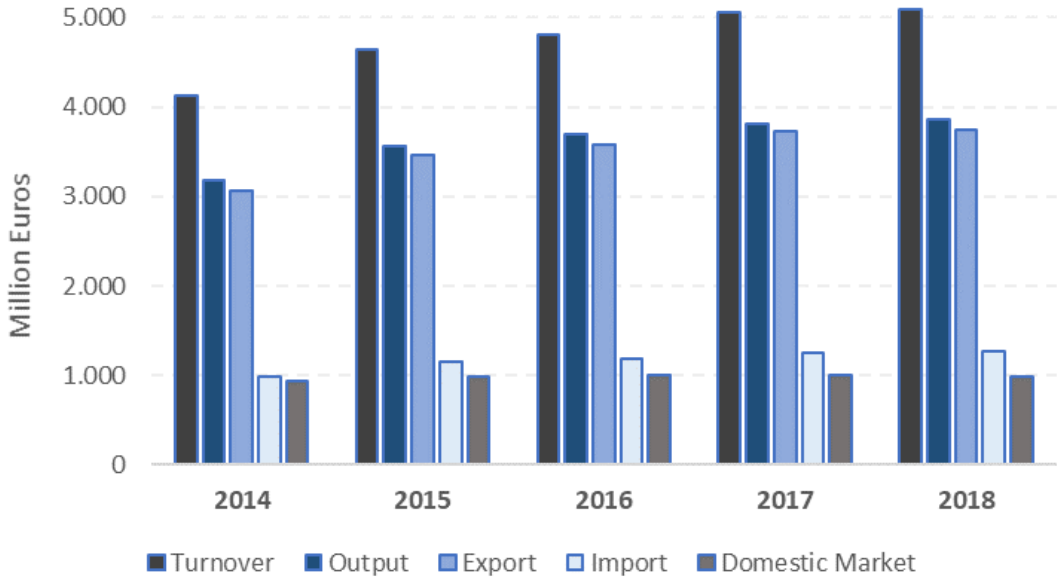
Italian Made In is appreciated worldwide since it is synonymous of quality. Eyewear sector is born as a highly handmade job, where artisans worked frames by hand and used qualified materials. Product resulted in a high quality and durable offer to customers. The expansion of the sector and the introduction of machines for the mass production did not change this perception of the Italian product, making it still highly valuable in the global market.

As of today, the cluster has expanded and includes also companies located in other sites of the Veneto region. Despite the "difficult" position in which it was born, geographical location did not negatively affect the performance and the development of the district. Calalzo di Cadore (where the first opticians started the industrial production) is in fact a small mountain village that at that time was not well served by the main roads and infrastructures: railway has been built only between 1912 and 1914, and also as of today the motorway ends 40 kilometres away from the village. The low weight and (in general) small sizes of spare parts allowed to not make logistics an issue[69]. In the years, the core of the district moves towards the valley and, as of today, the main industrial areas of the Belluno eyewear district are those of Longarone, Alpago and Agordo.

From a small town in Calalzo, today Italy plays a dominant role in the eyewear industry. With 867 firms operating in the sector in 2018, four companies amongst the word-wide leaders are Italian: Luxottica, Safilo, Marcolin and De Rigo. In 2018, Italian production increased by 1,6% from 2017, reaching a value of 3.865 million of Euros, and employment increased as well (+2,3% from 2017). The Italian export counts for the 90% of the production of this sector and products are mainly sold to Europe (North-East countries like Sweden, Norway and Poland are increasingly importing made in Italy eyeglasses) and America. Asia counts for almost 16% of Italian exports, but in 2018 the trend has been negative as compared to 2017 data. The country that had a huge hike from 2017 has been Africa, with an increase of 16,2% compared to the previous year. For 2019 these positive trends seem to be confirmed. Notwithstanding the general stall of the economy due to commercial tensions with China and the negative performances of the German and American economies, in the first semester of the year the total export increased of around 7% compared to 2018 period. Imports are mainly from Asia (75%).

[69] Bramanti and Gambarotto (2008)

In terms of volumes, in 2018 Italian manufacturers exported 103million pairs of spectacles, of which 67% sunglasses and the remaining share was eyeglasses' frames[70].



Graph 6: Details of the Italian eyewear industry in the period 2014-2018
Source: Author's elaboration based on data from EUROM I General Assembly (2019)

In the last fifteen years, Asian producers have become more competitive due to their quality/price ratio: wages are about 20 times lower than in Italy, with 90 thousand estimated employees working in production. The main difference between Asian and Italian production is the target: Italy is focused on a medium-high and luxury segment, while China medium-low.

The quality required for a Made in Italy certified product does not allow Italian companies to compete on prices. This pushed firms to develop their good and bet on offering differentiated products based on design, quality and services offered to customers. Firstly, trademark has become fundamental in driving sales, as well as giving an added value to the product for increasing financial means and driving up sales. Together with this, time-to-market must be shortened as much as possible but without losing the focus on the quality standards needed for selling worldwide a guaranteed Made in Italy product. A firm's capability of offering a customised product highly depend also on the supply chain network on which it relies on. The choice of innovative suppliers allows the company to quickly create new designs and adapt products to the changing market demand.

[70] ANFAO (2018) and Camurati (2019)

4.1.2 Eyewear: from function to fashion accessory

Eyewear was born with the purpose of correcting eye diseases, but the evolution of the market increasingly allowed to find the best shape, size and colour for a fashionable value added. As eye tests are of easier access, purchasing power has increased and we have become more educated about the damaging effects of the sun for eyes, function and style have combined resulting in a shift towards making glasses a fashion accessory. Innovations in lenses and frames technologies has been well welcomed due to the increasing number of individuals with eye disease and who must resort to them.

Eyeglasses have always given an "intellectual" look to individuals, but today both eyeglasses and sunglasses are spread worldwide and are regularly present on catwalks and worn by celebrities and influencers as a signal of elegance and be up to date with latest trends. This increased the perception of the eyewear as a fashion accessory like clothes, shoes and bags, to change on a regular base as market trends evolve. For many individuals, this "obsession" for being fashionable meant also wearing eyeglasses frames with fake lenses or without them, just for the need of showing.

This evolution in the perception of eyewear with the proactive approach of consumers has favoured the market, giving manufacturers the opportunity to expand their offer and the network in which they operate. On the other hand, this strong influence of fashion trends on the sector requires high flexibility from producers and not all of them are strong enough for the required level of adaptation.

At the beginning, eyeglasses were sold by opticians and small retailers. As the interest in the sector and the mass production started, luxury brands begin to enter the market adding frames and sunglasses to their collection. In the '60s, *maisons* like Dior and Pierre Cardin tried to launch their frames in the market but has been Luxottica that found a way for introducing fashion styles in the mass production: in 1988 it signed an agreement with Giorgio Armani, an Italian luxury fashion house. Since then, the desire for premium frames and sunglasses has grown as well as the premium brands which entered the eyewear market; Prada, Chanel, Gucci, Dolce and Gabbana, Valentino and Ray-Ban are just some of them. Fashion stylists and designer carefully choose producers to whom entrust their brand name, favouring those with high productive and commercial solidity. Collaboration between stylists and producers is not occasional but has become a long-term investment. For Ray-Ban the evolution history has been longer. It has been the first sunglasses producer for the military, in the '20s, with what is worldwide famous also today: the Aviator shape. During the years it has been able to innovate

and adapt its offer to the market request, and its products has been used in many famous films and by celebrities since the '70s. In 1999 the brand has become part of the Luxottica's portfolio and in 2003 it added the frames sector as well as junior sector.

The fashion industry of eyewear is based on what we can identify as "product romanticising", that is the value added given by individuals to a common good just because of the brand name printed on it, and this is the reason why customers are willing to pay hundreds of Euros for a simple good as a frame or sunglasses that has become a fashion signature. Trademark has become one of the most important competitive weapons capable of deeply influence sales.

The increase in luxury products and the value at which they are trade on the market fostered the negative side of luxury products, common to all categories: the increase in the circulation of counterfeit products, especially in developing regions. This has been favoured also by the spread of e-commerce shops, that has widened the geographical area which fakes can reach. A difference between brands' product and imitations is the quality of the material used, but it is not always easy for a customer to recognize which is the real product due to the high specialisation that even counterfeits' market has reached in these years. Along with the lower quality of the counterfeit products, they could also bring damages to customers if, for example, sun protection lenses are not certified for UV sun protection. Brands and manufacturers are developing solutions for guarantee the origin of frames and sunglasses. One solution has been found in the adoption of RFID[71] tags, a technology for the identification and achievement of information regarding the product, giving each item a unique DNA. This technology traces the eyeglasses all along its supply chain and then makes it easier to verify the authenticity, ensuring its quality and safety[72].

Luxottica has developed its innovative traceability system based on RFID technology, which works through a RFID tag equipped with a sensor embedded in the frame. As of today, this technology is still under development and has been testing on some of the house brands of the Group, as Oakley and Ray-Ban[73].

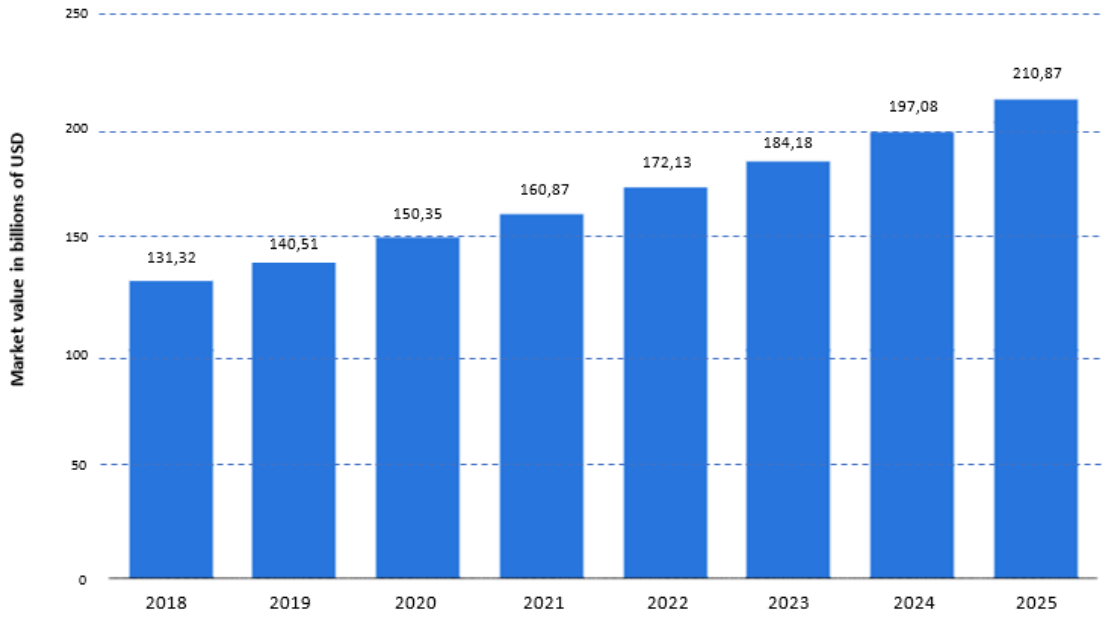
[71] Radio-Frequency Identification
[72] RFID For Brand Protection (www.nxp-rfid.com)
[73] http://www.luxottica.com/en/about-us/unique-approach/brand-protection

4.1.3 The global market of eyewear

The global eyewear market is composed of four categories:

- spectacles (prescription glasses)
- contact lenses
- sunglasses
- eyewear related products (cloths, pouches, etc)

As of 2018, the market's value was of around 131 billion USD, and it is forecasted to reach a value of 210.8 billion USD by 2015[74] (*Graph 7*). Contribution for the expected growth is given by the increase in ophthalmic disorders (especially amongst youth due to their tendency to spend most of the time looking at screens), the rise of individuals who can afford luxury goods and an increase in disposable income. The market is also facing a proactive approach from consumers, giving retailers and manufacturers the opportunity to expand their customer base. Channels of distribution are both offline (retailers, boutiques and other physical shops) and online. In this sense, e-retailing is expanding and its success is growing, especially in regards of sunglasses and eyewear related products. Eyewear is expected to experience a rapid growth rates in the next ten years also driven by the expansions amongst individuals of digital products as augmented reality visors and smart glasses, almost non-existent today if not for professional use.



Graph 7: Value of the global eyewear market from 2018 to 2025 (in billions of USD)

Source: adaptation from https://www.statista.com/statistics/300087/global-eyewear-market-value/

[74] https://www.statista.com/statistics/300087/global-eyewear-market-value/

In terms of volumes, in 2015 the number of units sold was around 2.7 billion, and the forecast is to reach 3.92 billion units in the next 5 years. 40% of the market share is represented by frames and sunglasses, inside which 35% is represented by fashion brands' products.

The highest revenues in the global market of eyewear are generated by Europe (with the share of 45% in the global market in 2016[75]) and North America. In Europe this value is mainly due to the higher average selling prices for eyewear combined with an increasing tendency towards luxury category. In North America, instead, the major contribution to this increase is due to the raising in disposable income. In addition to this, the increase in e-commerce companies which offer low-cost deals is raising competition in the market, pushing prices of eyewear down and then forecasting an increase in the market demand.

Market of eyewear is very fragmented and frames and sunglasses' segment is dominated by few key players: Luxottica, Safilo Group, Marchon Eyewear, De Rigo Vision and Marcolin Eyewear. Most of them have created a strong position by offering an extensive and diversified portfolio of products. Italy represents one of the leaders in the eyewear production with four Italian companies amongst the best 5 actors, representing around the 70% of the world eyewear market of the high-medium target (from 100 Euros up), with the 50% of world production on licence and fashion luxury brands. Concerning lenses segment, instead, major players are represented by Essilor, Johnson & Johnson Vision Care, Cooper Vision and Carl Zeiss[76].

The global leader of eyeglasses and sunglasses is Luxottica, followed by Essilor, a French company leader in the lenses market. In 2017, the two companies merged and in October 1st, 2018 EssilorLuxottica was born. After the merger, the Group acquired GrandVision, a retail chain, and Barberini S.p.A., an Italian producer of glass lenses. These two acquisitions allowed Luxottica to integrate even more its supply chain while integrating and reinforcing its Made in Italy production as well as expanding its presence worldwide thanks to the huge numbers of GV's shops[77].

[75] https://www.researchnester.com/reports/eyewear-market-global-demand-analysis-opportunity-outlook-2024/268

[76] https://www.marketwatch.com/press-release/fashionable-contact-lenses-expected-to-boom-the-eyewear-market-with-a-noteworthy-value-in-future-2019-04-18-12197382?mod=mw_quote_news

[77] https://distribuzionemoderna.info/estero/essilor-luxottica-tocca-17-dot-200-punti-vendita-con-lacquisto-di-grandvision - http://www.luxottica.com/it/luxottica-completa-lacquisizione-barberini-italia

4.2 Product design and 4.0 technologies: process and material innovation for a sustainable frame

As mentioned in the previous chapter, the aim of industry 4.0 is also to make the manufacturing industry more competitive through a sustainable business model, based on a circular system. The development of new sustainable products can be applied to the eyewear sector as well, a highly technical industry in which 4.0 technologies can be employed in many phases of the production process.

As we are experiencing a global plastic waste crisis, innovation must be applied not only to processes but also to the materials used in the production, and conventional sunglasses contributes as well to unnecessarily pollution. It turns out that glasses are of ideal use for recycled materials.

Materials and process innovation are strictly correlated. Predictive maintenance should be integrated with "smart materials", as they can serve as sensors for detecting production issues through the process analysis and elaboration of data. Also, in additive manufacturing the development of new materials is necessary for guaranteeing the quality of the output given that traditional materials may not be suitable for this type of highly technological and digital work.

The ability to innovate processes (new manufacturing technologies) and products has become a critical competitive factor, as much as the distribution capability and the trademark.

4.2.1 Process innovation

The creation of a sustainable eyewear, as any other product, must start in the design phase. As mentioned in the first chapter, designing a product with the aim of making it circular and provide a solution for its components at the end-of-life is the first step for a circular system.

Processes are tailored based on the production particularities of glasses. The choice of the material used, the shape and the complexity of the frame affect the design and the production phases of the product. The variability of the shape and the structure of the glasses are influenced by three factors: the close relationship with fashion, which determines seasonal changes in the market demand; the tendency of giving shorter life to the product, which consequently requires a continuous renewal and innovation in the production processes; the growing segmentation of the market and the number of different products requirements. Another determinant affecting earlier phases of the process is the technology and the processes required by the nature of the

materials used for the product; different materials have different chemical-physical characteristics which require specific manufacturing for preserving the durability and the aspect, and this becomes even more important when material are combine in the same eyeglass (for example plastic frame and metal temples require different production processes, but must be coordinated in order to fit together). These tailored requirements are further complicated by the need of cooperation between stakeholders involved in the process all along the supply chain, as external designers and suppliers.

After the design and the product definition, the process engineering phase starts with the creation of the first prototype. From a sustainable viewpoint, in the prototyping phase for each change made to the model a new prototype is produced, increasing the waste produced and the time-to-market. In this sense, the introduction of new technologies can help in reducing both, making it easier the tests and changes before starting mass production. In mass production, the model is broken down into multiple components (temples, nose pads, bridge, frame, etc) and for each of them different machines and manufacturing are required.

The creation of a frame can be then divided into three macro-phases:

1. the creative phase, where stylists and designers conceptualize the ideas for the model, taking into consideration the trends and the structure the final product should represent;
2. the technical phase of design, consisting of the definition of the technical aspects of the model, including innovative requirements for the shape, the material or the colour required;
3. manufacturing phase, where machines required for the production are constructed and tested[78].

Developing and production actors should be cooperating during all the processes, in order to promptly detect issues and arrange for changes. What is required in the production of eyeglasses is the flexibility of the supply chain: eyeglasses are highly different one from the other, specifications change between models and the production line must be flexible enough for satisfy the requirements. When changes in materials occurs, this flexibility becomes even more important for assuring the quality of the final products.

[78] De Toni, Nassimbeni, and Maierotti (2001)

4.2.2 The role of 4.0 technologies for materials innovation in the development of sustainable frames

One of the aims of Industry 4.0 is to enhance circular economy and therefore the production of sustainable goods. In this view, there is the need of innovating the inputs of production, finding recyclable raw materials which do not lower the qualities and performances of the products. In manufacturing processes where 4.0 technologies are adopted, this need of finding new materials is even more marked. For example, in additive manufacturing there is the need of a material which, once printed (then molten before and solidified later), will have the same performances of traditional ones.

Materials can be classified into four categories[79]:

- Materials with variable properties. Characteristics of the material varies as the environment conditions changes, as shape deformations after a pressure or a damage
- Materials with variable structures or composition. Their chemical and/or physical composition changes under the influence of external factors, can decompose or regenerate
- Materials with variable functions. Functions change due to external variations. They could have an incorporated intelligence with the ability of self-diagnosis, self-learning, forecasting events and being able of analyse, distinguish and discriminate. These materials could be used as electrical and optical materials.
- Shape-memory materials. They are able to return to a pre-set shape when temperature changes or when they are stimulated.

These characteristics are typical of what are indicated as intelligent materials, that is those which have the ability to autonomously change its physical and chemical properties as external variations occur. Intelligent materials allow the interaction between innovative materials and the digital approach of 4.0 technologies, simplifying "communication" between the two worlds and making easier their processing technique and the resulting performances of the final product.

In the eyewear sector, producers are always looking for the most light, durable, resistant and, in latest years, also eco-friendly material. The most common materials used for the production of frames and sunglasses are acetate, metal, titanium and in latest years are coming back also wood, bamboo and leather as base materials for new products.

[79] Gruosso (2018)

Wood

Wood is a 100% eco-friendly material but it is not easy to work, especially in mass production with the use of industrial machines it can easily break or compromise the quality and durability of the final product. For this reason, real wood frames and sunglasses are generally more expensive than traditional ones. In 2013, Gucci launched an eyewear collection made of liquid wood, an eco-friendly 100% organic bio-plastic material made from wood fibres of sustainably managed forests and natural wax; the packaging of the collection was sustainable as well, made with certified paper from eco-managed forests and minimised in dimensions for limiting stock volume, weight and number of loads to be shipped, minimizing the CO_2 emissions by 60%[80]. In addition, Gucci provided customers with a brochure of instructions for returning the case and contribute to the recycling process.

Titanium

Titanium glasses, as wood, are expensive too, since it is considered a luxury material in the sector. It is used in military, aeronautics and biomedical sectors; it is lightweight, flexible, hypoallergenic and highly resistant, and the quality of titanium glasses is surprisingly high. It is requested mainly by athletes thanks to its ability to resist under all weather conditions and do not get ruined by sweat.

Acetate

The leading material in the eyewear production is acetate, a natural polymer composed mainly by cotton cellulose. Acetate cellulose is resistant, durable, easy to work and can be produced in a huge number of colours and textures. In Italy firms producing acetate frames and sunglasses are 59, of which 46 are in the Veneto region. Cellulose acetate sheets are supplied mainly by two big Italian companies: Mazzucchelli and La/Es[81].

Suppliers are at the basis for creating circular business model, and cooperation between companies and suppliers is important in this sense because allow to develop materials based on the requirement of the market and, at the same time, identify issues related to the subsequent production process and respectively arrange for changes before entering the mass production. Despite the already eco-friendliness of the acetate material, co-working with brands, designers and clients have pushed both Mazzucchelli and La/Es to developing a new bio-based material started from the acetate itself.

[80] http://www.safilogroup.com/en/PR_2013-09-30_gucci-presents-new-version-of-sunglasses-in-liquid-wood-material

[81] Data of 2017 (http://spexmagazine.com/locchiale-in-acetato-di-cellulosa-in-lastra/)

Mazzucchelli in 2011 developed the new cellulose acetate *M49*, with an increased number of elements derived from natural resources and 100% biodegradable, being the forerunner of the market in this innovation. This new material has been tested and certified as eco-friendly, biodegradable and recyclable, confirming the required quality standards for the frames and sunglasses production. The M49 maintains all the aesthetical characteristics and colouring of the traditional cellulose acetate, with the only difference that bioplastics are used. The bioplastic is entirely produced by Mazzucchelli, and the cost as compared to traditional acetate is 20% higher. The first test of this material has been done with Gucci. In an interview, Elena Orsi Mazzucchelli (Product Development Manager) explains that this decision of developing a new bio-based material was "*for responding to the environmental needs and indulge sensibility of clients who are careful to the use of materials deriving from renewable sources*[82]".

In addition to the introduction of the new acetate, Mazzuchelli is also developing a process for recycling the wasted acetate. An American company, Eastman, is implementing a supply chain for the recycle of acetate and will then resell it to Mazzuchelli that will work it and transform it in acetate sheets to be used from companies again. This process is expensive due to shipping costs from Italy to America and, for dealing with this, companies are forming a consortium. Limits of this recycle project for Italian companies is given by the law on the export and import (for America) of waste, but this obstacle will be overcoming soon.

On the same line, La/Es developed its biodegradable acetate for responding to customers' needs, *Biocell*. It does not contain toxic phthalates[83] and or release any phenol during decomposition. In its production process, La/Es has developed the internal know-how needed for completely integrate the supply chain from the raw material until the final *Biocell* acetate sheet, granting the performances and the quality of its products to customers.

For both companies, anyway, the colour choice offered for the biodegradable acetate is very restricted, making eyewear actors still prefer traditional acetate due to the higher diversification they can reach in production.

Acetate is one of the most used material for the production of frames and sunglasses because, once firms are equipped with the necessary machines, the processing techniques of this material are of easy understand. Even if the new materials proposed by Mazzucchelli and La/Es are still based on acetate, production processes may require to be adapted. When physical structure

[82] https://www.mazzucchelli1849.it/blogs/news/a-conversation-between-elena-orsi-mazzucchelli-and-20-20-europe?locale=it&locale=it

[83] Group of chemicals used to increase the flexibility of the plastic. Health effects of exposure to phthalates are being studied by several institutions showing a link to cancer and human reproductive issues.

changes, machines must be adapted to the new flexibility, temperature and weight required for the reworking. In many cases, manufacturers produce frames and sunglasses using both traditional materials and new bio-based materials, requiring separate production lines. The adoption of Big Data Analysis and IoT is a key driver for analysing the processes and identify where changes are needed.

Lenses' material

Materials' adoption concern not only the production of frames, but also lenses. Most common materials used for lenses' production are glass, plastic and polycarbonate.

Glass is the most natural and old-used element for lenses. Nowadays, it is mostly used for corrective lenses or standards models, since the colour choice for being used for sunglasses is limited. The performances of this material are above all the others, but glass lenses result heavy and very fragile, resulting in a possible danger for the individual if they should chip. Above all the mentioned materials, glass lenses are the most expensive.

As of today, glasses lenses are still supplied given their high quality and performance capabilities, but during years new materials has been developed for deal with the dangerousness of this type of lenses.

A first substitute has been identified in plastic (also called organic glass): weightless, less dangerous because it does not chip and gives wider possibilities for sunglasses lenses' dyeing. Despite this, plastic is easier to scratch and are not completely sustainable from the environmental point of view, even if in recent years the adoption of bioplastic also in lenses' production is increasing.

The real innovation for lenses has been the adoption of the polycarbonate. Polycarbonate is an eco-friendly material and 100% recyclable, adaptable to multiple shapes and give full protection against UV rays. Polycarbonate lenses are the most weightless in the market and, even if are not as performant as glass lenses, their resistance to impacts is 10 times higher than other materials[84]. Polycarbonate is a plastic material but a group or researchers found a process through which this material can be recycled without the danger for it to release bisphenol A, a toxic substance contained in polycarbonate. This innovative process of recycling would be sustainable for the environment and would lead to the recycle of a widely spread harmful material preventing its dispersion in nature.

[84] https://www.lentiamo.it/materiale-lenti-occhiali-da-sole.html

4.2.3 Sustainable actors in the sector: green manufacturers in the global eyewear market

There are companies that make frames and sunglasses functional, fashionable, of quality and at the same time are eco-friendly. There are many brands that claim the sustainability of their products, but not always this is real. These cases make customers lose their trust on all the category, therefore negatively impacting also companies which really rely in eco-friendly materials for offering to the market sustainable products. Sustainable manufacturers promote the upcycling of materials, recycled sunglasses and the use of other eco-friendly materials like wood, bamboo and bioplastic.

Below are presented two brands with and eco-friendly approach, where material comes from plastic recycled by fishing nets and certified wood of the Dolomites.

Costa Del Mar is an American manufacturer founded in 1983 and based in Daytona Beach (Florida), today fully owned by Essilor. Costa is popular in water sports sunglasses market, mainly fishing, since it was born by a group of fishermen. In the last years, Costa launched "Kick Plastic", a project with the aim of reducing the amount of single-use plastic that eventually ends up in the oceans, the amount used by the company in production and launch a movement for the preservation of the watery world. In 2018 they improved their project by launching a new collection, the Untangled Collection, in partnership with Bureo for recycling fishing nets got back from the oceans. Bureo is a company that collects fishing nets when meet their end of livers or retrieve them when discarded in the ocean (since in many cases there are not dedicated infrastructures available for the dismissal and fishermen too often get rid of them in the ocean), clean and divide them based on the material, and recycle them into small pellets for then creating new products designed for brining end of life solutions.

The focus of Bureo is narrow, since it is on fishing nets only, but it is a starting point in promoting a circular economy for preventing waste from entering oceans in the first place. In the partnership with Costa, Bureo supply Costa with the plastic pellets which are then moulded for producing sunglasses frames. Another part of the Kick Plastic initiative is the Bio-Resin Raw Material Process, where frames are produced using a resin deriving from the castor oil rather than petroleum, reducing the emissions and the overall carbon footprint of Costa. This material is used in the production of all plastic sunglasses frames and it guarantees to the product the desired durability, lightweight and resistance under the hardest conditions[85].

[85] https://www.costadelmar.com/us/en/inside-costa/protect

Another company that combines tradition, sustainability and style is Dolpi, an Italian start-up born in 2014 in the Belluno area and today based in Rovereto inside the *Progetto Manifattura*. *Progetto Manifattura* is a research hub with the aim of offering to companies a production platform where they can access services and specific knowledge for promoting sustainability in manufacturing; in addition, it promotes partnerships with companies all around the world for integrating competencies and support[86]. Wood eyeglasses have become famous since the begin of this century and you can find numerous companies which sell them online, but the offer of Dolpi is based on the history of the raw material, high quality and sustainability. Dolpi is the first pair of glasses made from the wood of trees growing in the Dolomites (the brand name is in fact a combination of the Italian names *DOLomiti* and *AlPI*) and are the only PEFC-certified wooden glasses in the world. The PEFC certificate grant that no wood derives from controversial sources, as illegal knocking down or from protected areas, and it is guaranteed through the traceability of the supply chain. For this label to be applied on products, all actors along the supply chain must possess a PEFC certificate. The success of Dolpi is based also on the history their collections bring, and on the uniqueness of the product. For example, in 2016 the firm created a limited edition, called Tiziano, from the wood of a monumental beech tree felt down in 2012 after a strong storm, and which was believed to be the tree under which Tiziano Vecellio was used to rest.

The design of each Dolpi eyeglass is guaranteed by the involvement in the process of Lucio Stramare, an international expert of fashion trends who has been working in the eyewear industry for more than 20 years. Each frame is supplied with a case also made of wood or leather and paired with the pair of glasses. The company focuses on the sustainability of materials and on the preservation of wood's aesthetic which is not subject to artificial treatments, maintaining its natural aspect and colour. The target of the market is medium-high, with prices that goes from 380 to 500€ for a frame, excluding the lenses. The start-up started its business in the national market, but soon its quality and unique products have been recognized all around the world and, as of today, Dolpi's glasses are exported in all Europe, North America, Australia and Japan, as well as increasingly in India and China[87].

On the internet there are plenty of e-commerce shops which sell frames and sunglasses of different brands claiming their eco-friendly materials used, but most of them are unknown and their real processes are of dubious origins, representing sometimes a possible damage for the

[86] http://www.progettomanifattura.it/
[87] https://www.dolpi.it/ - https://www.ladige.it/popular/mode/2018/04/23/ora-occhiali-legno-vengono-dolomiti

consumer (both to health and economical). The choice of certified and proven sustainable brand is a first step for sustain firms which really put an effort in promoting a circular system.

4.3 Sustainable innovation through the adoption of 4.0 technologies in the production process

Starting from the second half of the '90s, the increasing competition deriving from Asian producers has led to the reduction of SMEs in the Italian district. Asian producers were able to drastically reduce the cost of the product also due to the much lower wages paid to its employees, allowing a cheap production in large scale; SMEs could not compete on prices, given their limited ability of reaching economies of scale and amortise costs. In contrast to the general SMEs' negative reaction to this increasing competitiveness, big groups and internationalized companies have not been affected by this crisis: globalisation, openness to foreign markets and delocalization of processes have strengthened their position. These changes have, on one side, increased the turnover of the sector but, on the other hand, national employment has decreased.

During these years of crisis, lot of specific knowledge has been lost in the district and, once economy started to re-flourish, reshoring companies had to internalize lost production processes or deallocate to external suppliers with the required competencies. Big companies have been able to develop the macro-processes by themselves, and this has been a strategic advantage for the reshoring of production. In this view, big companies continued to growth and SMEs that survived are only the ones that has been able to acquire new technical and managerial competencies, inventing in innovation and technology development for integrating with the foreign market as well.

As of today, companies and SMEs in the eyewear sector differ mainly under the technological aspect. Eyewear has always been an industry where artisan work plays an important role and, while in leader companies' technological evolution is considered fundamental for the survival and the competitiveness of the business, SMEs are still late on technologies and digitalisation of processes. Products' quality, materials' innovation and advanced design are the most evaluated characteristics today in the market. Even if 4.0 technologies' potential is not yet fully exploited, for the Italian eyewear sector their adoption in the district is 20% higher than in non-district areas[88].

[88] Aversa, Checcucci and Iadevaia (2019)

4.3.1 Most relevant new technologies adopted in gasses production

The eyewear sector is a field which gives plenty of space for the adoption of 4.0 technologies, both in the processes and the products. New technologies have allowed to enable a circular system in the sector, increasing resources efficiency and traceability.

On the supply chain and production processes side, big data analytics and cloud storages are adopted for the collection and elaboration of data along the supply chain for promptly detect issues and improve their management in the future, optimising the production process. Safilo, for example, stated how the adoption of big data brought important benefits for the company processes' management. First visible effect in the short period has been the elimination of paper which, beyond the positive environmental impact of such decision from a big company, as reduced also the likelihood of confusion and mistakes. Secondly, it has been possible to better identify which were the required skills and competencies for doing the specific job, assuring that selected employees had the necessary training[89].

Along the supply chain has found its application also the traceability of the product, in order to granting transparency on the materials used and on the location of production phases, especially for brands which wanted to differentiate themselves by certifying their products as from sustainable resources. This technology is being helpful also in lowering the market of counterfeit frames and sunglasses, giving customers a way of recognizing the authenticity of the product they are buying, preventing possible damages derived from the not certified production process adopted by false producers.

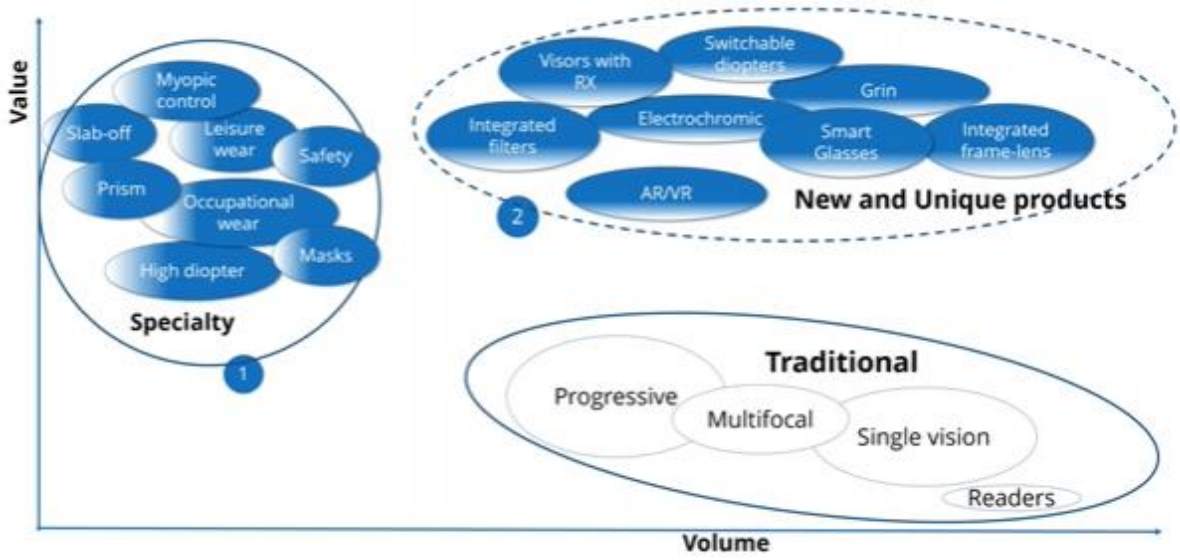
Another new technology which has been increasingly adopted in this sector is additive manufacturing, especially for the economic and environmental benefits it could bring, increasing the request for a service-based business based on customisation rather than traditional product-base. Anyway, customisation possibility has some limits of application in the case of big companies working with mass production volumes.

The evolution of processes as well as of finals products has been integrated with the adoption of Internet of Things. These devices allowed the creation of smart glasses. One of the first attempt of creating a smart glasses has been done by Luxottica in collaboration with Google for the launch of the Google Glasses, but they did not have the expected success: price was high and performances was below expectations.

[89] https://www.youtube.com/watch?v=dkncEmwSMeg

Another attempt has been made by Oakley (owned by Luxottica) and Intel, which designed the Oakley Radar Pace, smart glasses which aim is to improve athletes' training sessions. This model, as opposed to Google Glasses, has been positively welcomed by the market: price was lower than Google Glasses and they was designed for a specific target, athletes, being able to better satisfy their needs.

4.0 technologies can be adopted for glasses' accessories as well. Luxexcel is the only company in the world with the certified technology for 3D printed lenses for commercial use. They developed a process through which lenses (mostly ophthalmic) are printed and become transparent as soon as they are out of the printer, so no polish treatment is needed. The benefits of printing lenses are recognised in the increased efficiency (shorter supply chain because this replace more than thirty phases of a traditional lenses' production process), reduction in waste of more than 90%, customisation of product due to higher flexibility in lenses design and, one of the main aim of the company, the possibility to enable smart eyewear. Luxexcel today is in the speciality market and focuses on niches (number 1 on *Graph 8*), but its aim is to focus on lenses that today do not exist and through which it would be possible to integrate technology (number 2 on *Graph 8*). This will be possible because with 3D printing it would be feasible to print two layers of lenses between which it will be inserted a screen (*Figure 19*).



Graph 8: Lens Market Dynamics

Source: Sher (2019)

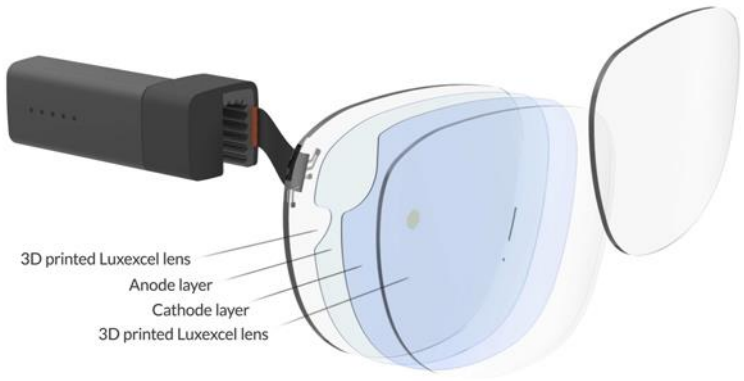


Figure 19: 3D printed lenses with embedded sensors

Source: https://www.luxexcel.com/ophthalmic-inspiration/showcases/1-3d-printed-lens-with-embedded-sensors

4.4 Additive manufacturing in eyewear production: applications of 3D printing in the sector

Traditional manufacturing has been the enabler of the industry we have today but the developments the world has undergone in these years highlight the limitations of this approach. Processes nowadays are a combination of humans and machines, robotics and computers interaction, where most of technologies are based on the subtractive technique: objects are created starting from one or more blocks of raw material from which are cut away pieces and worked until reaching the desired shape. In this way, the quantity of waste produced is substantial. This concept is in contrast to the technological advance of modern manufacturing techniques, based on additive manufacturing. As already mentioned in the previous chapter, additive manufacturing technology has been defined by ASTM (2010) as "*a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies*". A subset of additive manufacturing, but often used as synonymous of the term, is 3D printing. The application of additive manufacturing in eyewear requires certified manufacturing factories. Especially for eyeglasses, there is the need of authorization for production and distribution in the market.

3D printing firstly appeared in the eyewear industry in 2007, where the first mover has been the German brand *Mykita*. It started exploring 3D technology back in 2007, when it launched its customisable "Mylon" collection of polyamide material's frames produced using the SLS technique. This collection won several awards thanks to its positive result of innovation, with light weight and durable products offered to the market. Its first productions with 3D technology

have been mainly a market strategy based on the uniqueness of its offer rather than on building a new manufacturing process, given the high costs required for this technology.

Despite the high costs of this technology, there are several online retailers which offers customised frames based on additive manufacturing technology. Amongst all, in 2014 a Protos Eyewear's project has been funded through crowdfunding: by uploading two pictures of the face, the online retailer would return a tailored 3D printed frame, made by bioplastic material[90].

3D printed customised frames and sunglasses are gaining attention from customers and producers. Despite the limitations that will not allow this technology, at least as of today, to replace the actual manufacturing process for mass production, glasses have been recognised as the perfect good to be produced with 3D printing, produced worldwide by global enterprises as well as smaller online retailers and start-ups: can highly benefits from personalisation possibilities and often designed with unusual shapes, which becomes yes a mass product but also a luxury unique piece.

Over the past 10 years, eyewear production through 3D printing has gained significant potential in the medium-long term, becoming an interesting niche in the market. In 2018, additive manufacturing eyewear market was a very small percentage of the global market, counting for only 0.09 billion USD, but it is expected to grow to be worth up to 1% of the global eyewear market by 2028 (considering only 3D printed eyewear final application)[91] (*Figure 20*).

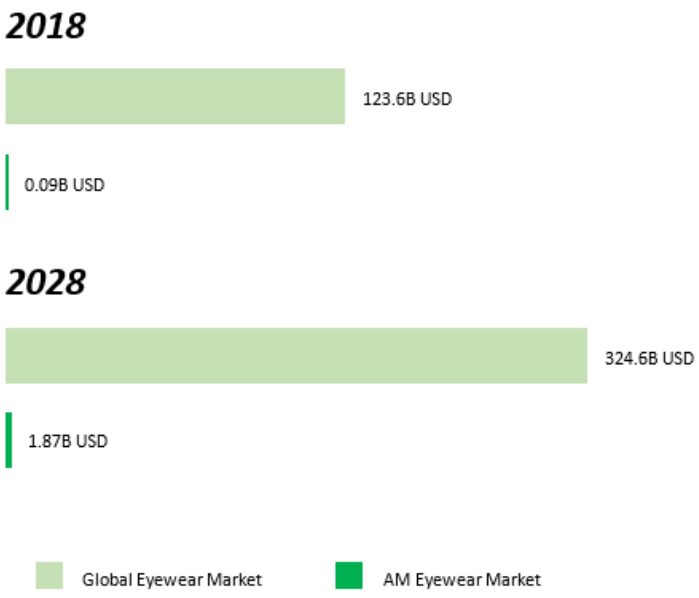
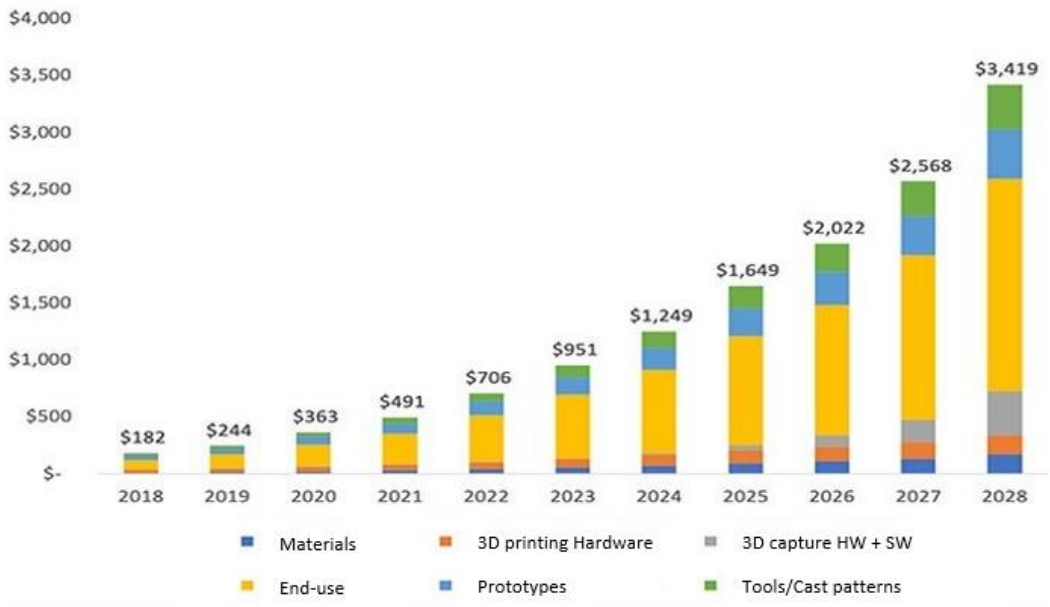


Figure 20: Global and AM eyewear market in 2018 and 2028
Source: adaptation from Sher (2019)

[90] https://coolmaterial.com/style/protos-3d-printed-eyewear/
[91] Sher (2019)

The market for 3D printing in the eyewear industry is expected to grow also due to the exponential increase in the demand for mass customisation and product personalisation. The overall industry growth is estimates to reach a value of 3.4 billion USD in 2028, considering all categories under additive manufacturing production: materials, end-use parts, 3D printing hardware, 3D capture hardware and software, prototypes and tools/cast patterns[92]. The final part production segment is the most significant today in additive manufacturing and is also forecasted to be the most valuable in the future ten years, reaching 1.9 billion USD (*Graph 9*).



Graph 9: All eyewear 3D printing revenues by segment (in Million USD) 2018 – 2028
Source: https://www.3dnatives.com/en/3d-printed-eyewear-280220195/

For industrial application, the adoption of 3D printing could have revolutionary benefits for both the production lead time and the ability to create unique models with complex shapes, optimizing production costs. In industrial production, due to the high volumes requested by mass distribution, most large manufacturers use 3D printers to create rapid prototypes that speed or improve their product design.

Luxottica started using this technology in prototyping around ten years ago, and from 2011 has been adopting it also for producing components that support final products, through lost wax casting technique. According to Federico Buffa, Engineering & Product Development Director

[92] https://www.3dnatives.com/en/3d-printed-eyewear-280220195/

of Luxottica, benefits are represented by the speed up of processes due to the transmission of the wax stamp's model to the printer directly through digital connection, as well as between plants located in different areas[93].

Different techniques of 3D printing technology are used, based on the desired output. Material jetting is used for highest level of prototyping and powder bed fusion for final parts, both require no support during the process, lowering the time of after-printing finishing. Extrusion technique, the first technique to be tested when 3D printing has been introduced, today is used for the production of basic prototyping and some internal-use spare parts, due to its lower final quality and the consequent higher amount of time needed for refinishing the result.

Additive manufacturing, and in particular 3D printing, has been in the market for over thirty years, but has been only in the last fifteen that it started to be adopted on industrial level and increasingly in the production of final goods. The use of 3D printing for prototyping purpose is therefore not revolutionary. As 3D printers become cheaper and more reliable, opportunities are starting to exist for creating models in addition to already existing prototypes.

In *Figure 21* we can see the phases of a life of a frame, from its planning to its mass production, and where and how 3D printing technology can be added to the different phases.

As mentioned above, prototyping is the phase in which 3D printing is more used. In this step, companies produce lot of prototypes in which minimal detail changes, with the aim of having physical models to show to the client. The client will select only one or two of the proposed models, and for this reason 3D printing is advantageous here: this technology allows to create more digital and physical products in a lower amount of time and with lower costs, allowing to produce at the same time different version of the same model, while traditional handmade prototypes require up to 15 hours each (depending on the complexity).

With a lower intensity, 3D printing enters in the phase where auxiliary equipment and small parts are produced. In this case, the technology works as support to the traditional manufacturing, printing for example stamps which will be then used in the classic production process. Limits in this phase are given from the finishing of the resulting product which could not meet the quality standard necessary for being sold with the final product.

Last phase in which additive manufacturing could help is the mass production, but as of today the adoption here is very limited due to the volume's constraint given by the market request.

[93] http://www.luxottica.com/it/luxottica-innovazione-stampa-3d

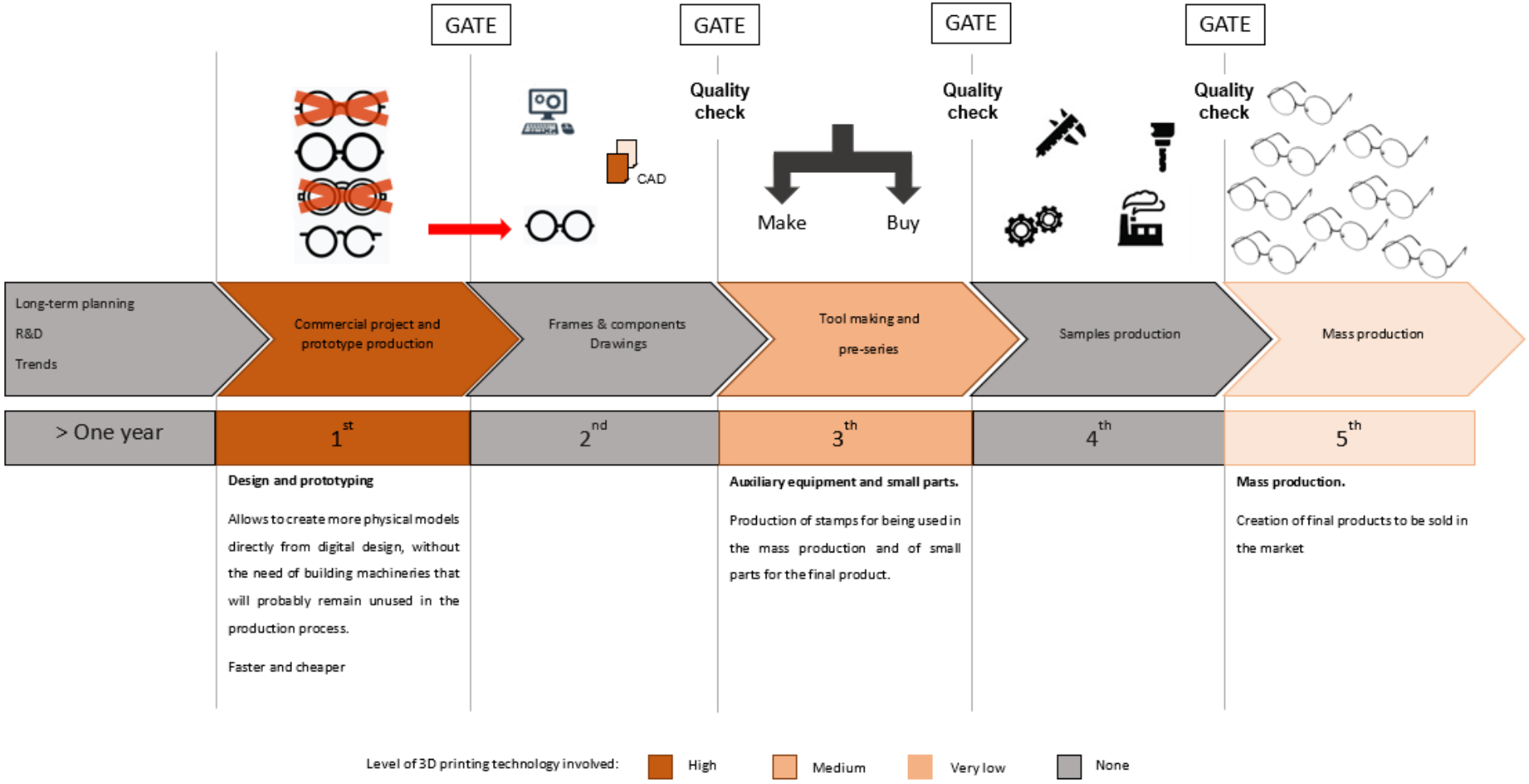


Figure 21: Phases in the industrial production of a frame and role of 3D printing

Source: Author's elaboration

4.4.1 Advantages of additive manufacturing technology in the production process

Under the economic aspect of a business, the main drivers for the adoption of 3D printing in the eyewear sector are represented by:

- an increased design possibility, where hazardous shapes can be printed and design can be customised through cooperating between the customer and the designer;
- an increase in innovation;
- the enhancement of resource productivity: from the same quantity of material, through additive manufacturing a company will be able to get more product rather than farm subtracting manufacturing, especially if waste is from non-recyclable material;
- shape complexity is free: producing a simple model or a complex model of same dimensions will require the same time, since printer works through layers;
- digital design manufacturing, with the consequent lower need of human interaction. 3D printers can work from remote for hours, requiring almost no need for continuous supervision;
- a reduction in the storage inventory costs, eliminating the excesses and the unsold production. In fashion industry, retailers hold between 25% and 40% of unsold products at the end of the season. With 3D technology, parts could be printed on demand lowering the need of building-up spare parts inventories.

Beyond the economic savings that can derive from this technology, benefits are also from an environmental point of view. Additive manufacturing could provide a step forward in environmental protection and resource productivity, helping achieve some of the most urgent environmental and resource issues we are facing. In addition to the already mentioned optimisation of resources and the consequent reduction of waste, through 3D printing is possible to implement a deallocated production where the SRT digital file produced for the part is sent around the world for being printed "*in loco*", lowering the logistics issues and transportation footprint produced by shipping physical products from one side to the other of the globe.

When printed, eyewear will need in any case a phase of finishing, where the excesses are removed and parts are smoothed. 3D printing process is therefore only "ideally" zero waste, but this does not change the fact that it is reduced by more than 90% in some cases. Another point in favour of this technology, is its ability of reusing plastic waste.

4.4.2 Materials for 3D printed eyewear: is it possible to be sustainable?

Most used materials in 3D printing eyewear are metal, nylon and plastic. In recent years also titanium started to appear. Due to the complexity under this technology, the development of new materials is not an easy process, and requires lot of researches and testing for evaluating the chemical and physical changes occurring to a new material when it is subject to a 3D printing process, for not compromising the quality and durability of the final product.

Plastic

For dealing with the issues that plastic use in the process can bring, in the years solutions have been developed and companies with the aim of finding a new employment for 3D's plastic waste are born.

A first solution has been found with the introduction of PLA, a bioplastic which has become the most common used alternative to traditional plastic. PLA bioplastic represent a sustainable innovation because it allows the reuse of products for a considerable number of times, by re-melting the recycled material, lowering plastic pollution. PLA plastic is mainly used to produce prototypes in design[94].

Numerous are the project launcher worldwide for reducing plastic waste from 3D printing. *3DEVO*, a Dutch company, developed a machine capable of transforming the plastic waste into 3D printable granules, which can be then turned into filaments to be used in the 3D printer[95]. This is just one of the many companies offering a way of recycling the waste produced by the 3D printer during the process. Another Dutch company instead, *Refil*, produce 100% recycled filaments from four materials: PET filaments from plastic bottles, PLA filaments from white plastic, ABS filaments from car boards and HIPS filament from old refrigerators[96].

These recycled filaments from plastic waste are used in 3D printers which use extrusion technique of printing. In addition to recycled and bioplastic, in the last years hemp filaments have been introduced, but despite their eco-friendliness, their adoption in eyewear is not much common yet, with only few sites selling 3D printed hemp-made sunglasses[97].

[94] Stimolo (2019)
[95] https://3devo.com/
[96] https://www.re-filament.com/about
[97] https://hemprinted.com/

Nylon

Another diffuse technique of 3D printing which allows to reach also a more defined product and higher quality has been mentioned is the powder bed fusion. For this process, the primary used material is nylon 12 (PA 12).

Innovations have been made also for Nylon 12, in order to making it smoother at the end of the process and reduce its porosity, granting high performances and durability of the final frame. Nylon has however quite negative sides: it is not biodegradable and its production has a big impact on the environment both for water and energy consumptions. For limiting the negative impact of this material, HP has developed its reusable PA12, designed to minimize waste and allowing leftover powder from one build to be used in subsequent builds; reducing to the 20% the volume of new powder used in each process, since 80% comes from the previous production[98].

Metal

Metal 3D printers are used mainly for the production of prototypes or small components. In the case of small components companies must pay attention to the technique used, since the dimensions of the output make it difficult to finishing them.

For each different alloy must be used different printers, because chemical and physical structure of the metal change and must be worked differently. The recyclability therefore depends on the alloy used. In any case, with the technique of the powder bed fusion, metal powder can be reused reducing therefore the need of virgin one[99]. Due to the high cost of the metal powder, 3D printers with this material are not highly diffused.

4.4.3 Limits of 3D printing technology

Additive manufacturing, meaning 3D printing, brings numerous benefits for the eyewear sector, as shown in the paragraph before. This technology, however, still has some important limitations that restrict its potential application in the industry.

First of all, the main limit is represented by the time of production required by this technology. Not considering the design and prototyping phases, where time could be in part saved[100],

[98] https://www8.hp.com/it/it/printers/3d-printers/materials.html

[99] For every new process recycled powder and virgin one are mixed because using only recycled powder could compromise the performances of the final product.

[100] For a prototype, production time through 3D printing technology rather than by hand is reduced of about 60%, from 15 to around 4 hours. (Source: https://www.youtube.com/watch?v=7WCNdJx70oA)

physical production of the good takes lot of time, restricting the possible applications for the mass production therefore not allowing to scaling up production. Leader companies in the eyewear sector has huge volumes of production for the mass distribution, and printing entire frames or sunglasses is not bearable. The bigger the volume of the object which needs to be printed, the longer the time it will takes. In this sense additive manufacturing is preferred when custom parts, or low-volume production runs, are needed. For example, for creating a customized detail on the frame, or for adding a small complex-shape detail to the temples or frames.

Another limit of 3D printing for the eyewear sector is the possibility of working one material at a time, restricting creativity chances. Frames are frequently made by a combination of different materials, as acetate and metal, and with 3D printing it is only possible to manage the production of them separately. This requires a deeper work during designing phase because once parts would be put together, they have to fit and perfectly wedge in one to the other without requiring further production phases. Even if this obstacle is limited by the fact that generally in mass production, as we said before, no entire frame is produced as one piece with 3D printing but usually only small parts or details, there could be cases, for example in the prototyping phase, where companies may have the necessity of producing multi-materials objects. Moreover, the selection of alternative materials is quite limited. Nylon is ideal for eyewear manufacturing, titanium, plastic and other polymers have been increasingly introduced but other possibilities have not been fully implemented and require further tests before they are ready for final production.

The limit of multi-material has also an impact on the costs. In the case of metal, the company will need a 3D printer for each different alloy. Steel, copper, beryllium and titanium need a different printer each and, considering the cost of a single 3D printer[101], a company can either focuses on one metal only (but trends change fast, and the investment could become soon wasted) or the economic investment require is quite prohibitive, and this is one reason why lot of companies decide to not invest at all and rely on external partnerships if needed.

The limited material selection impact also the final quality of the frames. 3D printing technologies have generally a high results' definition and resolution, but this output is strictly connected with the choice of the material. Some materials have chemical and physical properties which tend to result in rough and porous surface finishes, in contrast to the

[101] Depending of the technique used and the brand, 3D printers for industrial use cost tens of thousands of Euros

smoothness of other more traditional techniques of production. This highlight the need for greater uniformity in production quality: strength and resistance of parts is not uniform and tend to be weaker in the direction of the layers in which they are built. Moreover, production is not standardized as in traditional machines so outcome depends on multiple different factors (input material conditions, external temperature, etc), resulting frequently in produced parts having varying properties between them.

4.5 Adoption of 3D printing technology towards product personalisation: business models and benefits of the service-based eyewear

One of the main drivers of the adoption of additive manufacturing is the (almost) unlimited creativity it allows. This creativity gives to manufacturers the possibility of customising products based on individuals' demand, increasing customers' engagement to the brand and satisfaction.

Beyond the on-demand production, one biggest driver for 3D printing adoption in eyewear is the mass production of standard models that are then personalised for the individual client: additive manufacturing technology can be used to support the design and the assembly and re-assembly of the final model, by producing modular products that can be then customised by adding personalised 3D printed details.

For the personalisation of an entire model, 3D scanning hardware and software have been developed, both online and in shops, which allow customers to find their perfect-fit frame.

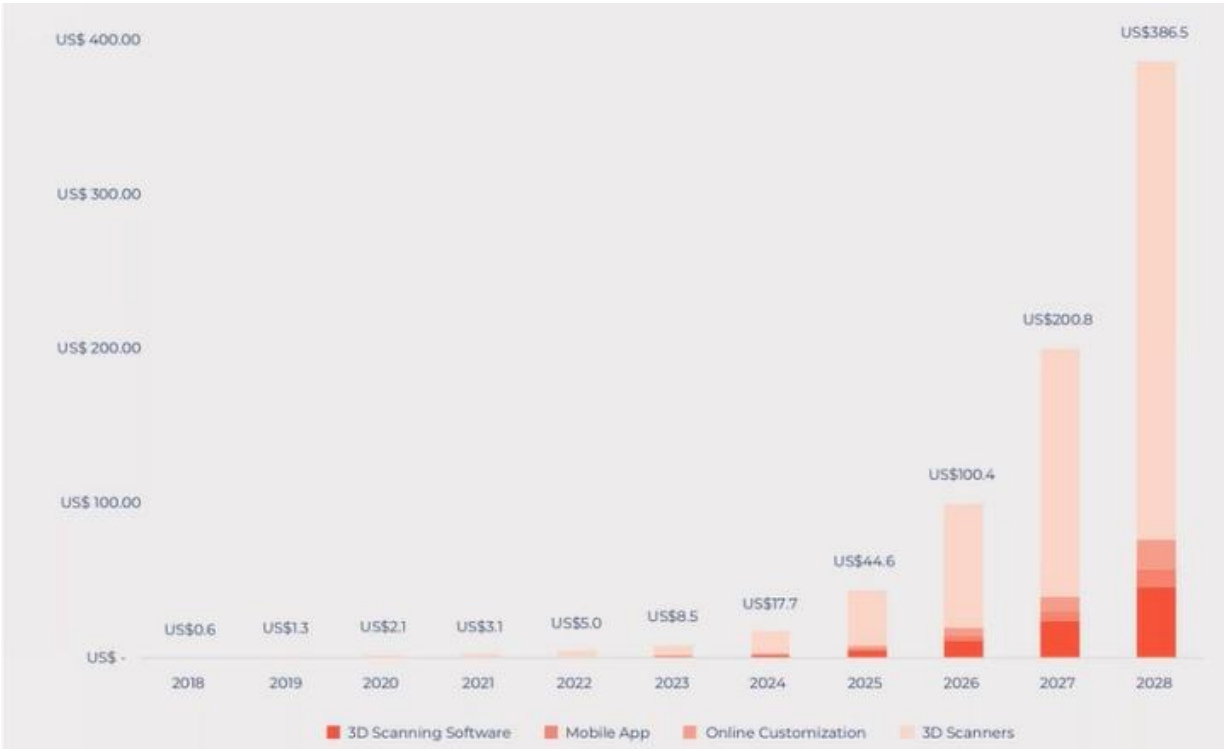
SmarTech Analysis, a provider of market research reports and industry analysis for the 3D printing and additive manufacturing industry, proposed a business model of customised eyewear with the adoption of additive manufacturing technology (*Figure 22*).

Figure 22: Business model for additively manufactured mass customised eyewear

Source: Sher (2019)

In this business model, engagement of the client occurs through a physical shop, an app or the website. The device will scan the customer's face utilizing 3D scanning technology, and the individual will then define which are the needs he wants to satisfy, select the frame in a way to suit his unique face shape and choose the lenses. Will be then created a 3D model in a computer, elaborated by the software and sent for production to the 3D printer. Ideally, the final customised product will be delivered in ten days/two weeks.

Personalisation business model requires that, beyond 3D printing machines, the company integrates a series of others 4.0 technologies as well, for all the process of facial scan, data collection and transmission. The increasing offer of customised frames and sunglasses and the correlated need of related digital technologies make the forecast of these technologies sharply increase for the next ten years (*Graph 10*).



Graph 10: 3D capturing Software and Hardware sales in eyewear (Million USD) 2018 – 2028
Source: Sher (2019)

The benefits of a personalised product for a customer are both in terms of comfort and of fashion trends. For sunglasses, uniqueness and fashion plays a key role in the choice of a customised glasses. For those instead who must wear eyeglasses all day, uniqueness could play its role but most important driver of choice is the comfort they could give; they are tailored on your face features and this means that also the guarantee of a perfect eye diseases correction: perfect distance of frame and lenses from the eyes, which is not always easy to align in a standard frame.

What producers must offer to customers for growing under a personalisation-based business model is scalable quality (increasing volumes keeping quality as a focus point), consistency, variety and flexibility.

Examples of brands offering tailored frames are *Yuniku* and *Hoet Design Studio*.

Yuniku is a digital platform designed for creating instore experience. Its first improvement has been on the target vision creating, opposed to the standard frame-centric, the first vision-centric frame, where lenses are placed before designing the frames instead of adjusting them later based on the existing model. This platform allows both existent and new brands to get in touch with customers, offering from its side the knowledge of 3D printing software. Key in its process is the cocreation in the design phase, acting like a bridge between customers and brands.

Hoet Design Studio instead is formed by a group of designers. Their idea is based on the fact that, since they are the designers, they feel responsible for everything that goes in the market because the production process starts with the. They offer functional aesthetical design: the use of 3D printing is for reducing waste (as part of their social responsibility duty) and freedom of design, while aesthetic is reached collaborating with customers for creating a personalised eyewear based on their requests[102].

4.6 Eyewear companies adopting 3D printing technology: the case of the leader companies in the sector

Despite the already mentioned advantages of adopting 3D printing technology in eyewear production for enabling circular economy and for offering a customised product to consumers, the limitations impact mainly big industries where volumes required are for mass production.

While for small retailers is easier to offer customisation services due to the lower volume on which they are based on (especially on the Internet, there are numerous sites that offer this possibility), for leader companies of the eyewear sector the adoption of 3D printing technology is redirected towards other purposes like quicker prototyping, spare parts production and customisation limited to small details.

In this section, we will see the approach to additive manufacturing of four of the leader companies in the design, production and distribution of the eyewear sector.

4.6.1 Luxottica Group SpA

Luxottica is the global leader company in the eyewear design, manufacturing and retail. Founded by Leonardo Del Vecchio in 1961 in Agordo for the production of frames and small components for third parties, today its wholesale network counts more than 150 countries and the retail network almost 9.100 shops. Production is spread over thirteen production plants: six in Italy, three in China, one in Brazil, United States, Japan and India[103]. In 2018 the company registered a turnover of 8.929 Billion Euros and counted more than 80 thousand employees worldwide. Its brands portfolio includes more than 30 brands amongst which Chanel, Armani Group, Dolce e Gabbana, Prada, Michael Kors, Ray-Ban, Valentino and Persol. A key

[102] Sher (2019)
[103] http://www.luxottica.com

competitive advantage is given by the totally vertical integrated supply chain: design, product development.

Luxottica has always been in search of innovations and improvements, introducing new materials and combinations for offering an always new product to the market. In line with this, the company adopted digital technologies in the production processes for monitoring the phases and improving the identification of issues and speed up the resolution. But Luxottica did not limit the adoption of 4.0 technologies in the production processes and logistics, instead integrated them in the final product as well. In collaboration with Google first and Oakley and Intel later, Luxottica developed the glasses with integrated the IoT technology. The Google glasses has been a failure, due to the high price and the high expectations of customers that has not been fulfilled. The second attempt, from the collaboration between Oakley and Intel, resulted in the launch in 2016 of the *Radar Pace* glasses, which offer a system of customizable training session through the customer's voice.

For over a decade Luxottica has been a pioneer in 3D printing, aiming at speeding up the prototyping phase and for producing some end-product support components. Today Luxottica uses additive manufacturing for certain parts of the frame, however the usage is limited to simple parts within the broader supply chain or for prototyping and R&D work[104].

As for the other big companies, Luxottica's production volumes limit the possibility of adoption of 3D printing technology in the mass production. Moreover, the finishing process for the 3D printed frames does not meet the quality standards required by Luxottica[105]. For these reasons, it is clear why the adoption of this technology is mainly focused on the prototyping phase, where time the time between the designed model and the physical prototype is reduced, and on the production of simple parts.

4.6.2 Safilo Group SpA

Safilo is the second-largest company in the eyewear sector for the production of frames and sunglasses, with a turnover of 963 Million Euros for the 2018. The company has been founded in 1934 in Calalzo di Cadore, when Guglirlo Tabacchi acquired the first Italian producer of lenses and frames, which had been active since 1878. Aa of today, Safilo counts 6.597 employees spread in the seven productive plants (four in Italy, one in Slovenia, one in the US

[104] https://digital.hbs.edu/platform-rctom/submission/is-the-value-proposition-of-3-d-printing-eyewear-in-inventory-management-and-limited-made-to-order-customization-or-in-fully-consumer-designed-eyewear/
[105] http://www.luxottica.com/en/luxottica-innovation-3d-printing

and one in China), direct retail presence in more than 30 countries and almost 50 distribution partners in the other countries. Safilo can count on a diversified portfolio of brands from luxury to contemporary fashion, mass cool and outdoor sports, showing names as Carrera, Dior, Marc Jacobs, Jimmy Choo, Hugo Boss, Givenchy and Fendi.

Safilo started introducing digital technologies in its production process years ago, integrating machines and devices amongst all plants. The aim of this choice was to reduce production time and wastes, as well as minimise paper used if managing processes through the exchange of documents. Every worker in the production process has at his disposal a display though which he can have every information on the model he is working, included hints, issues or missing parts. Data are then collected and analysed from a software, which provides real time statistics on productivity, machineries' performances and the most popular flaws detected[106].

The company started investing in 3D printing in 2016, with the acquisition of a Stratasys J750 3D printer for optimising the prototyping workflow. This adoption allowed the company to produce multiple variations of the frames at the same time, increasing the output range of choices and reducing the costs and time (*see Table 3*) of developing new models[107].

Method	**Time**
Handmade prototype	15h development + 3h finishing = 18h
Printed prototype	3h print + 3h finishing = 6h
Savings	*12 hours (66%)*

Table 3: Safilo - production time for a handmade or printed with Stratasys J750 3D printer prototype
Source: Wyman (2016)

The adoption of this technology allowed Safilo to increase its design variety and creativity as well, keeping up with the high speed and innovation required by the fashion market.

Started from prototyping, in 2017 Safilo launched its first collection made with 3D printing technology, expanding therefore its application to the mass production. The new capsule collection, OXYDO, has been made in partnership with Materialise NV, a Belgian company amongst the largest and most long-established independent companies in the additive manufacturing and 3D printing sector. The collection offered an innovative, contemporary and

[106] Redazione BitMAT (2019)
[107] Wyman (2016)

sophisticated interpretation of the Italian fashion aesthetic, proposing shapes which are possible to reach only through the use of the 3D printing technology. The design of these frames has been developed in collaboration with the artist Francis Bitonti. For this mass production, anyway, Safilo relied on Materialise's 3D printers. In fact, polyamide structures upon frames has been produced in the plant of Materialise[108].

This collaboration between Safilo and Materialise had the aim of getting as much closer as possible to the customers' expectations, highlighting how additive manufacturing can really improve the eyewear offer in the market, since the only limit is the designers' creativity. Anyway, the approach of Safilo to the collection made it clear that, due to the current state of technology, internal investments in 3D printing are worth for the adoption in prototyping, but for the mass production there are still limits which make it convenient to go produce outside.

4.6.4 Marcolin Eyewear SpA

Marcolin is one of the four leaders in the eyewear industry, with more than 14 Million frames and sunglasses sold in 2018 and a turnover of 482 million Euros (+2,8% compared to 2017). It is present in 125 countries and can count on 150 distributors worldwide[109]. Founded in 1961 in the Cadore area for the production of temples, in 1967 it presented the first line of eyeglasses. As of today, its portfolio boasts brands like Tom Ford, Moncler, Ermenegildo Zegna, Victoria's Secret, Roberto Cavalli, Tod's, Emilio Pucci, Swarovski, Dsquared2, Guess, Diesel, Kenneth Cole, Timberland and more.

Marcolin started to adopt 4.0 technologies more than fifteen years ago, with the digitalisation and integration of the planning, control and forecast functions. This allowed the company to better managing the high number of employees and keep under control the supply chain, for assuring the availability of the highly variable productive mix required by the market.

Amongst all 4.0 technologies adopted, Marcolin has been using additive manufacturing and 3D printing in the prototyping phase for years (especially for the production of small parts of their products) but only relying on external companies. In 2016, Marcolin Eyewear started a collaboration with The FabLab with the aim of evaluating if the internalization of 3D printing processes could have been worthwhile

[108] Materialise (2017)
[109] https://www.marcolin.com/it/gruppo/il-gruppo

The FabLab is a research and development centre and laboratory, founded in 2013 by Massimo Temporelli, Francesco Colorni and Bernardo Gamucci. Inside the centre companies can find designers, technicians, digital and analogical machines for support in prototyping or small series production, exploiting the shared know-how and taking part to training sessions as well[110].

During the collaboration between the two companies, The FabLab analysed industrial processes used by Marcolin for understanding which could have been the best 3D printing typology for the integration in the production process. Together with this, the analysis aimed also at studying which would have been the production processes that could benefit the most from the introduction of this technology; design, prototyping or production phases. After this analysis, lasted more than a year, in 2017 Marcolin acquired its first internal 3D printing for rapid prototyping scope[111].

As of today, 3D printing technology is used for prototyping mostly.

4.6.3 De Rigo Vision Spa[112]

De Rigo has been founded in 1978 in the Cadore area. Amongst the four companies considered it is the last born, but it has developed soon and has become one of the leader company in the eyewear production industry. The company counts more than 3.000 employees and a turnover of 427 Million Euros in 2018. De Rigo is promoting a continuous Research & Development activity in its business, enhancing its innovations in new technologies, materials and products. In its portfolio the company has brands like Chopard, Furla, Carolina Herrera and Trussardi.

The adoption of 4.0 technologies in De Rigo started less than ten years ago, but not at the same extent of the other companies mentioned above. Part of the production and logistic processes are enabled but integrating all the industrial system with digital technologies would require the implementation of a total new management tool, and the benefits that would derive are lower than the costs. 3D printing is one of the technologies adopted.

As of today, De Rigo exploit internal 3D printers only for the prototyping, while for different purposes it relies on external companies that offer the technology as a service: De Rigo creates the 3D design and send it to the third party that in two-three days send back the printed piece.

[110] https://www.thefablab.it/chi-siamo/
[111] Temporelli (2017)
[112] Information of this section derived from an interview with the company

As long as service work fast and with quality results, there will no convenience for De Rigo to internalise the technology.

Each year, the company produces about three thousand prototypes, but only one/two hundred are made through 3D printing. In addition to this, components produced with this technology are about two hundred. The traditional milling process remain therefore more competitive.

It can be understood that for De Rigo, 3D printing does not represent an advantageous technology as it is today. As producers adopt it and technology evolves, 3D printers in the future will become cheaper and compatible with more materials but, as of today, the limits on volumes, materials and colours represent a big obstacle for the company, and the investment required is not worth it.

Conclusions

The technical process required for the production of a frame makes the eyewear sector adapt for the application of 4.0 technologies. Moreover, the always evolving fashion trends require continuous innovation and creativity from the designers, which can improve also the materials used in production, introducing new innovations.

When adopting 3D printing in the production of glasses, limits on the possibility of being sustainable are given by the limited range of materials amongst which companies can choose. The adoption of 3D printing therefore enhances the possibility of innovating processes, but innovation of materials is still limited and requires lots of researches, testing high investments.

Additive manufacturing allows to reduce the waste produced during the processes, but not all materials tested for the use with 3D printing can be recycled. Therefore, for being sustainable manufacturers must rely on different production processes, as traditional ones, in which eco-friendly and biodegradable materials can be used.

The different approaches to this technology and the possibility of offering a personalized frame designed and 3D printed highly depend on the dimensions of the company. Due to the limits, especially on volumes, imposed by the actual state of this technology, in the industrial production 3D printing is adopted mainly in the prototyping phase where companies can reach substantial benefits in terms of time and costs reduction, but for the mass production this technology still need to be improved. Different is the approach of small retailers that, due to the

much lower volumes they need to produce, can base their commercial strategy on the personalization of the frames and invest more in 3D printing technology.

After this analysis, it can be understood why services of customisation in the frames and sunglasses re offered mainly by online producers or small retailers, for which the major limits imposed by 3D printing technology does not represent a big obstacle as for industrial producers.

In the eyewear sector, for the adoption of 3D printing companies must evaluate the breakeven point of the investment. A machinery for the traditional production process can cost up to tens of thousands of Euros, so when the volumes required are high it is convenient to redirect the choice toward this approach. Instead, if volumes are low and the possibility of experimenting with shapes and structures are extended, the adoption of additive manufacturing technologies could be the most appropriate choice.

Conclusions

The aim of the thesis was to analyse at what extent 4.0 technologies can enhance circular economy in the fashion industry, and in particular how much the eyewear sector can benefit of additive manufacturing technology for a transition to a more sustainable production. Eyewear industry shifted in years making glasses becoming a fashion accessory, and therefore contributing to the unnecessary pollution that consumerism is producing.

The circular system is seen as the best solution for reducing the exploitation of limited resources and final waste, creating a model where since the design phase each component has a purpose when the product will reach its end-of-life. This model requires companies to rethink all their global value chain in order to align their processes with those of their suppliers.

For this purpose, 4.0 technologies can play an important role. The introduction of disruptive technologies allows companies to better manage the resources they have, maximising the efficiency of both materials used and processes adopted. The creation of 4.0 supply chains will result in a combination of sustainable management and digital innovation, allowing companies also to improve their business model and offer services to the market, not just products. Amongst all 4.0 technologies, 3D printing is just the tip of the iceberg of what is known as digital fabrication, but is also the most revolutionary and fascinating because completely transform the logics of the production process: from subtractive manufacturing to additive manufacturing, allowing to reach shapes and structures that only the creativity of designers can limit.

For the eyewear sector, however, the limits imposed by this technology do not allow its adoption in industrial production for the purpose of being sustainable. Eyeglasses producers that rely on sustainable materials must use them in the traditional processes, since most of them are still not compatible with the 3D printing technology. Its use is therefore restricted to prototyping and ancillary phases, where the aim is to reducing costs and time. The same limitations impose restrictions also on the ability of industrial producers to offer personalised frames and sunglasses.

The main difference is between world-leader companies in the design, production and distribution of frames and smaller independent producers, for which volume constraint does not apply and can therefor offer to the market the customisation of the frame creating personalized and complex shapes that with traditional production processes cannot be reached.

As it appeared from the analysis, 3D printing technology adoption today is quite limited in industrial production, but producers are confident that in the near future this technology will be subject to impressive improvements. Main necessary improvements are recognised in the increase in the production speed, the integration with multiple technologies and, for pursuing a sustainable grow as well, the innovation of materials compatible with the 3D printing process.

As producers start to adopt 3D printers, technology will evolve allowing a large-scale adoption and a possible ever-increasing introduction in the mass production.

APPENDIX 1

Below there is list of the 2019 Global 100 Most Sustainable Corporations in the World index is edited by *Corporate Knights*. The methodology used for the ranking is:

- Eligibility: public-listed companies with gross revenue of a minimum of $PPP-currency $1B. All industries and geographies are initially considered.
- Approach: ranking is based on publicity-disclosed data and companies are contacted for data verification. Methodology is based on up to 21 key performance indicators (KPIs). Each company is scored only on the KPIs that are deemed to be the priority for the Corporate Knight Industry Group, plus eight universal KPIs.

In short, companies are screened for: sustainability disclosure practices, financial health, product categories and behaviour and financial sanctions. Results are then arranged based on the priority indicators and weights per Corporate Knights Group Industry to which the company belongs[113]. Below the first 50 companies of the rank[114].

Rank	Company	Country	GICS	Overall score
1	Chr. Hansen Holding A/S	Denmark	Food or other Chemical Agents	82.99%
2	Kering SA	France	Apparel and Accessories	81.55%
3	Neste Corporation	Finland	Petroleum Refineries	80.92%
4	Ørsted	Denmark	Wholesale Power	80.13%
5	GlaxoSmithKline plc	United Kingdom	Biopharmaceuticals	79.41%
6	Prologis, Inc.	United States	Real Estate Investment Trusts	79.12%
7	Umicore	Belgium	Primary Metals Products	79.05%
8	Banco do Brasil S.A.	Brazil	Banks	78.15%
9	Shinhan Financial Group Co.	South Korea	Banks	77.75%
10	Taiwan Semiconductor	Taiwan	Semiconductor Equipment	77.71%
11	Pearson PLC	United Kingdom	Personal Professional Services	76.91%
12	Outotec Oyj	Finland	Machinery Manufacturing	76.53%
13	McCormick &Company	United States	Food and Beverage Production	76.20%
14	Cisco Systems, Inc.	United States	Communications Equipment	76.12%
15	Natura Cosmeticos S.A.	Brazil	Personal Care and Cleaning	75.55%
16	ERG S.p.A.	Italy	Wholesale Power	75.39%

[113] For the detailed methodology, see: https://www.corporateknights.com/wp-content/uploads/2018/10/2019-Global-100_Methodology-Final.pdf?v=20181205

[114] For the complete list, see: https://www.corporateknights.com/reports/2019-global-100/2019-global-100-results-15481152/

17	Analog Devices, Inc.	United States	Semiconductor Manufacturing	75.31%
18	Novartis AG	Switzerland	Biopharmaceuticals	75.19%
19	CEMIG	Brazil	Electric Utilities	75.18%
20	Sanofi	France	Biopharmaceuticals	75.16%
21	Ericsson	Sweden	Communications Equipment	74.92%
22	Bombardier Inc.	Canada	Aerospace and Defense	74.79%
23	UPM-Kymmene Oyj	Finland	Forestry and Paper Products	74.42%
24	BNP Paribas SA	France	Banks	74.14%
25	City Developments Limited	Singapore	Real Estate Invest.+ Services	72.73%
26	BioMérieux SA	France	Diagnostics and Drug Delivery	72.15%
27	Royal KPN NV	Netherlands	Wireless and Wireline Telecom	71.78%
28	Siemens AG	Germany	Industrial Conglomerates	71.35%
29	Valeo SA	France	Consumer Vehicles and Parts	71.15%
30	LG Electronics Inc.	South Korea	Computer Hardware	71.04%
31	Amundi SA	France	Investment Services	71.01%
32	Ecolab Inc.	United States	Food or other Chemical Agents	70.70%
33	CapitaLand Limited	Singapore	Real Estate Invest.+ Services	69.92%
34	Vestas Wind Systems A/S	Denmark	Electrical Equipment + Power	69.54%
35	ING Groep NV	Netherlands	Banks	69.41%
36	Electrolux AB	Sweden	Household Appliances and Furn.	69.22%
37	Teck Resources Limited	Canada	Metal Ore Mining	69.11%
38	Dassault Systemes SA	France	Software	69.10%
39	HP Inc.	United States	Computer Peripherals	68.32%
40	Comerica Incorporated	United States	Banks	68.11%
41	Sun Life Financial Inc.	Canada	Insurance	68.06%
42	VERBUND AG	Austria	Wholesale Power	67.34%
43	Kone Oyj	Finland	Machinery Manufacturing	67.24%
44	Suncor Energy Inc.	Canada	Integrated Oil and Gas	67.04%
45	ABB Ltd.	Switzerland	Industrial Conglomerates	67.04%
46	Eli Lilly and Company	United States	Biopharmaceuticals	66.87%
47	Nordea Bank AB	Sweden	Banks	66.70%
48	Autodesk, Inc.	United States	Software	66.35%
49	Metso Oyj	Finland	Machinery Manufacturing	66.17%
50	AstraZeneca PLC	United Kingdom	Biopharmaceuticals	65.79%

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