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The Paradigms of Industry 4.0 and Circular Economy as Enabling Drivers for the Competitiveness of Businesses and Territories: The Case of an Italian Ceramic Tiles Manufacturing Company

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Abstract: Sustainable development and the circular economy are two important issues for the future and the competitiveness of businesses. The programs for the integration of sustainability into industrial activities include the reconfiguration of production processes with a view to reducing their impact on the natural system, the development of new eco-sustainable products and the redesign of the business model. This paradigm shift requires the participation and commitment of different stakeholder groups and industry can completely redesign supply chains, aiming at resource efficiency and circularity. Developments in key ICT technologies, such as the Internet of Things (IoT), help this systemic transition. This paper explores the phases of the transition from a linear to a circular economy and proposes a procedure for introducing the principles of sustainability (environmental, economic and social) in a manufacturing environment, through the design of a new Circular Business Model (CBM). The new procedure has been tested and validated in an Italian company producing ceramic tiles, using the digitalization of the production processes of the Industry 4.0 environment, to implement the impact assessment tools (LCA—Life Cycle Assessment, LCC—Life Cycle Costing and S-LCA—Social Life Cycle Assessment) and the business intelligence systems to provide appropriate sustainability performance indicators essential for the definition of the new CBM.

Keywords: industry 4.0; circular economy; sustainability; manufacturing; industrial district (ID); Italian ceramic industry; circular business models (CBMs)

1. Introduction

In the debate on the different paths through which to achieve the objectives of environmental sustainability, the relationship between Industry 4.0 and the circular economy continuously emerges more clearly (Tseng et al. 2018). Circular economy means a different approach to production methods. In other words, it goes from a linear process that sees the use of raw materials and the generation of production waste that is thrown away, to a model that regenerates itself, transforming what is commonly considered waste into a resource. A passage that is first and foremost cultural (Lieder and Rashid 2016). The transition to a circular economy is a revolution and an opportunity: It is a question of enhancing what is hidden in waste and production waste.

The industrial system, at the end of the production and consumption cycle, must develop the capacity to absorb and reuse waste and slag. The circular economy refers to a development model where the waste of one company becomes the raw material of another (Singh and Ordoñez 2016). The use of technology should aim not only at improving business processes, but also their sustainability. For this reason, Industry 4.0 and circular economy are candidates to be two sides of the same coin. In fact, to implement the principles of circularity, it is necessary that companies: (1) Adopt the techniques of eco-design of products so that they can be continuously regenerated; (2) innovate the business model by including the concept of “servitization” to transform the product from a physical good to an integrated solution product-service; (3) redesign the supply chain using an effective and efficient reverse logistics, able to collect products at the end of their life and recover their value (Bressanelli et al. 2018). In all this, the digital technologies (IoT—Internet of Things) developed in the context of the fourth industrial revolution can enable the transition from the linear model of economy to the circular one. In short, the circular economy develops using the business models, technologies and skills of Industry 4.0.

Moreover, a sustainable approach to economic activity is fundamental for developing the competitiveness of territories, and in the manufacturing sector, industrial districts are the social structures capable of producing and disseminating sustainable practices and, at the same time, being beneficiaries of their development in the territory (Real and Lizarralde 2017).

2. Aims and Objectives

The aim of this research is to propose a procedure to include the three pillars of sustainability in business operations, orienting the company towards the evolution of the business model from linear to circular. To do this, the following research question must be answered:

- *How can a manufacturing company integrate sustainability principles into its business and corporate strategies in a simple but effective way?*

For this reason, the theoretical bases will be laid through the construction of a conceptual model that will be validated through the analysis of a representative case study of an important European manufacturing reality, which is at an advanced stage of implementation of the Industry 4.0 paradigm. Finally, a new Circular Business Model will be proposed as a possible way of integrating sustainability principles into company operations. To achieve this purpose, the following specific objectives have been set:

1. To elaborate a theoretical framework based on the analysis of the literature, to circumscribe the subject of the research;
2. To identify the relevant variables and enunciate theoretical propositions that will serve as the basis for the construction of a conceptual model;
3. To map the phases of a manufacturing process in order to identify the nodes of the system that present environmental criticalities in terms of consumption of resources and polluting emissions;
4. To design a network of digital sensors capable of measuring consumption and all production data at different stages of the process;
5. To select and validate impact assessment tools (environmental, social and economic) and business intelligence solutions for sustainability data processing;
6. To design a new Circular Business Model (CBM) to complete the integration of the pillars of sustainability in the corporate strategy.

3. Theoretical Framework

In order to understand the relationships between sustainable development and industry 4.0 paradigms, this section presents the main concepts related to the three pillars of sustainability and IoT technologies applied to the manufacturing industry. It also provides an overview of knowledge about industrial clusters as places where innovation is rapidly developing and diffusing.

3.1. Sustainable Development and Businesses

Sustainability and development meet and integrate each other in the concept of “Sustainable Development”, which in the last 20 years has been the subject of different interpretations. The most famous definition is that of the Brundtland Report (Keeble 1988): “[D]evelopment that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Keeble 1988). Another definition is that formulated in 1991 in “Caring for the Earth: A Strategy for Sustainable Living”: “[T]he satisfaction of the quality of life, keeping within the limits of the carrying capacity of the ecosystems that support us” (Munro and Holdgate 1991). The two definitions together give a clear understanding of the concept of sustainable development as a benefit for both people and ecosystems. The World Summit in Rio de Janeiro (1992) marked a historic step in the awareness of the global environmental problem, which cannot be addressed by repairing the damage “a posteriori”, but by reorienting the way of producing and consuming towards environmental and social quality (Meyer and Baltes 2004). The World Summit on Sustainable Development (WSSD) in Johannesburg (2002) expanded the concept of Sustainable Development as an integration of three closely linked dimensions: Environment, economy and society (Von Frantzius 2004).

Therefore, environmental sustainability requires an awareness of natural resources, of the vulnerability of the environment and of the impact that human activities and decisions have on it. This dimension includes the elements and regulations necessary for the “conservation” of living beings, the ecosystems in which they live and the bio-geochemical cycles that support them. Without natural resources available indefinitely there is no development: At most we can talk about growth, which will not last in time (Hackett and Dissanayake 2014). Economic sustainability requires knowledge of the limits and potentials of economic growth and knowledge of their impact on society and the environment. It is necessary to generate sustainable income and employment for the livelihood of the population, through the rational and efficient use of resources and decreasing the use of non-renewable resources (Jänicke 2012). It follows that if we want to replace one (harmful) development model with another (virtuous) one, we must take into account the cost/benefit ratio. If the costs of the new model are higher than the benefits, it is not applied and (sustainable) development is not pursued. Therefore, not only theoretical statements and recommendations are sufficient, but a model of change, including economic change, is also necessary. Finally, social sustainability means the ability to guarantee conditions of human well-being (security, health, education, democracy, participation, justice) equally distributed by class and gender (Vallance et al. 2011). When inequalities increase and social cohesion is lost, economic and environmental sustainability cannot be achieved.

It follows that respect for fundamental human rights, protection of the environment and protection of natural resources are the basic principles of the concept of sustainability in which companies are also called upon to participate for the sustainable development of the successful business model. Management’s attention to social and environmental impacts in business management and integration with local economic and social issues are necessary choices to ensure the company’s long-term stability and development. A firm can be considered “social” when it not only respects the principles of economic ethics and pursues long-term growth, but also contributes to the sustainability of development in a macroeconomic sense, so as not to compromise the ability of future generations to meet their needs (Epstein 2018). Therefore, the interconnection between long-term profitability and the competitive and territorial context drives the companies to bear the environmental, social and economic impacts generated by their activities, in addition to the expectations of their stakeholders.

Industrial companies must respond to this new social awareness and assess the effects of their policies on workers’ and consumers’ health, on the economic and social structures of the countries where they operate and, above all, on the physical environment and the environmental sustainability of development (Bateh et al. 2015). The positions that companies take on sustainable development have become aspects of their competitiveness: Each responds to the challenges in a defensive or proactive way, giving different priorities to the various components of sustainability (Tukker and Tischner 2017). For some, savings and efficiency gains achieved through a reduction in energy consumption are more

important (Dobrotă and Dobrotă 2018). For others, promoting “green” initiatives is a way to improve the image, pursuing “ethical” leadership (Lee et al. 2015). For others, it is a way to create a bond with customers, based on emerging values. Many companies pursue a combination of the three.

Regardless of the way chosen, the competitiveness of a company depends on the surrounding environment and the community in which it is located, just as the well-being of a company depends on the possibility of having competitive companies in its territory that can create wealth and quality employment (Barzotto et al. 2016). There is a long-term synergy between environmental, economic and social objectives; and to maximize this synergy, business strategies and public policies must be adopted on the basis of the principle of shared value, i.e., by ensuring that both the competitiveness of enterprises and social conditions benefit from it at the same time (Wolf et al. 2016). In this way, the business is not simply considering, in addition to financial strategies, social and environmental factors, but also integrating these aspects into those same strategies: Sustainability, therefore, becomes an integral part of the core business of the company (Fischler 2014). This new approach has even proved to be successful, not only on the environmental and social level but also on the strictly financial one: The efficient and rational use of natural resources, the recovery and recycling of materials, the exploitation of renewable energies, the correct and good management of company personnel, in fact, are, especially in the long term, a plus for the profits of the company itself. The companies that, in recent years, have given more importance and shown great attention to their social and environmental responsibility, have also proved to be the most attractive for investors themselves, increasingly attentive to the issue of sustainability (Salvioni et al. 2018).

However, the greater sensitivity towards sustainability issues cannot be reduced to a mere “environmentalist” attitude on the part of companies but must be seen as a new economic vision. It is precisely in this direction that the concept of the Circular Economy, i.e., the economy capable of regenerating itself, is increasingly asserting itself as a paradigm of sustainability (Geissdoerfer et al. 2017). A circular economy, therefore, is based on two different material flows: The biological ones, able to be reintegrated into the biosphere, and the technical ones, destined to be revalued without entering the biosphere (Saavedra et al. 2017). At the base of this model there is a radical and overall rethinking with respect to the classic production model, based on the over-exploitation of natural resources that, after having been transformed into products and consumed, are inevitably disposed of, and that reaches the maximization of profits only through the reduction of production costs (Stahel 2016). Adopting a circular approach, on the other hand, means reviewing the functioning of the entire supply chain involved in each production cycle: From design, to production, to consumption, to destination at the end of life (Tantau et al. 2018). The Circular Economy is therefore an enormous opportunity to integrate sustainability into the company’s vision (Gaspar et al. 2018). Different pressures can lead companies to move this new system of sustainable development, but a factor not sufficiently highlighted concerns the huge business opportunities that the Circular Economy offers (Roper et al. 2017). Unlike the Linear Economy, where the flow of materials takes place in a sequential manner (extraction, production, consumption and disposal) putting pressure on natural resources and sending large quantities of resources to landfill, transforming waste into resources is instead one of the cornerstones of the Circular Economy, where the concept of waste does not exist and a product does not “die” after its primary use, but starts a new life in another form (Den Hollander et al. 2017). In this new economic model, a series of recycles are operated within the processes and the focus shifts from maximizing the “flow” (sale of finished products) to enhancing the “stock” (maintenance of materials, components and products to their maximum usefulness and value). The circular approach has the great advantage of allowing companies not only to free themselves from the constraints of resources, but also to increase resilience and competitiveness, promoting the full integration of sustainability in their strategies and creating shared value for the whole of society (Bag et al. 2018). The concept of business therefore becomes the cornerstone of the change that implies a natural transition from an individualistic approach to a participatory and shared one (Santos et al. 2018), whose objectives are no longer the advantage for the individual company, but for the community and the territory of reference.

This greening aspect of the business therefore offers the great opportunity to develop a sustainable global economy, an economy that the planet is able to sustain. The trend towards the “green” aspect of business has been driven by the regulations defined at both European and global level for the protection of the environment (Domenech and Bahn-Walkowiak 2019). There would therefore be a stable trade-off between sustainability and economy. On the one hand, there are the social benefits of strict environmental and social standards. On the other hand, the private costs incurred by industries for pollution prevention and social policy, which lead to higher final product prices and reduced competitiveness (Dabhilkar et al. 2016). If this static view in which technologies, products, processes, consumer needs are constant is true, then it would be inevitable to conclude that regulations increase costs (Babool and Reed 2010). In reality, companies operate in dynamic competitive contexts where, in order to survive, they continually seek innovative solutions to outperform competitors, satisfy customers and comply with regulations (Porter 1995). Setting sustainability standards can, on the other hand, initiate the creation of innovations that lower the total cost of a product or increase its value. These innovations enable companies to use resources (raw materials, energy, labor) more productively, thereby compensating for the costs of improving environmental and social impacts (Adams et al. 2016). The conclusion is that this so-called resource productivity makes companies more competitive, rather than reducing their ability to compete. Therefore, we assume that:

Proposition 1 (P1). *Strategies aimed at integrating sustainability into business, as well as improving environmental conditions and social cohesion, become a competitive advantage for the companies that implement it.*

3.2. Fourth Industrial Revolution and Sustainable Development

So far there have been three industrial revolutions in the Western world (Qin et al. 2016): In 1784 with the birth of the steam engine and consequently with the exploitation of the power of water and steam to mechanize production; in 1870 with the start of mass production through the increasingly widespread use of electricity, the advent of the internal combustion engine and the increase in the use of oil as a new source of energy; in 1970 with the birth of information technology, from which arose the digital era destined to increase the levels of automation using electronic systems and IT (Information Technology). The fourth industrial revolution exploits different technologies that allow you to connect to the Internet any type of device. The purpose of this type of solution is essentially to monitor and control and transfer information and then carry out consequent actions (Schuh et al. 2015). This set of technologies is referred to by the term Internet of Things (IoT), used for the first time by Kevin Ashton, a researcher at MIT (Massachusetts Institute of Technology), to define the connection between material objects with a structure composed of virtual representations (Madakam et al. 2015). Compared to the past, this is not a revolution dictated by a change in consumer habits, or by technologies developed for other fields and then applied to industry. Instead, it is a radical change in the conception of production processes. In every aspect, from time and cost efficiency to quality monitoring (Preuveneers and Ilie-Zudor 2017).

However, it is common to use the term Industry 4.0 to refer to the fourth industrial revolution, which today is seen as the process of digitizing the manufacturing sector that, by renewing the value chain, changes the way of working but also the nature of organizations. The level of innovation is such that today the synonym of Industry 4.0 is smart manufacturing, where the suffix “smart” becomes the common denominator of an integrated management of information, associated with the use of digital technology (Oesterreich and Teuteberg 2016). The expression “Industries 4.0” (in German) was used for the first time at the Hanover Fair in 2011 in Germany (Jazdi 2014). In October 2012 a working group dedicated to Industry 4.0, chaired by Siegfried Dais of the multinational engineering and electronics company Robert Bosch GmbH and Henning Kagermann of Acatech (German Academy of Sciences and Engineering) presented to the German Federal Government a set of recommendations for its implementation. On 8 April 2013, at the annual Hanover Fair, the final report of the working group was released (Sanders et al. 2016). So, with IoT and Industria 4.0 we refer to the ongoing change related

to the increasing automation and networking of machines and devices. The difference is in the final focus. While the American term “Internet of Things” focuses on individual products, Industry 4.0 focuses on the ecosystem of industrial production (Wortmann and Flüchter 2015). In both sectors, it is not possible to draw a line between the industrial-economic and the domestic/private spheres.

Although there is no commonly accepted definition, Industry 4.0 is generally seen as a process that will culminate in a new conception of industry, from the development of new products and services, to research and innovation, to validation and production, with the lowest common denominator being a high degree of automation and interconnection (Zimmermann 2018). The new digital technologies will have a profound impact in the context of four lines of development: The first concerns the use of data, computing power and connectivity, and is divided into big data, open data, Internet of Things, machine-to-machine and cloud computing for the centralization of information and its storage. The second is that of analytics: Once the data has been collected, it is necessary to obtain value from it (Ardolino et al. 2018). Today, only a few of the data collected is used by companies, which could instead obtain advantages from “machine learning”, i.e., from machines that improve their performance by “learning” from the data gradually collected and analyzed (Lee et al. 2018). The third line of development is the interaction between man and machine, which involves the interfaces “touch”, increasingly widespread, and augmented reality. Finally, there is the whole sector that deals with the transition from digital to “real” and that includes additive manufacturing, 3D printing, robotics, communications, machine-to-machine interactions and new technologies to store and use energy in a targeted way, rationalizing costs and optimizing performance (Liu et al. 2017).

Thanks to the digitization of businesses, the modern industrial scenario is to be understood as a place where people and machines coexist in the same environment and guarantee efficient production. Thanks to the Internet of Things applied to the “factory” system, the interaction between human and cyborg (union of artificial elements in a biological organism) is made possible: The sensorization (that is to say, equipping with sensors) of production processes therefore favors not only environmental sustainability and energy efficiency, but also allows the operator to be monitored, promoting social well-being (Henz 2018). The debate on Industry 4.0, both in the academic and managerial spheres, is often centered on the influence that digital technology is exerting on organizational models and, more generally, on the labour market: It is certainly a significant impact that is forcing us to change our approach to problems and experiment with new solutions. Moreover, Industry 4.0 is system innovation. And in this context, 4.0 products, goods and services must be designed to react responsibly towards the environment and society (Altmann et al. 2017).

The speed and breadth of adoption of IoT solutions for production in Industry 4.0 therefore depends not only on technical factors, but also on environmental, economic and social ones. On the one hand, there is the potential for greater efficiency in the use of resources and energy (Reis and Kenett 2018). On the other hand, the challenge is to maintain the pre-eminent role of man in this new production area. A need for sustainability, therefore, not only economic and environmental, but above all social, which translates into Work 4.0, i.e., the need to develop a new way of working, which instead of penalizing workers offer them more and better opportunities, making available different modes of employment (Seghezzi and Tiraboschi 2018). Therefore, the issue of sustainability can be addressed from several points of view. First, when talking about sustainability, it is important to consider the entire life cycle of a product and to focus on the high level of recyclability of materials produced by industry. Incorporating the aspects of re-manufacturing, reuse, repair, recycling already at the design stage of the life cycle of the new product substantially changes the levels of sustainability of production processes. Secondly, IoT technologies can help in the reintegration and repair processes and in the reusability of components, products and machinery. Finally, logistics optimization can play a key role: Flexibility and reaction times of the industrial and logistics system can be substantially increased through digitization. This results in increased efficiency and resource savings, which implies great potential for increasing the sustainability of manufacturing processes and products (Garbie 2016).

All this entails a paradigm shift that is not only productive, but also organizational. The transition is from the linear operating scheme where, once consumption has ended, the cycle of the product that becomes waste also ends, forcing the economic chain to continually resume the same classic scheme: Extraction, production, consumption, disposal: To the circular scheme that is a system in which all activities, starting from extraction and production, are organized in such a way that someone's waste becomes a resource for someone else. This new operative paradigm flows into the concept of circular economy, that is, a model of economy that (unlike the linear one) reduces and eliminates waste, differentiates the sources of material supply and makes consumer products live longer, maximizing their value in use (Murray et al. 2017). There is therefore a link between the development of a circular economy model (aimed at achieving not only profitability and profit objectives but also those of social progress and environmental protection) and the affirmation of the industry 4.0 paradigm and IoT technologies (De Sousa Jabbour et al. 2018). On the one hand, the circular economy is designed to self-regeneration, since in its strategies the materials of biological origin must be reintegrated into the biosphere while the technical ones must be revalued without being able to enter the biosphere (Geissdoerfer et al. 2017). On the other hand, the fourth industrial revolution, thanks to the increased capacity to interconnect and cooperate productive resources (physical assets, people and information both within the factory and along the value chain), can not only increase competitiveness and efficiency, but also encourage the introduction of new business models to the point of profoundly transforming the industrial sector and the mechanisms through which to produce value, innovation, employment and well-being (Stock et al. 2018). In general terms, a business model allows you to understand how a company decides to create, distribute and collect value, a set of strategies with which the company wants to gain competitive advantage (Osterwalder and Pigneur 2010). This traditional definition refers to a linear economic model, in order to move towards the principles of the circular economy it is necessary to evolve towards a Circular Business Model where the production processes and resources used are able to regenerate (Bocken et al. 2016). We formalize this as follows:

Proposition 2 (P2). *The business transformation introduced with Industry 4.0 favors convergence between business and technology in new production models, promoting a sustainable evolution of human existence in its social, environmental and economic dimensions.*

Proposition 3 (P3). *The Industry 4.0 paradigm and the technologies of the Internet of Things are able to stimulate the transition from a linear to a circular business model.*

3.3. Sustainable Development and Territories

Sustainable development, understood not only in terms of respect for the environment but above all as a guide to economic, social and cultural growth, has become a world imperative, as set out in the 17 objectives of Agenda 2030 adopted in 2015 (Colglazier 2015). However, leading development to follow a trajectory of sustainability, encounters objective difficulties of both a technological and a cultural nature, as well as high levels of complexity and indeterminacy. At macroeconomic level, for public decision-makers, acting sustainably means adopting a very long-term viewpoint, thinking of the generations to come, while in an entrepreneurial perspective it also means giving a different signal to those interested in assessing not only the current condition but also the future growth prospects of a company (Goodwin et al. 2015). In order to reduce the complexity of the problem, the local dimension has recently been enhanced as a privileged area for sustainability experiences, orienting research towards a microeconomic level, albeit limited to environmental aspects only, and neglecting socio-economic aspects (Huttmanová 2017).

The territory can therefore be analyzed from multiple perspectives for the creation of sustainable value as the place of origin of the well-known phenomenon of industrial districts (ID), often forerunners of the concept of "circular economy". Industrial districts are concentrations of small and medium enterprises specialized in the production of the same good, or parts of the same good, in a

territory whose population is characterized by common socio-cultural traits (De Marchi et al. 2017). The productive processes that characterize them employ qualified manpower and with a deep knowledge of the product; the innovation happens from the direct learning (learning by doing) and on the base of the stimuli coming from customers and suppliers (Ferretti and Parmentola 2015). The network that binds these enterprises, however, is not only economic, but also cultural and values. This last dimension of the industrial districts has been one of its major strengths, allowing to create collaborative relationships based on knowledge and trust that have often proved to be lasting (Caraganciu et al. 2018). One of the characteristics that has allowed the success of the industrial districts is the marked ability to unite specialization and flexibility also in absence of a form of coordination “central” but acting spontaneously on the basis of the demands of the market (Guido et al. 2011). Therefore, the industrial districts do not represent only an aggregation (at the micro level) of firms engaged in a specific production, but a space in which the systems of relations or interaction between economic subjects are created and developed and knowledge, information and experiences are exchanged. This network makes the territory a factor of competitiveness with the character of a public good as an element of connection between businesses and the macroeconomic system, encouraging relations and the exchange of knowledge between public and private agents (Camagni 2017). Becattini (1979) has identified in the districts a new agent of the meso-economic level (placed between the macro-economy of the nation-state and the microeconomics of the business), as a new unit of investigation of the industrial economy.

The potential ability to disaggregate production processes within the supply chains of the districts (De Cecco 2007), allows a shift of attention to sustainability from an individual practice of a single company to that of a network and district. In fact, individual actions for the protection of the environment or for social guarantees, could produce limited results that could even be frustrated by unethical behavior of other actors in the supply chain (Cohen-Rosenthal and Musnikow 2017). On the contrary, actions designed and implemented in a collaborative way between the economic agents of the district will allow to legitimize and develop more ambitious projects, as well as to provide them with the necessary conditions to be effectively developed. Therefore, the factors that determine the success of a district are the same as those that underlie the policies of local sustainability, it follows that industrial districts are potentially the nucleus from which to start an action of sustainable development. At the same time, sustainability becomes an opportunity to build collaborative interactions and partnerships between public and private actors.

The industrial districts represent a specific characteristic of the Italian productive system, which differs for this peculiarity, from the industrial systems of other countries at an advanced level of development. Founding elements of the Italian districts are the dynamism of the small and medium enterprises that constitute them and that are a direct expression of a lively and diffused entrepreneurship, and their capillary presence on the territory of the country (Barzotto and Mariotti 2018). Italian legislation (Italian Law 1991) defines industrial districts as “local territorial areas characterized by a high concentration of small businesses, with particular reference to the relationship between the presence of businesses and the resident population as well as to the productive specialization of all businesses”. This definition underlines the close relationship between industrial and social reality. The success of the Italian industrial districts is explained by the increase of the competitiveness of the single companies thanks to micro and macroeconomic advantages (Carbonara 2018). First, they stimulate the development of skills in the territory, discouraging people from emigrating; then they increase the need for technologically intensive services, contributing to further develop local competitiveness; finally, they stimulate the propensity for entrepreneurial initiative. It is therefore possible to identify in the territory a mesoeconomic space, intermediate between the micro space represented by the enterprises of the district and the macro space constituted by the entire national economic system (Pecqueur 2014). In the mesoeconomic space, manufacturing activities are carried out and systems of relations or interaction between economic subjects are created and developed, and knowledge, information and experience are exchanged. These relations of

synergic interdependence between economic agents (private and public) make the territory a factor of competitiveness (Del Baldo and Demartini 2016).

One of the largest Italian industrial districts is the one that produces ceramic tiles, known as the district of Sassuolo, located between the provinces of Modena and Reggio Emilia in northern Italy (Bianchetti and But 2016). The heart of the mechanical-ceramic production activity is concentrated in this area, together with all those activities that work at the service of the ceramic industry, from logistics to design, from design to decoration. This industrial reality has also developed many best practices in the field of environmental sustainability with excellent performance in terms of energy efficiency, recycling and recovery of materials and water, and packaging (Mosconi 2017). We formalize this as follows:

Proposition 4 (P4). *Industrial districts are the mesoeconomic spaces in which the adoption of the principles of sustainability is favored by the cooperation and interdependence between the district economic agents at the microeconomic level.*

Proposition 5 (P5). *The improvement of the competitive position of the district, due to the effect of the realization of sustainability, is positively reflected on the firms in the territory.*

3.4. Sustainability Indicators

The three pillars of sustainable development are understood as the ability to maintain the same level of quality and reproducibility of natural resources (environmental sustainability), ability to generate income and labor for the livelihood of the population (economic sustainability) and, finally, ability to generate conditions of human well-being, understood as security on the ground, health and civil rights fairly distributed (social sustainability) (Wilson 2015). The orientation towards sustainability therefore requires a set of environmental, economic and social performance indicators that can assess, represent, and monitor sustainability, and that are comparable in time and space (Strezov et al. 2017). To quantitatively determine sustainability indicators, the best-known tools are those based on life cycle analysis methodologies, whose objective is to screen a product/process/service to monitor its costs, consequent environmental and social impacts, and opportunities for improvement throughout its ideal life cycle (Valdivia et al. 2013). For a long time, on the other hand, interventions to reduce the (above all) environmental impacts of products and services were mainly directed at the production and waste management phases. This approach has given important results, especially at the micro (business) level, but has proved not to be enough to ensure the reduction of overall impacts (production, use and decommissioning), with the consequence of neglecting any major impacts that may occur in places and times other than those of production. Therefore, thinking in terms of the life cycle of a product or service means thinking about all the phases of its life “from the cradle to the grave”, from the extraction and processing of raw materials to production, packaging, distribution, use and then reuse, recycling, recovery of materials and energy and disposal, seeking where possible to reduce all impacts (Gbededo et al. 2018). Life Cycle Thinking (LCT) can be defined as a new approach that proposes to consider all aspects of the life cycle of a product or service before starting its design, implementation and distribution (Laso et al. 2017). Applying a similar approach means that for each product we will consider all the operations (design, production, transport, use, and end-of-life) and the material and immaterial inputs and outputs connected with its realization.

The main operational and evaluation tools for Life Cycle Thinking are Life Cycle Assessment (LCA), for environmental impact assessment (Hauschild et al. 2018); Life Cycle Costing (LCC), for economic impact assessment (Ciroth et al. 2015); and Social Life Cycle Assessment (S-LCA), for social impact assessment (Zamagni et al. 2015). Making an assessment means making a diagnosis, a design, collecting all the information on the product, on its impact, improving the understanding of the environmental, economic and social impacts of a company. It is the objective and purpose of the LCA to decide “from where to where” to study environmental impacts (Rashid and Yusoff 2015).

We can focus on a broader study that goes from the production of raw materials to the disposal of the final product (from cradle-to-grave) or on a more limited part where the information is more familiar, namely the one that goes from the raw materials to the boundaries of the production plant, just before the product or service passes into the hands of the consumer or a step of subsequent processing (from cradle-to-gate). In fact, beyond the gate of the production plant there are various scenarios of use and end of life that belong mostly to consumers and that I can also provide for a reuse of the product at the end of life as a second component of a new product (from cradle-to-cradle). The LCC focuses on costs at every stage of the life cycle (expenditure on raw materials, energy, depreciation, personnel costs) and answers the question: How much the process cost and what economic impacts it has. It also includes externalities, i.e., the economic valuation of the environmental impacts determined by the LCA (Moreau and Weidema 2015). The S-LCA, on the other hand, represents the new frontier of the life cycle approach because it is proposed to introduce a social dimension to the LCA's own quantitative assessments in order to quantify the potential social impacts caused to people as a result of a product's life cycle (Fan et al. 2015). We propose the following:

Proposition 6 (P6). *Life Cycle Thinking (LCT) is a strategic approach that aims to consider environmental and socio-economic impacts as decisional variables in the planning and definition of business strategies.*

Proposition 7 (P7). *Life cycle methodologies (LCA, LCC and S-LCA) are operational tools aimed essentially at assessing and quantifying environmental, economic and social impacts.*

4. Methodological Framework

This paper is mainly based on an explanatory research, aimed at understanding the issues related to sustainability in the industrial environment, for this reason a qualitative methodology was adopted for the theoretical conceptualization and to respond to research questions, later supplemented by quantitative methods to validate system through a case study. Following the development of the theoretical framework and the construction of the conceptual model, the procedure used to achieve the specific objectives and answer the initial question provides for integration between the three impact assessment tools (LCA, LCC, LCC, S-LCA). In this respect, in accordance with ISO 14040, ISO 14044 and ISO 15686, the same main phases have been adopted for each dimension (environment, economy and society), namely: Objective and scope, inventory analysis, impact assessment and interpretation of results. Subsequently, thanks to the information obtained, the principles of sustainability have been integrated into the company's strategy by changing the business model.

4.1. Objective and Scope

The objective of this sustainability analysis is to evaluate the environmental and socio-economic impact of the ceramic production of the company involved in this study. While the functional unit, that is to say the object of reference of the study, corresponds to 1 m² of ceramic tiles. To answer the research question, the ceramic production industry in Italy was chosen as the reference industrial sector for the following reasons:

- Italy is seventh in the ranking of the most industrialized countries in the world and second in Europe behind Germany, so it is among the most technologically advanced countries in the manufacturing field (Paolazzi and Traù 2017).
- Italy, together with Germany, is the country in Europe that has most implemented the new paradigms of Industry 4.0. as enabling factors for the digitization of manufacturing (Bortolini et al. 2017). This process has been favored by the presence of numerous supply chains of highly integrated firms to form industrial districts with a high index of technological specialization.
- In this context, the ceramic district of Sassuolo represents one of the best European practices in the digitization of industrial processes (Mattioli 2018) and in the management of environmental sustainability (Da Ronch et al. 2013).

On the other hand, the company that was the subject of the case study, is among the TOP 10 of Italian ceramic manufacturers and among the TOP 5 for economic performance. Moreover, having started a process of digitization of processes and operations, it is better suited to validate the innovation of the business model.

4.2. Inventory Analysis

The inventory consists of a quantitative description of all flows of materials and energy through the system, both incoming and outgoing. For this purpose, the limit of the system has been defined as the part of the supply chain that goes from the sources of raw materials to the company's warehouse: From cradle to gate. Subsequently, the components of the system were represented in a composite process flow diagram. Once the process has been delineated, it has moved on to the data collection phase. These are of two types: Those related to input flows and those corresponding to output flows. The first ones refer to materials, transport and energy; the second to products and gases released into the air, water and soil. The aim was to draw up a real environmental balance sheet, for which it was necessary to check the quality of the data. To carry out this task, the networks of sensors and meters within the Supervisory Control and Data Acquisition (SCADA)¹ system already present in the company were used, which were connected by means of a Manufacturing Execution System (MES)² via a WiFi connection to the internal Enterprise Resource Planning (SAP ERP)³ system. This analysis was carried out using the SimaPro 8.0.2 software⁴ and the IMPACT 2002+⁵ evaluation method to quantify the environmental and socioeconomic impacts.

4.3. Impact Assessment

This evaluation is a technical-quantitative and qualitative process to evaluate the effects of the environmental and socioeconomic impacts of the criticisms highlighted in the inventory. The data collected in relation to the production cycle were transformed into a table of environmental, economic and social impacts caused by the functional unit under study. The inventory data have been divided into categories of impacts related to three main areas of environmental protection: Resource depletion, human health and environmental conservation.

4.4. Interpretation of Results

The last part of the study consists of developing critical analyses of the results in order to draw conclusions and offer recommendations for improving the environmental performance of the system analyzed. This phase has made it possible to understand the result of the analysis, contextualize it and be able to indicate an improvement through the identification of appropriate impact indicators

¹ Supervisory Control and Data Acquisition (SCADA): It is a centralized system that collects real-time data from various sensors and meters at remote locations (production unit) and sends it to an MES that manages and controls the data. This control system focuses on the process.

² Manufacturing Execution System (MES): It is a computerized system that has as its main function the management and control of the production function of a company. MES works in real time to enable control of multiple elements of the production process by providing information that helps production managers understand how current system conditions can be optimized to improve the product. By focusing on the product, it is in an intermediate position between the planning system (ERP) and the control system (SCADA).

³ Enterprise Resource Planning (ERP): It is a management system that standardizes, rationalizes and integrates business processes across all departments of the company: Finance, human resources, procurement, distribution and others. Typically, the software runs on an integrated platform that uses common data definitions that run on a single database. This planning system is customer-centric and serves to facilitate business decision making. SAP ERP is one of the main ERP systems produced by SAP AG: <https://www.sap.com>.

⁴ SimaPro is a professional tool for collecting, analyzing and monitoring the environmental performance of products and services. With SimaPro it is possible to model and analyze complex life cycles in a transparent and systematic way, following the ISO 14040-14044 standards. PRé Sustainability is the developer of SimaPro: <https://simapro.com>.

⁵ Impact 2002+ is an environmental assessment method, implemented by the Swiss Federal Institute of Technology Lausanne (EPFL), which is based on the identification of 4 environmental damage categories: Human Health, Ecosystem Quality, Climate Change and Resources. <https://www.epfl.ch>.

to reduce the environmental and socioeconomic impact of the whole system. It has been used as a Business Intelligence⁶ tool (SAP BusinessObjects suite). All this data has provided the necessary information to design the new business model that integrates the principles of sustainability.

5. Results

5.1. Conceptual Model

As a conclusion of the literature analysis a theoretical model has been drawn, which is shown in Figure 1. It aims to provide a conceptual background to respond to the research question and to support the application to the case study. The different blocks of the model are correlated with each other by the propositions enunciated in the theoretical framework and built on the basis of the analysis of the literature. The strategic objective of the model takes up the challenge arising from the research question: “How to increase the competitiveness of a company in an industrial district through the adoption of practices of environmental, economic and social sustainability?”. On the one hand, the territory offers a favorable competitive context for achieving the goal of sustainable enterprise, thanks to the opportunities offered by the socio-economic structure of the industrial district (mesoeconomic space) and by the relations that exist between individual enterprises (microeconomic space) along the same supply chain. On the other hand, the Industry 4.0 paradigm and IoT technologies provide the technical platform to collect process data and build powerful databases to conduct economic and social environmental impact assessments, using LCA, LCC and S-LCA tools respectively.

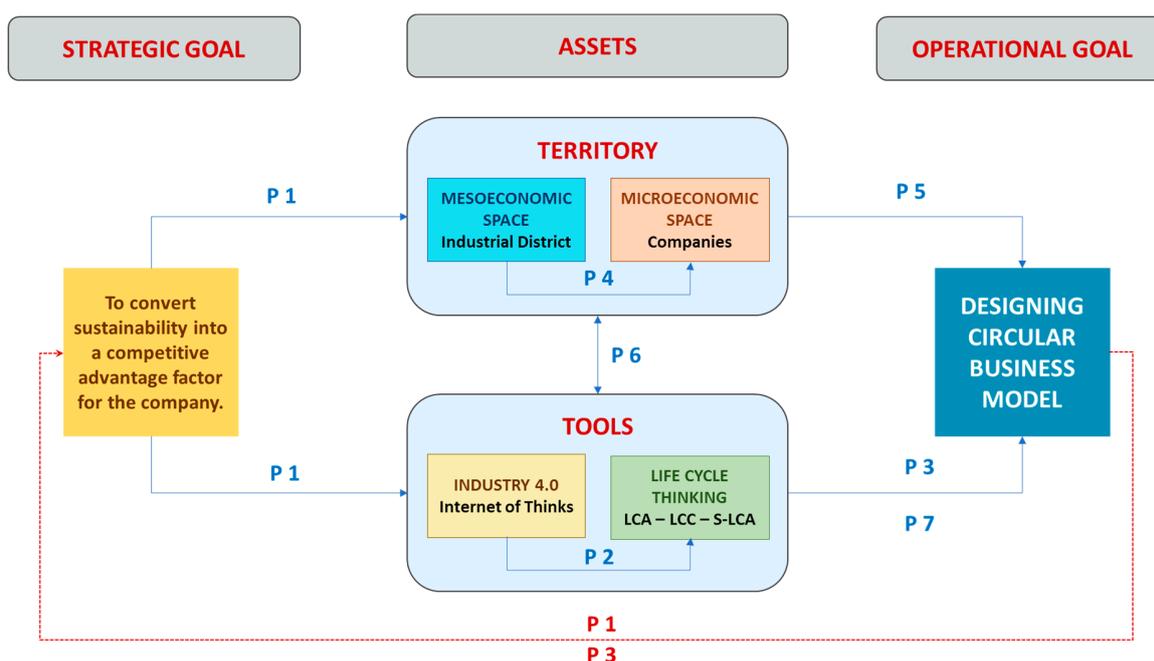


Figure 1. Conceptual model for the integration of sustainability into the business model of a company in an industrial district.

⁶ Business Intelligence is the process and basic technology, which allows transforming data into information, information into knowledge and knowledge into plans that guide the decision-making process at different levels of the organization. The results of the business intelligence process represent a fundamental support for strategic decision making. Therefore, business intelligence represents the key instrument for the evolution towards an increasingly effective and strategic information management. SAP BusinessObjects Suite is the complete Business Intelligence and Business Analytics solution for companies that already use SAP as their ERP.

The integration of all these assets, both socio-economic and technological, provides the information needed to design a new circular business model that represents the operational goal to integrate sustainability into the business of the enterprise. The proposed conceptual model already introduces an element of circularity: The operational findings from the implementation of the Circular Business Model within the company offer useful indications to support the strategic planning of top management to pursue an improvement in competitiveness through the principles of sustainability.

5.2. Map of Process Phases

Adopting the Life Cycle Thinking approach means considering the products and processes with which they are made, throughout their entire life cycle. It offers a systemic view of the production processes, monitoring resource consumption, the production of waste and scrap and emissions into the atmosphere at each stage of the process (Figure 2). This vision is achieved by following step by step the path that goes from the extraction of raw materials, through all manufacturing and transport activities and that after use (the useful life spent in the form of economic goods), comes back to the environment in the form of waste. It is therefore a question of considering the history of a product or a process “from the cradle to the grave”.

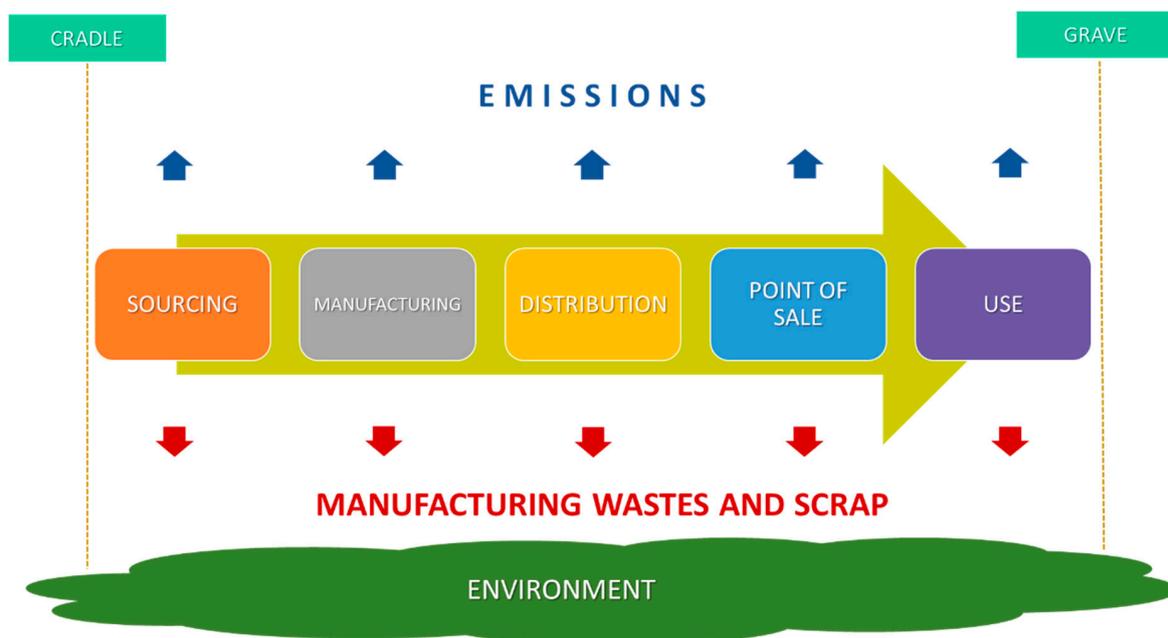


Figure 2. Diagram of a general manufacturing process.

The manufacture of ceramic tiles is a complex process consisting of several sub-processes and phases that we have mapped and schematically outlined, as shown in Figure 3. The raw materials for the ceramic body are generally transported to the site by trucks and are unloaded and stored in special covered areas, in separate batches depending on the type. From the warehouse, the raw materials are sent to the ceramic body preparation department. The grinding of raw materials takes place in mills with water as a grinding vehicle, resulting in a compound called slip (water content of 30–40%) that is sent to the spray dryer. At this stage of the process, the slip is sprayed against the current with a flow of hot air (500–600 °C), which causes the instantaneous evaporation of most of the water, resulting in the formation of round agglomerates of fine particles, which are the right powder for the next phase of pressing. Forming consists of shaping the tiles to the desired size and is carried out in the pressing operation that aims to compact the powders by applying a pressure (varying from 40 to 50 mPa), which modifies, rearranges and adheres the granules of a spray-dried ceramic body, with the aim of obtaining a raw compacted product. With drying, the residual water of the ceramic

body (about 6–7%) is removed from the formed product in accordance with the need to guarantee the integrity of the tiles in order to protect the product from breakage and dimensional distortions during the subsequent glazing, decoration and firing phase. The preparation of the glazes (grinding in water of the various constituents) has the aim of obtaining the glazes ready for application in the form of an aqueous suspension of fine particles. Glazing and decoration consists of applying glazes and inks to the surface of previously pressed and dried tiles. The firing of the tiles consolidates and sinters the support and/or glaze of the tiles, so as to give the product its mechanical characteristics of resistance and chemical-physical inertia, adapted to the various specific uses. After firing, the tiles are then sent to the sorting line, which is mainly characterized by a size and flatness control unit, a visual sorting position and an automatic packaging system.

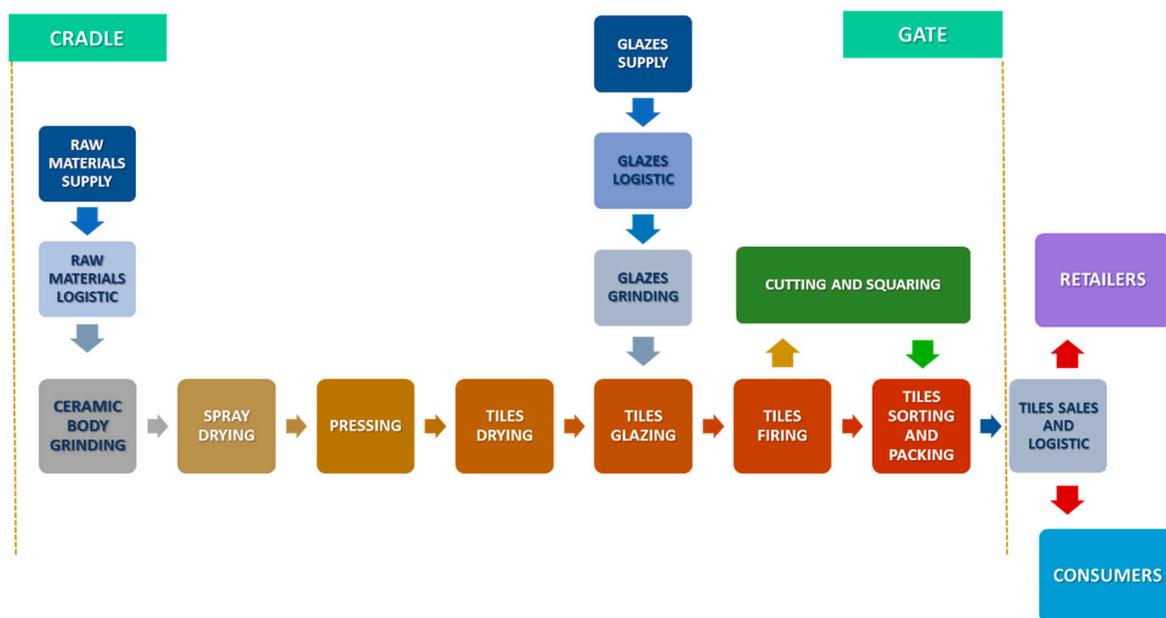


Figure 3. Diagram of the manufacturing process for ceramic tiles.

After firing, the tiles can be subjected to further processing: Cutting, rectifying, polishing, lapping. Polishing consists of the controlled removal of the surface layer by means of special abrasive discs. Lapping is a finishing process consisting in carrying out an abrasion operation that gives the tiles a fairly smooth surface but not completely polished and reflective. Rectification allows to obtain perfectly squared tiles and cutting to obtain complementary formats (smaller) from the basic ones (larger). Gruppo Ceramiche Gresmalt is the company analyzed in this study. It is one of the leading Italian ceramic companies and is located in the district of Sassuolo. In 2017 the company produced 18 million sqm per year of porcelain stoneware tiles, with a consolidated turnover of 180 million euros and an EBITDA of 20%. The Group, which employs over 500 people, has three production units and 75% of its production is sold through three commercial brands for the direct sales channel. The remaining 25% is destined for the large-scale retail market. In this research the study was conducted from the cradle to the gate of the factory, therefore not to the grave, to circumscribe and better discern the problem.

5.3. Building an Industry 4.0 Environment

The transition to a circular economy aimed at integrating sustainability into the company's business, has required a structural change in the traditional manufacturing model. This change was carried out through the digital transformation of the production system in one year of activity (October 2017–October 2018), implementing in the ceramic production process the main enabling technologies of Industry 4.0.

The evolution towards industry 4.0 consists of integrating new production technologies, to improve working conditions and increase productivity and quality. These production technologies create collaboration between the elements characterizing the production, i.e., exchange of information between machinery and plants, in the broadest sense, so not only machines in the production department but also automatic warehouses for feeding the production lines or storage of finished products and any other device that is part of the workflow of value creation. The digital innovation in our case study was based on the Enterprise Resource Planning (ERP) already implemented by the company. The ERP already integrated and governed all business processes, so we intervened on the change of forms of information exchange. The assumption for the change was that from the moment a plant is able to receive and transmit information, it will be relatively easy to use it to equip processes already managed by the information system, even if previously through other forms of data collection. Therefore, the design of the Industry 4.0 environment has focused on the dialogue systems between plants in the different phases of the process to communicate with each other and with the information system, receiving orders, executing them, communicating their progress and communicating data on resource consumption and emissions, as well as useful information to plan production and arrange for appropriate maintenance.

The roadmap for the digitization of the ceramic production process provided for the installation of a network of meters (sensors for the acquisition of factory data capable of measuring consumption and emissions of machines) for each phase of the process (Figure 4). These sensors are intelligent and interconnected, able to collect some process data and communicate with each other without, however, giving significant information on production trends. In order to generate usable knowledge from the collected data, it is necessary to have a series of MES (Manufacturing Execution System) which are software capable of exploiting the data (thanks to inter-functional algorithms) and providing managers with useful information to make the right decisions at the right time. The MES systems translate the data collected and give it meaning, allowing a precise knowledge of what is happening in the factory in real time.

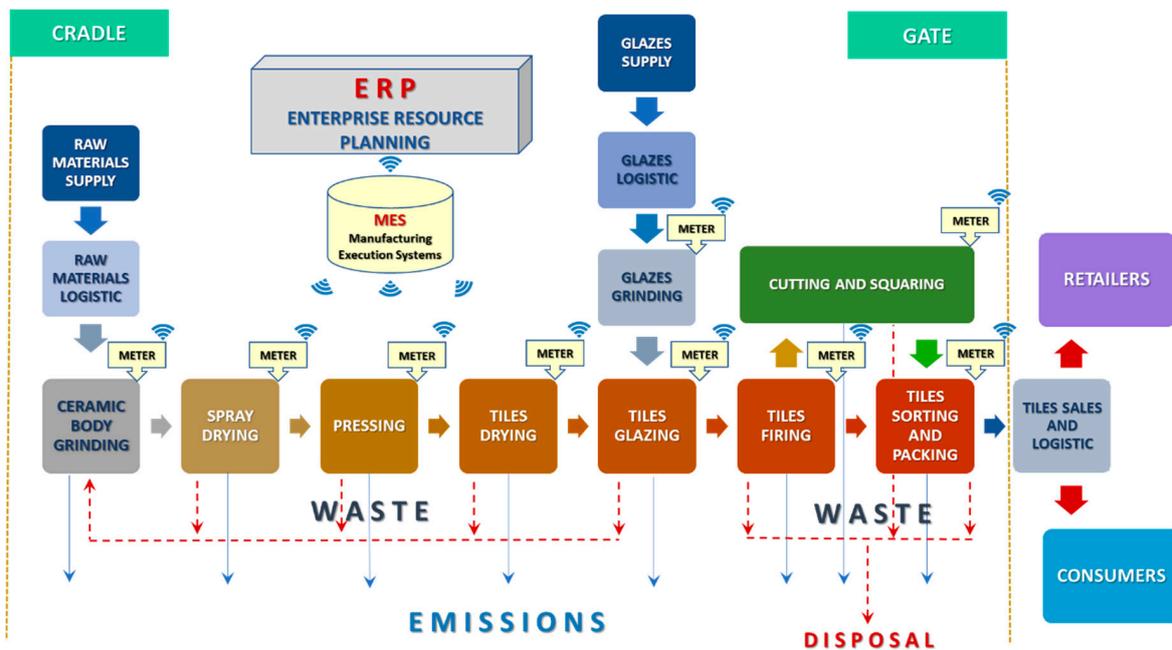


Figure 4. Monitoring of manufacturing data in an IoT environment.

The MES is therefore able to interface the planning system (ERP) with the control systems (Meters) (planning systems) using a WiFi network to support the factory management processes and decision making for top management.

5.4. Sustainability Assessment

Sustainability assessment aims to ensure that the principles of sustainable development are taken into account in manufacturing processes and business strategies. It is a dynamic process of continuous learning that aims to integrate ecological, social and economic aspects. The assessment of the sustainability of the processes of the company under study was conducted through the integration and elaboration of data from different primary sources (Figure 5). The manufacturing data is conveyed to the ERP via the MES network, while the company data is already stored in the database. Therefore, for each business function, the data relating to the processes shown in Table 1 below are available. The ERP therefore has a suitable database to carry out the subsequent technical analysis for environmental (LCA), economic (LCC) and social (S-LCA) impact assessment. The connection between the database and the assessment software is ensured by a business intelligence system that interrogates the ERP by selecting the data for further processing.

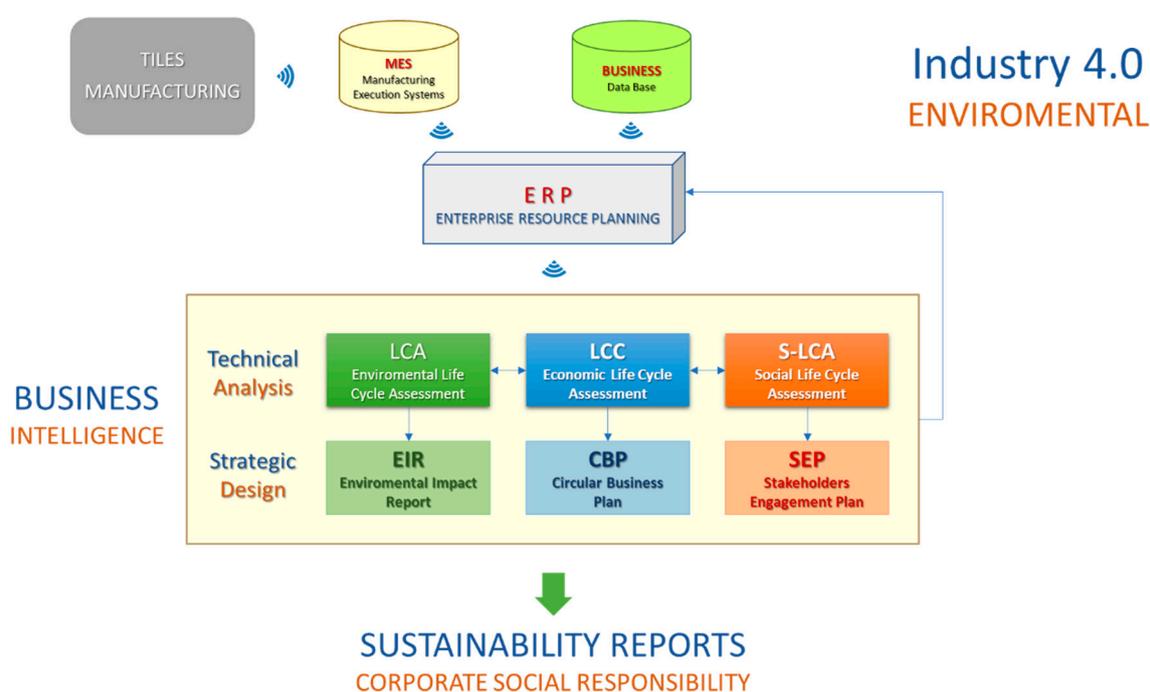


Figure 5. Assessing ceramic manufacturing data in an Industry 4.0 environment.

Table 1. Enterprise Resource Planning (ERP) data integration framework.

SOURCES OF DATA			
Manufacturing	Business Administration	Sourcing and Sales	Logistics and Warehouse
Bill of Materials management	General accounting	Supplier orders	Products anagraphic management
Productivity	Credits and finance	Customer orders	Warehouse movements
Consumption of resources	Planning and control	Sales Force Management	Order to delivery management
Emissions	Human resources	Marketing	BarCode management
Scrap products	Information Technology	Quality Control	Fiscal Valorization

The environmental impact study was carried out with the LCA (Life Cycle Assessment) tool, considering the production process from the cradle to the gate. Since 1997, the LCA methodology has been regulated at the international level by the technical standards of the ISO 14040 series, which

prepared a single reference standard that can be adopted in all countries of the world for environmental management systems.

In 2006 the ISO standards were updated and replaced by: ISO 14040:2006 (framework) and ISO 14044:2006 (requirements and guidelines). As described above, inventory data were collected by monitoring the entire process, from the extraction of raw materials to packaging of the finished product, recording at each stage energy and material consumption and emissions of pollutants into the air, water and soil.

Referring to 1 m² of ceramic tiles produced as a functional unit, the results of the study are shown in Table 2, in comparison with the average data of the Italian ceramic industry determined by an LCA study carried out to prepare the Environmental Product Declaration (EPD) for the ceramic sector (Confindustria Ceramica 2016). The greenhouse effect indicator is calculated by considering, among the substances emitted into the air, those that contribute to the global warming potential of the planet earth. The mass quantity of each substance, calculated over the entire life cycle of the product, is multiplied by a weight coefficient, called the Global Warming Potential (GWP). CO₂ is the reference substance for this indicator. The reduction of the stratospheric ozone layer is calculated as the previous indicator, but with reference to a different coefficient, called the Ozone Depletion Potential (ODP). The substance taken as a reference is, in this case, a chlorine-fluorine-carbide and precisely the CFC-11. The acidification indicator is linked to the emissions into the air of particular acidifying substances, such as nitrogen oxides and sulphur oxides. The reference substance is SO₂ and the weight coefficient is called the Acidification Potential (AP). The eutrophication indicator assesses the effect of increasing the concentration of nutrients in aquatic environments. The substances contributing to eutrophication are phosphorus and nitrogen compounds. The reference substance is phosphate (PO₄) and the weight coefficient is called the Nutrification Potential (NP). Under the name summer smog are grouped all those volatile organic substances that lead to photochemical formation (in the presence of solar radiation) of tropospheric ozone. The characterization factor is called photochemical ozone creation potential (POCP) and the reference substance is ethylene (C₂H₄). The abiotic depletion potential (ADP non-fossil) quantifies the consumption of abiotic resources related to the extraction of materials involved in the production process. The characterization factor is expressed in kg_{Sb-eq} and is a function of the current state of the resource and the extraction rate. The consumption of abiotic resources from fossil fuels is indicated as ADP fossil fuels and expresses the consumption of resources in relation to the lower calorific value (MJ/kg) for each m³ of fuel extracted. The results show that the company's environmental impact indicators are aligned with the values of the district benchmark.

Table 2. Life Cycle Assessment results for 1 m² of ceramic tiles.

ENVIRONMENTAL INDEX	UNIT	COMPANY	BENCHMARK	Δ
Global warming potential	kg CO ₂ -eq.	9.77	10.50	−0.73
Ozone depletion potential	kg CFC11-eq.	6.78 × 10 ^{−10}	6.10 × 10 ^{−10}	6.80 × 10 ^{−11}
Acidification potential	kg SO ₂ -eq.	1.84 × 10 ^{−2}	2.47 × 10 ^{−2}	−0.0063
Eutrophication potential	kg PO ₄ ^{3−} -eq.	1.96 × 10 ^{−3}	2.75 × 10 ^{−3}	−0.0008
Photochemical ozone creation potential	kg etheneeq.	1.40 × 10 ^{−2}	2.37 × 10 ^{−3}	0.01163
Abiotic depletion potential for non-fossil resources	kg Sb-eq.	3.41 × 10 ^{−5}	9.19 × 10 ^{−5}	−6.00 × 10 ^{−5}
Abiotic depletion potential for fossil resources	MJ	145	157	−12

For the evaluation of the economic impact, the Life Cycle Costing (LCC) technique has been used, it is a methodology that allows the evaluation of all the costs that the product generates during its life cycle. In this study we have followed a dual LCC approach. Environmental LCC (E-LCC) which considers the life-cycle costs of a product incurred by the actors involved, including externalities that are expected to be internalized. This analysis is complementary to the LCA analysis. Conventional LCC (C-LCC) is based on a purely economic assessment that considers the costs of the different phases of the life cycle incurred only by the company. External costs or costs not directly incurred by the producer are not considered. For the determination of the E-LCC, the EPS calculation model was used (Martínez et al. 2015), which estimates the economic cost of polluting emissions based on the

willingness to pay (WTP) of the responsible company, to avoid a worsening of the situation created or to remedy a damage caused, attributing an economic value to the damage. The model identifies four main categories of damage: Human Health, Ecosystem Production Capacity, Abiotic Stock Resource, Biodiversity. The results are shown on the left in Table 3, the E-LCC allowed to monetize the negative externalities produced during the life cycle of ceramic production, i.e., the estimation of the possible (indirect) costs of pollutant emissions.

Table 3. Life Cycle Costing (LCC) for 1 m² of ceramic tiles.

ENVIRONMENTAL LCC		CONVENTIONAL LCC	
Human Health	0.15	Raw Materials	1.77
		Electrical Energy	0.34
Ecosystem Production Capacity	0.16	Thermal Energy	0.57
		Consumables	0.75
Abiotic Stock Resource	0.58	Packages	0.28
		Human Resources	1.45
Biodiversity	0.0019	Accessories	1.09
		Amortizations	0.56
TOTAL (€/m ²)	0.89	TOTAL (€/m ²)	6.81

The C-LCC, from a market perspective, has the purpose of determining the costs attributable to the production process always in the framework of cradle-to-gate already followed for LCA. Table 3, on the right, shows the main cost items (costs of resources, consumables and finance), to which is added the cost of labor (human resources) which gives this evaluation a first social value. The sum of the extensions (E-LCC) with the production costs (C-LCC) constitutes the Societal Life Cycle Costing (S-LCC) which includes all the costs associated with the life cycle of a product from an economic and environmental point of view, offering the company the possibility of considering the social costs related to the environmental and economic ones.

For the evaluation of the social impact with the Social Life Cycle Assessment (S-LCA), the focus is shifted from the LCA impact categories to the stakeholders. The aim is to evaluate the consequences of the social relations that are created within the context of the manufacturing of the ceramic product and to understand how the actors involved in the process can influence them (positively or negatively). Therefore, AA1000 (AccountAbility 1000) has been used to design a Stakeholder Engagement strategy. This is a voluntary membership standard developed since 1999 by the International Council of the Institute of Social and Ethical AccountAbility (ISEA), made up of companies, NGOs, universities and consulting firms. It aims to “*improve the responsibility and performance of organizations*” and focuses on the quality of ethical and social commitment to the various business stakeholders (Tschopp and Nastanski 2014). Based on these guidelines, we have designed a model of involvement inspired by the concept of accountability, i.e., the company’s ability to explain the actions for which it is responsible for its stakeholders. Through dialogue with stakeholders, the aim is to direct the company towards the implementation of their expectations, so as to integrate actions in the social, environmental and economic fields into a single and coherent management model (Figure 6). The model is based on three foundations: (1) Accountability is centered around corporate responsibility; (2) this responsibility requires the company to have the ability to learn and innovate effectively on the basis of stakeholder engagement; (3) this engagement is at the heart of all business processes.

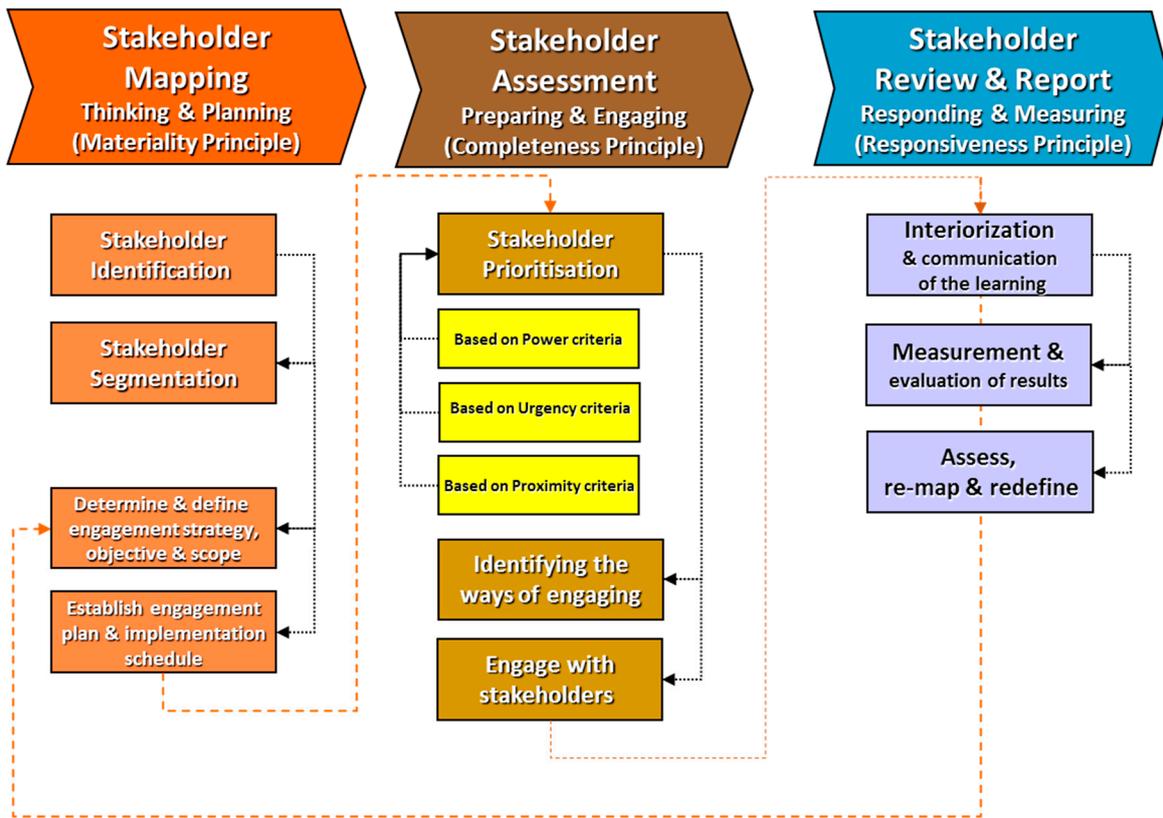


Figure 6. Stakeholder Engagement process phases (own elaboration based on the AA1000 standard).

At the basis of the stakeholder engagement process there is always a strategic reflection on the objectives of stakeholder involvement and on the priority strategic company objectives (Figure 6, left-hand column). In order to design effective stakeholder engagement processes, it is necessary to have a clear understanding of who the relevant stakeholders are (identification) and how and why they should be involved by the organization (segmentation). The company must therefore define and map the most significant stakeholders to achieve its goal. Establishing clear criteria for stakeholder mapping avoids that involvement is guided by non-strategic considerations. Once these cornerstones have been established, the stakeholders are mapped, and the engagement intervention is planned.

This first analysis is aimed at identifying the most significant issues for the company and its stakeholders (Materiality Principle). The next phase of Assessment ((Figure 6, central column). consists of prioritizing the stakeholders on the basis of three criteria, analyzed jointly: (1) Power (Is their power to influence the firm significant or relatively limited?); (2) urgency (What lengths are they prepared to wait, in order to achieve their outcomes?); (3) proximity (Are they closely associated or relatively remote from the firm activities?). Defining the parameters described above, prioritizing stakeholders, is functional to identify and implement the best engagement strategy. This second phase aims to understand what the impact of business activities is and what stakeholders think about it (Completeness Principle). The last phase of the process, “Review and Report” (Figure 6, left-hand column), allows to evaluate the stakeholder engagement initiative and define the main “lesson learned” for the next engagement cycle. It allows the company to monitor and evaluate the overall quality of stakeholder engagement in terms of commitment, process and integration of its integration into the overall strategy of the company. The objective is to continuously improve the process, learning and gathering feedback from its stakeholders and communicating with them on the results that have emerged. This last phase aims to define actions to provide adequate responses to stakeholders (Responsiveness Principle).

Therefore, using the Stakeholder Engagement Model described above and in line with the guidelines proposed by the Unep/Setac study group (Arcese et al. 2018) to identify the main stakeholders, the main categories and sub-categories of stakeholders related to the ceramic supply chain have been identified (Figure 7).

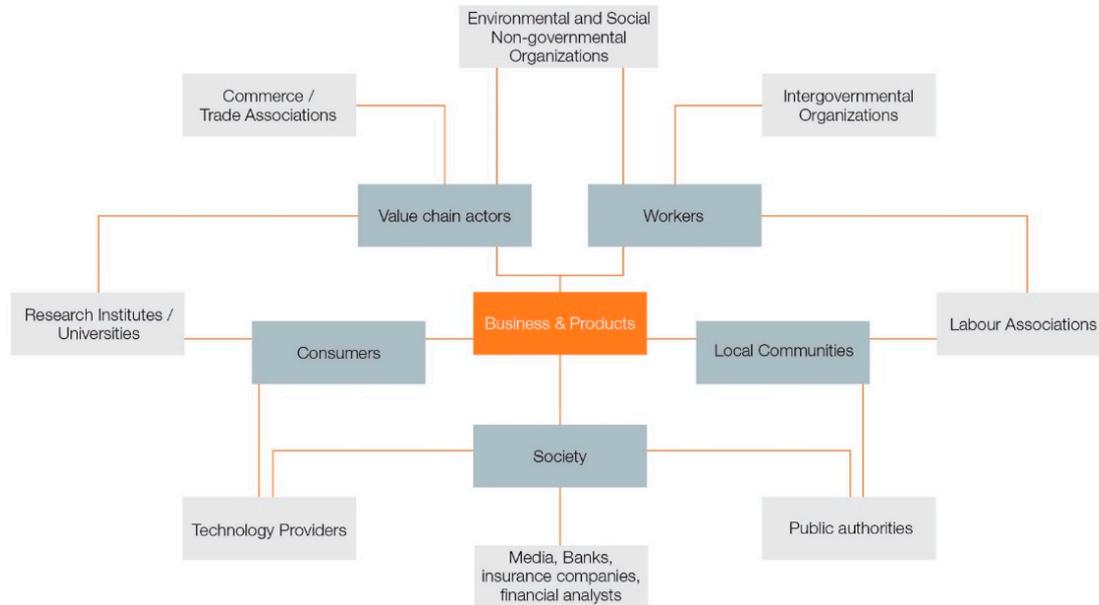


Figure 7. Stakeholder categories and sub-categories of the ceramic supply chain.

Figure 7 shows the identification of the main stakeholder categories in the dark grey boxes, and the segmentation into subcategories in the light grey boxes. Following the pattern of the Figure 6 model, the prioritization of the subcategories of stakeholders is shown in Table 4.

Table 4. Prioritization of stakeholders in a ceramic firm.

STAKEHOLDERS	Power Criterion	Urgency Criteria	Proximity Criteria	Total Prioritization Index	Prioritization order
Private Business	9	9	9	26	1
Staff Personnel	6	8	9	23	2
Trade Unions	7	8	8	22	3
Local Public Institutions	9	6	6	22	4
Environment	5	7	4	16	5
Suppliers	5	4	6	15	6
Trade Channel Operators	4	5	5	14	7
Public and Private Organization	4	4	4	12	8
Partners	4	3	4	11	9
Competitors	5	3	3	11	10
Media	4	3	4	10	11
Final Consumer	3	4	3	10	12

For each criterion (power, urgency and proximity) an index has been attributed to each stakeholder and the sum of these provides a total index of prioritization. In the table, the stakeholders are listed by order of importance: From the first to the twelfth.

5.5. Business Model Innovation

The sustainability analysis described above has made it possible to collect all the elements needed for strategic planning aimed at innovating the business model, moving from the traditional linear to the circular scheme. Therefore, if the business model is defined as the union of its three main pillars: Creation, distribution and capture of value (Massa et al. 2017), innovation can only be the implementation of a change to one or all three dimensions, to create something new or better. In our study, the innovative element, compared to the current model, will be the implementation of elements related to environmental, economic and social sustainability. To describe and illustrate the business model of the company under study, we have used the Business Model Canvas (BMC) tool, which is a scheme within which the company explains how it intends to address the nine fundamental aspects of its business (Joyce and Paquin 2016): Customer Segments; Value Propositions (the value of products or services offered for each segment); Channels (the channels through which to reach the customer); Customer Relationships (the relationships that are established with the customer); Revenue Streams (the revenues generated); Key Resources (the key resources of the company); Key Activities; (the key activities to make the business model effective) Key Partnerships (the key partners with whom the company intends to ally itself in order to create value for the customer); Cost Structure (the cost structure for resources, activities and key partners).

Figure 8 shows, using the BMC, the scheme of the current Business Model of the ceramic company involved in this research. It is obviously a linear model (take-make-dispose), which through the nine basic elements provides the set of organizational and strategic solutions that allow the company to create, distribute and acquire value. The Key Resources for the functioning of the business are identified in the ceramic supply chain both in terms of goods (raw materials, machinery) and services (technological and financial). The activities are linked to the manufacture of ceramic tiles (design, production, logistics, marketing and sales, planning and control). For the operational activities, the company has three manufacturing units, five logistics warehouses, IT infrastructure, know-how, human and financial capital. The operational activities correspond to a cost structure, due to manufacturing, research and development, commercial and administrative and financial costs. The Value Proposition consists of the realistic promise to offer the market collections of porcelain stoneware tiles, manufactured in Italy and with the best value for money. These collections are placed on the market through three channels (large-scale retailers, independent distributors and specialist shops) through a widespread sales network that ensures a direct relationship with distributors, also ensuring the provision of ancillary services to the product that creates value. The market segments are four: Residential customers, business customers, commercial and public buildings. The revenue streams derived from the proceeds that the company obtains from the sale of ceramic tiles to the different customer segments.

Moving from a linear to a circular business model may seem easy in theory, but it proves complex in practical application, and many different paths can be taken. In this study, to manage the transition between the two models, we focused on stakeholders to broaden the ways of creating value by also taking into account the environmental, economic and social benefits. Recently Accenture (Lacy and Rutqvist 2016) proposed five types of CBM: (i) Circular Supply-Chain (search for innovative renewable, recyclable resources that can be used in consecutive life cycles); (ii) Recovery and Recycling (recovery of waste and by-products from a production process); (iii) Product Life-Extension (maintenance, updating and repair of the products); (iv) Sharing Platform (renting, sharing and exchanging non-utilized goods); (v) Product as a Service (combining a physical product with a service component).

CIRCULAR BUSINESS MODEL				
KEY PARTNERSHIPS	KEY ACTIVITIES	VALUE PROPOSITION	CUSTOMER RELATIONSHIPS	CUSTOMER SEGMENTS
Raw material suppliers	Ceramic tile designs	Provide collections of porcelain stoneware tiles totally made in Italy and with the best value for money.	Extensive sales network	Residential customers
Suppliers of glazes and inks	Manufacturing of ceramic tiles		1to1 interaction with distributors	Commercial buildings
Plant and machinery suppliers	Marketing and sales	Apply eco-design techniques to the development of new products, using ecofriendly and resource saving raw materials.	Offer of ancillary services to the product	Public buildings
Suppliers of electricity	Facilities operations & maintenance		On-demand product development	Business customer
Suppliers of methane	Sourcing			Green consumers
Packaging suppliers	Logistics planning			
Suppliers of chemical additives	Management Accounting & Control	Develop innovative solutions for our manufacturing processes for sustainable growth while respecting people and the environment around us.		
IT Solution Providers				
Financial services providers				
KEY STAKEHOLDERS	KEY RESOURCES		DISTRIBUTION CHANNELS	
Private business	Three manufacturing units		Large-scale retailers	
Trade channel operators	Five logistics warehouses		Independent distributors	
Suppliers	IT Infrastructure		Specialized stores	
Staff person	Human capital		Cloud based interactive multi-channel	
Final consumers	Operational know-how			
Competitors	Financial assets			
Public Institutions	Energy-efficient manufacturing system			
Environment	Resource-efficient manufacturing system			
Partners				
Trade unions				
Public and private organizations				
Media				
COSTS STRUCTURE		REVENUE STREAM		
Manufacturing costs		Volume of sales		
Commercial costs		Value recovered from the use of recyclable materials		
Research & development costs				
General and administrative costs				
Financing cost				
Environmental costs (externalities)				
Social costs				

Figure 9. Representation of the new Circular Business Model inspired by Business Model Canvas.

6. Discussion of the Results

The conceptual model designed to support the integration of sustainability into the business model of a manufacturing company within a ceramic district has highlighted important strategic and operational relationships, which were then verified thanks to the case study. The territory, as a characterizing component of an industrial district, represents a factor of competitiveness that is expressed both at a mesoeconomic level (the district) and at a microeconomic level (the enterprise). Therefore, the improvement of the competitiveness of the local system is reflected in the single enterprises that compose it and, vice versa, the success of the enterprises contributes to the success of the district. In accordance with Proposition 4 (P4)⁷ it was observed that in the Italian ceramic district, the collaboration between players in the supply chain, as well as the stimulus to compete outside the district on global markets, has led to the development of good practices of environmental sustainability that have been reflected in environmental performance indicators and that have encouraged the development of regulations taken as a model also from other countries. In this context, a further improvement in sustainability performance is objectively favoured compared to other industrial realities. Proposition 5 (P5)⁸ was also verified, because the analysis of the sector sustainability Benchmark with those of the case study, showed a total alignment of values, showing that the “behavior” of the district stimulates individual companies to increasingly virtuous behavior and companies contribute to the excellence of the district. Moving from the “meso” level of the district to the “micro” level of the case study, it was observed that it is possible to go beyond just environmental sustainability, expanding the strategic outlook to the business model and market expectations. In this perspective, corroborating the statements in Proposition 1 (P1)⁹, sustainability becomes a factor of competitive advantage because it induces the company to reformulate its value proposition

⁷ P4: Industrial districts are the mesoeconomic spaces in which the adoption of the principles of sustainability is favored by the cooperation and interdependence between the district economic agents at the microeconomic level.

⁸ P5: The improvement of the competitive position of the district, due to the effect of the realization of sustainability, is positively reflected on the firms in the territory.

⁹ P1: Strategies aimed at integrating sustainability into business, as well as improving environmental conditions and social cohesion, become a competitive advantage for the companies that implement it.

by expanding the possibilities of development of new market segments composed of consumers, increasingly sensitive to environmental evolution.

In a district, the supply chain is already inter-connected because of the interdependent relationships (often informal) existing between economic agents. In this chain, therefore, a fertile ground is developed for the diffusion of the Industry 4.0 environment and for the digitalization of the entire system. Confirming Proposition 6 (P6)¹⁰, it was observed that collaboration between companies in the district to promote process and product innovation also encourages the development of good environmental and socio-economic practices that can be quantified through the tools of Life Cycle Thinking (LCA, LCC, S-LCA). Therefore, consistent with Proposition 3 (P3)¹¹, we can identify two important assets that can help district companies to implement sustainability strategies in their business models: One of a social character (the territory) and the other of a technological character (the Industry 4.0 environment, IoT technologies and impact assessment tools).

The mapping of the manufacturing process of ceramic tiles, has highlighted the complexity of this manufacturing system that can be seen as a set of many sub-processes (and separate phases), each of which uses resources and produces processing waste and emissions. IoT technologies and the Industry 4.0 paradigm have provided support to collect, store and process all manufacturing data, overcoming the objective difficulties in managing data in this industrial system. ERP and business intelligence software were integrated with the environmental (LCA), economic (LCC) and social (S-LCA) impact assessment tools for the first technical analysis aimed at the subsequent strategic design oriented to the innovation of the business model towards sustainability, confirming when asserted in Proposition 7 (P7)¹².

The environmental sustainability analysis showed that the company under study has environmental performances comparable with the district averages, confirming the theoretical hypotheses that saw a synergic relationship between company results (at the micro level) and the district systemic results (at the meso level). The life cycle costing with its environmental and conventional components made it possible to determine both the value of the externalities associated with the production of 1 m² of ceramic tiles and the industrial costs. Summing up the two values obtained, one of the social components of the manufacturing process arises. Finally, the social sustainability analysis identified the key stakeholders related to the company's business in order to design appropriate strategies for their engagement, confirming when stated in Proposition 2 (P2)¹³.

The easy availability of production data for evaluation, thanks to the IoT technologies of process sustainability, together with the Canvans Business Model, has made it possible to define the current linear business model and to design a new circular business model that allows the integration within the company of the principles of environmental, social and economic sustainability.

7. Conclusions

In recent years, both society and business have become aware that in order to stimulate economic development it is necessary to use methods that look simultaneously at the technological aspect, the increase in productivity and the reduction of resource consumption. From this point of view, there are two closely related trends, which the manufacturing world, especially in its most advanced segments, is beginning to understand and appreciate: Innovation based on digital technologies and the transition to the circular economy. While digital innovation aims to increase productivity, develop new

¹⁰ P6: Life Cycle Thinking (LCT) is a strategic approach that aims to consider environmental and socio-economic impacts as decisional variables in the planning and definition of business strategies.

¹¹ P3: The Industry 4.0 paradigm and the technologies of the Internet of Things are able to stimulate the transition from a linear to a circular business model.

¹² P7: Life cycle methodologies (LCA, LCC and S-LCA) are operational tools aimed essentially at assessing and quantifying environmental, economic and social impacts.

¹³ P2: The business transformation introduced with Industry 4.0 favors convergence between business and technology in new production models, promoting a sustainable evolution of human existence in its social, environmental and economic dimensions.

products-services and establish new connections between manufacturers and customers, the circular economy makes it possible to reduce production costs, ensuring the sustainability of production processes and encouraging the development of new products, more in line with the environmental sensitivity of the new generations.

In this study it was verified that the circular economy is a possible economic model that goes beyond the mere business perimeters and that implies profound changes in the process, important not only within the companies that want to equip themselves with this model, but also in the relations between the actors of the chain: The stakeholders. Moreover, in an industrial district, circularity, from the microeconomic level of the enterprise, is also able to affect the mesoeconomic level (systemic) and consequently the macroeconomic level and therefore, due to its leverage effect, can be even more effective. In these terms, the circular economy represents a new frontier for sustainability and therefore for Corporate Social Responsibility. The responsible behavior that a company shows towards its stakeholders shifts the attention from a product-oriented production and consumption model to a solution-oriented model. A proactive approach to sustainability must go beyond mere compliance with environmental regulations and try to change processes and vision, rebuilding from scratch the foundations on which the company rests, for example through business model innovation, in order to integrate innovation and sustainability as a strategic choice of competitiveness. Therefore the efforts to build sustainable development give companies a new ethical role: To create new values in addition to economic growth.

Integrating sustainability into corporate values and transforming it into a competitive advantage is also an objective aimed at by the European Union with Directive 2014/95/EU, which requires large companies Public Interest Entities (e.g., listed companies) to file, together with the financial statements, a non-financial statement to illustrate the actions taken in relation to the environment, personnel, social impact, human rights, and in the fight against corruption. In order to produce this type of report, innovative tools and methodologies, as Life Cycle Thinking tools, are needed to measure the sustainability of companies through economic, environmental and social performance indicators that can also be extended to the entire value chain. In this direction a particular role is played by innovation and new technologies, as Industry 4.0 and IoT, to monitor in real time operational flows and performance, and thus improve the quality of managerial decisions by combining the need for competitiveness with respect for the principles of Corporate Social Responsibility.

This research has also raised the question of the relationship between innovation and sustainability: Does sustainability need innovation or does innovation need sustainability, its values and methodologies? With a traditional approach, the end result of the innovation process usually determines the production of products that respond to market needs. A sustainable approach, on the other hand, offers solutions (given by the integration of the product with the auxiliary services) able to respond to the needs of customers in a satisfactory manner but using fewer resources with a lower environmental and socio-economic impact. Therefore, the introduction of sustainability values in business strategies determines a greater propensity to innovation in business models. Therefore, technological innovation is accompanied by organizational innovation, a change that has positive effects on competitiveness. However, innovation becomes sustainable only if environmental criteria are applied to the entire life cycle of products: The entire company structure must therefore be involved in the different phases: From design to the production process, from logistics to marketing. This requires the extension of the boundaries of the system analyzed from "cradle-to-gate" to "cradle to grave", and possibly "cradle to cradle" in a perspective of complete circularity.

The theoretical development and case study have also shown that the circular economy can be seen today, in the current state of scientific knowledge, as an economic model capable of responding to the now obvious unsustainability of the linear economy. In fact, this current traditional model does not take into consideration pollution, the exhaustibility of natural resources and the conversion rate of inputs into outputs, so it is not able to ensure the sustainable development of the planet in the medium to long term. Circularity as an economic model can be applied at different levels: At a microeconomic

level in individual consumer behavior and in business strategies; at a mesoeconomic level in business networks, clusters, districts, industrial chains, and territories; at a macroeconomic level in economic, industrial and social policies. This shows that the circular economy can only be effective with a holistic and systemic approach, that is, every economic agent (individual, company, public institution) must adopt a virtuous approach to sustainability issues and this virtuousness must extend to the entire life cycle of the product, passing from the linear perspective (cradle-to-grave) to the circular one (cradle-to-cradle). To make this transition effective for companies, both at the level of operations and business, there is no other way to innovate the business model because it is the most appropriate tool to understand how to create, distribute and collect value, and to define a set of strategies with which the company wants to gain competitive advantage. On the contrary, if sustainability were seen only from the side of operations, therefore mainly associated with environmental issues, the opportunity to increase profitability and profits of the company would be lost. In this case, good practices of (environmental) sustainability would be translated into a mere cost, placing the question of the trade-off between economy and sustainability.

Another innovative element that emerged from this study was the need to integrate knowledge, expertise and methods from apparently distant scientific and cultural worlds. Just as technological innovation requires the contribution of sustainability and vice versa, chemistry, physics and engineering require the contribution of social sciences. In a perspective of sustainable development, they cannot do without each other, as was demonstrated in this study, which was based on the contamination of science in an attempt to respond fully to the research question posed in paragraph 3.

This research has also highlighted some of the critical issues that we set out below:

- Not everything that is potentially technically recyclable is environmentally friendly, economically and socially sustainable.
- The approach to circularity is ineffective if the reusing, recycling and recovery mechanisms are not able to reabsorb the product at the end of its life efficiently.
- The Circular Economy is not an economic model that necessarily needs to be adopted in order to declare sustainable the industrial activities.
- On the contrary, the adoption of (few, but rigorous) good practices aimed at environmental, economic and social sustainability may prevent the circular economy from being relegated to a temporary phenomenon.

Beyond the sometimes-emphatic definitions of the circular economy, in our opinion a balanced approach is more correct, with the intelligent use of resources as the basic philosophy of circularity. This may also mean that sometimes, under certain environmental and socio-economic conditions, recycling and reuse is not the most sustainable way forward. This assessment can only be conducted with a rigorous scientific method to understand the real effects of each industrial operation and/or business strategy. Life Cycle Thinking tools are an indispensable support to be aware, at the same time, of the three dimensions of sustainability: Environment, economy, and society.

Finally, it is necessary to underline the limits of this study, first of all its foundation on a single case study, even if it is representative of the ceramic sector. Secondly, the sustainability analysis will have to be extended outside the company's gates to cover that part of the downstream supply chain (distribution). Finally, it will be necessary to verify the effectiveness of the new circular business model and how this has improved the competitiveness of the company over time after its implementation. All these issues will be the subject of future research already planned.

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