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A Hazardous Materials Treatment Business Modelling in the Industry 4.0 Perspective

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Abstract

The today's world is marked by a massive diffusion of Industry 4.0 concept and, therefore, the quick change of business models implemented in this new scenario. In the systems of circular economy, designed to regenerate themselves, the products maintain their value added for a long period of time producing no waste. After a product's life cycle is over, the resources remain inside the economic system, and they can be reused for production goals creating new value. This paper develops a proposal aimed to understand the systemic capacity in triggering a closed loop circle for hazardous wastes also in the light of the potentialities offered by the achievements of Industry 4.0 through an industrial system of "glass ceramization" and the realization of tiles of inert material used in the market of public decoration or construction. In such a way, industrial waste management systems find a lever in driving force of the economy and innovation. This paper aims to understand how the Industry 4.0 contributes valorizes hazardous waste through the process of glass ceramization.

Keywords: Industry 4.0; circular economy; hazardous waste; glass ceramization; business model

1. Introduction

Different research reported in the scientific literature (Deubenera et al., 2018; Khanna et al., 2021) show the feasibility of wastes in ceramic matrices. However, a fully industrial implementation is hampered under different viewpoints including costs and a general social rejection. Rules and regulations have made waste recycling more and more relevant and problematic especially for hazardous waste. For example, manufacturing plants, especially those producing hazardous wastes, expenses linked to waste production have drastically increased over the last decades.

Within a dimension of valorization of wastes, the systems of circular economy, intended to regenerate themselves, the products retain their value added for as long as possible and with no waste. When a product reaches the end of its lifecycle (Ellen MacArthur Foundation, 2017; Prieto-Sandoval et al., 2018; Homrich et al., 2018) the resources remain within the economic system, so they can be reused a number of times for production purposes and thus create new value. From this perspective, the Italian regions show big gaps in terms of implementation of both the recovery processes and treatment processes and, therefore, different entrepreneurial tissues emerge in connection with the recycling industry (Masi et al., 2016).

The circular economy is not a new concept. To advance from a predominantly linear to a basically circular economy (Korhonen et al., 2018; Ghisellini et al., 2016; Millar et. al, 2019), changes must be introduced to the value chains, from product design to market and enterprise models, from methods of waste processing into resources to modes of consumption: this entails a real systemic change and a great innovative boost, in terms of not just technology, but also the organization of the company, the funding methods, and policies. Even in a strongly circular economy there remains some element of linearity since it doesn't stop the demand for virgin resources and produces waste residues to be disposed of. It is vital to provide the population with skills suitable to ensure a successful transition to employment generations.

It is an approach to economic development designed to benefit businesses, society, and the environment.

The stabilization of inorganic waste of various nature and origin, in glasses, has been a key strategy for environmental protection for the last decades.

Products derived from the glass ceramization have the capacity to retain many inorganic contaminants permanently, but it must be acknowledged that some criticism remains, with regard of the process costs and energy use.

Within the general approach to a more circular and resources-efficient economy conditions can be studied in order to address the potential opportunity given by the field of the process treatment of wastes.

Industry 4.0 makes it possible to build connectivity between technology and resources and skills in the context of sustainability benefits (zero impact—reduced economic cost—social equity) and can minimize the ecological effect of a product, a service, or a process based on the availability of footprint evidence and a traceable analysis (Ejsmont et al., 2020; Kumar et al., 2020). Besides, it helps to promote the efficiency of functions, for instance, reduction in the consumption of resources.

Consequently, Industry 4.0 may make a sustainability-related contribution to the development of digital sustainable operations making it possible to meet SDGs goals. Furthermore, the constant enhancement of smart technologies is seen as affecting sustainability. Yet the prospects of Industry 4.0 exist with its unknown effect on other areas like socio-environmental sustainability or creating opportunities for the implementation of Industry 4.0 by means of intelligent systems.

The paper continues as follows. After the first section focuses on aim and research questions, on contributions to the implementation of the sustainable development strategy and on a literature review so as to map the mainstream approaches in the field of circular economy and sustainable development with major emphasis onto new business models, the second section references the evidence from the industry. The third section is dedicated to explorative study followed by discussion. In the last section, there are the conclusions of the paper.

1.1 Aim and Research Questions

Despite producing benefits, Industry 4.0 requires a close analysis of these concerns as well. Both concerns and benefits could be in a clear way demonstrated in the triple bottom line settings: economic, environmental and social ones.

On the other side the advantages of glass ceramization are somewhat compensated by significant drawbacks, such as the high cost of plants and the energy consumption. The overall sustainability of the process is quite disputable, if the economic advantage relies only on avoided disposal costs (Rincón et al., 2016).

Accordingly, there arises a general question of how Industry 4.0 really influences sustainability in view of pros and cons. Among many already analyzed challenges and possibilities there are the comprehension of the Sustainable Development Goals and translation thereof into unified indicators/targets across industries from the perspective of certain functions. It requires setting regulatory values followed by threshold levels for material or energy consumption, etc. (Sikora et al., 2014).

This paper aims to analyze the dimension of the systemic capacity in triggering a closed loop circle for hazardous wastes. Specifically, by deepening the process of optimizing of the process of treatment and recycling of special and hazardous waste enforced by the potentialities offered by the achievements of Industry 4.0 through an industrial system of "glass ceramization" and the realization of tiles of inert material used in the market of public decoration or construction. In such a way, our industrial waste management systems could become a driving force of the economy and innovation.

Our research interest draws towards understanding those situated processes that are co-producing knowledge about valorization of wastes that is one of the basis of the circular economy business model approach. Specifically: the first question is how the Industry 4.0 contributes valorizes hazardous waste through the process of glass ceramization, the second question regards the analysis of a possible theoretical approach based on the enterprise architecture concept towards the creation of new circular business models in the field of glass ceramization.

1.2 Industry 4.0: Contributions to the Implementation of the Sustainable Development Strategy (Conceptual Framework)

As a contributor to the SDGs (which stands for Sustainable Development Goals), Industry 4.0 establishes a tight link between the production world and sustainability by way of building a notable relation between their elements.

Hence, the main attempts are focused on the instruments and techniques utilized in the all-embracing analysis of these terms. A lot of research or state-of-the-art reviews have been already accomplished by the academicians, particularl ceramiy as far as the sustainability and the Industry 4.0 phenomena is concerned.

Sustainable development is a challenge that can be won by creating a synergy between the circular economy and Industry 4.0 concepts. Several studies state that a synergy between the Circular Economy and Industry 4.0

concepts will be achieved by the more active usage of the Industry 4.0 technologies (Piccarozzi et al., 2023; Pinheiro et al., 2022; Jamwal et al., 2021, Jabbour et al., 2020). Thanks to the circular economy, companies have the opportunity to redesign their way of innovating and competing, playing an active and strategic role in the reengineering of processes and supply chains. This leads, as a consequence, to a more efficient management of resources, with the contribution of the technologies introduced by Industry 4.0, which become a tool for knowledge and monitoring in the use of resources and products (Geissdoerfer et al., 2017; VanWynsberghe et al., 2007).

The application of Industry 4.0 technologies shows promising opportunities in improving the management and efficiency in view of solid waste management (Cheah et al., 2022; Nascimento et al., 2019; Farzana et al., 2020, Saha et al., 2017, Berg et al., 2021). Machine learning, artificial intelligence and image recognition can be used to automate the segregation of waste, reducing the risk of exposing labour workers to harmful waste.

Industry 4.0 technologies can play an enabling role by providing the necessary information to unlock the potential of specific circular strategies. High value recycling of wastes requires not only specific information on parameters of material composition but also market-related information such as availability and supply, which are important for new business models based on the circular approach which require detailed knowledge of use patterns to enable logistics, design and distribution. Some instances of refuse can be enabled by virtual services, such as simulations, rather than material offers, but in order to gain this knowledge on the processes concerned, they have to be based on the new technological basis.

Remanufacturing of a product requires data on, for example, abrasion, use time, prior maintenance, etc. so that informed decisions on replacements and further utilization can be made. In the hazardous waste management the complex, multi-stage and globally distributed production processes make tracing the flow from raw materials to a final product a challenging task. From a sustainability perspective, the lack of transparency poses serious problems for social and environmental compliance in particular. Industry 4.0 technologies also generate indirect environmental, social and economic benefits by increasing traceability within supply chains through enhanced transparency of the end-to-end production flow by tracking the raw material path. Compliance with social and environmental standards is also better observable and controllable (Berg et al., 2021).

A methodical bibliography analysis of Industry 4.0 resulting in the simulating of links between sustainability functions and Industry 4.0 was demonstrated and a new trend of Sustainable Industry 4.0 was suggested in (Geissdoerfer et al., 2017). The United Nations SDG for 2030 stipulate that technological progress is a challenge to transit from traditional technological approach to artificial intelligence based mechanisms without restraining the sustainability of the industrial economy.

By the looks of it, Industry 4.0 has been progressing in many industries where the holistic paradigm is considered. For this reason, more emphasis on a separate research of the link between Industry 4.0 and sustainability and the benefits from their consolidation in the corresponding domains is required.

Beyond that, added value may be secured due to the use of different sustainability evaluation tools taking shape in an advanced technological framework.

From the other side, smart technologies still continue to evolve resulting in huge environmental burdens. Primarily, the traditional methods used to measure the harmful effect cannot evaluate such impact. Second, assessment of Industry 4.0 in facilitating the sustainability support is still missing. For this reason a research difference between the sustainability assessment field and technologies typical for a particular sector is evident. New prospects for reinforcing this research avenue are expected in simulating the decision making apparatus.

2. Material and Methods

The study approach entails the study of different scientific sources so as to answer research question of listed before. It is structured as follows: it begins with a literature review so as to map the mainstream approaches in the field of Circular Economy and Sustainable Development with major emphasis onto new business models highlighting the linkage to the secondary products as the vitrificated ceramic. Specifically, the literature review seeks to document as to how the definition of theory on new circular models can be applied to links to the Industry 4.0 in the field of sustainable development, in general, and waste management, in particular.

After that, on the base of the analysis of the European statistical data on the topic of hazardous wastes treatment reports we highlight the fixed relation and importance of this topic inside the Circular Economy concept (Bernardo et al., 2020) in relation to the capacity in generating volumes from hazardous wastes of the necessary flow of raw materials so as to trigger a secondary industry of glass ceramization.

The exploratory case analyzed according to Yin (2003) describes in the last part of the contribution presents a practical realization of a new business model on the field of Circular Economy. It answers to the need to deepen the conditions are necessary for the realization of a new sustainable business model in the field of waste treatment through an industrial system of glass ceramization aimed at valorising hazardous materials.

About the boundedness (VanWynsberghe et al., 2007) of the study any vitrification approach should be evaluated in the light of a complex economic balance including aspects related to the added value of the reuse of the vitrified product, the energy production and the recovery of metals together improve the commercial viability of the process.

2.1 New Business Models

Hazardous waste disposal is a challenge for many businesses and industries. Almost every size of industry, and some commercial enterprises, generate hazardous waste. The need for efficient hazardous waste management and disposal is important in order to minimize the risks to lives and the environment. The recycling is best way to manage hazardous waste to minimize the amount of hazardous waste.

In fact, for a sustainable development future, in the field of waste/resources management, we need to embrace the vision of a circular economy. In order to close the loop, it is essential to reuse products and to recycle materials (European Commission 2020).

The goal of circular economy consists in both increasing life cycle of different types of materials and waste and facilitating their reuse by treating them as manageable resources. Circular economy is not limited to waste management only but starts with development and production of the product, its consumption or its use as a secondary material, generating new business models. The industrial system of glass ceramization being a manifestation of Circular Economy has the enormous potential in contributing to the Sustainable Development Goals achievement, especially SDG 9 “Industry, innovation and infrastructure” and SDG 12 “Responsible consumption and production”.

With the circular economy the development model is based on the company’s using of waste, which becomes raw material. In this context, technology would allow the company not only to improve production processes, but also to enforce their sustainability. Thanks to the technological innovation it is in fact possible to minimize the use of energy, water and raw materials, reduce polluting emissions, better organize the end of life of the product. Industry 4.0 is not the introduction of a new technology, but a change that will profoundly revolutionize the corporate business model.

The disclosed a set of regulatory principles of business conducting that collectively create a sort of “perfect” business model oriented on sustainability (Stubbs et al., 2008). These researchers were the first in the field of case-based theory building for sustainability-focused business models, with Interface Inc. and Bendigo Bank as examples of sustainability-driven business entities. Their ideal type was composed of a number of cultural and structural features of an organization, such as promoting community culture, values and spirit, investing in employees’ loyalty and confidence, and participation in sustainability evaluating and reporting. Propositions about sustainability-oriented business models were also elaborated considering an organization’s goals and purpose, its approach focused on performance assessment, the need to take all stakeholders into consideration, how environmental aspects should be dealt with, whether the top managers in the organization initiate the important social, social and structure-related changes for sustainability implementation purposes, and whether both a system-level and a firm-level perspective should be used (Schaltegger et al., 2016; Osterwalder, Pigneur, 2009).

On all levels of an enterprise (generally, business, organizational, informational and technological ones which reflect an architectural approach to enterprise engineering) (Fici et al., 2019; Malyzhenkov et al., 2018) the sustainable development vision has produced new trends, with sustainability management among them. Sustainability management positions itself as a set of approaches that have to do with social, economic, and environmental issues in a complex manner in order to transform organizations so that they facilitate the sustainable development of the economy and the society, within the framework of the ecosystem (Martín et al., 2018). Nowadays, leaders, managers and businessmen face a challenge of contributing to sustainable development on the personal, company-wide, and social levels.

Hence, academicians and practitioners are constantly conducting research aimed to the problem if modified and completely new business models can help maintain, or even improve, economic prosperity, by either drastically reducing negative or creating positive external effects for the natural environment and society. This perspective applies to not only currently existing organizations and to the transformations of their business models. Different approaches to conceptualizing business models have been shaped based on business model research, but a general one includes recognition of and laying emphasis on its value creation function. Sustainability managements research is of a similar cross-disciplinary nature. In this context, the business model constitutes an excellent analysis unit to examine and advance the common approaches utilized by managers and entrepreneurs, as well as to prompt and revitalize old and modern business philosophies.

Accordingly, the business model concept is popular for more than one reason: it inspires new approaches in the areas of sustainable entrepreneurship and corporate sustainability management, and, at the same time, its traditional interpretation substantiates the business paradigm of egocentric value creation. Here, sustainability researchers and practitioners are invited to propose attractive and sound alternatives.

The transition to a more active business application of Circular Economy and Sustainable Development concepts has become a key issue for government and business. It is currently being promoted by the European Union (Circular Economy Package) (European Commission, 2019) as a material and energy model falls in with the definition delivered by many authors and envisaging that Industrial Symbiosis (IS) has been considered a main strategy to support the development of the European Commission (Domenech et al., 2019; Neves et al., 2019). The consumption of secondary materials is very important for a successful transformation from a linear economy to a EC oriented toward IS practices. Small and medium enterprises (SMEs) play in this scenario a crucial role as stakeholders in the development of CE systems, because it is impossible to build this model in relation to each company operating in isolation (Bassi 2019).

The circular economy constitutes an important challenge for the economic system because it requires carrying out activities and production and consumption processes that are sustainable and able to manage them in an aware and efficient way. In this transition, scholars have increasingly highlighted how economic growth can be combined with sustainable development from both an environmental and social points of view.

The concept of Circular Economy (CE) can be summarized as a paradigm shift aimed to prevent the depletion of resources by eliminating loops in energy and materials throughout its various implementation levels: micro (enterprises and consumers), meso (economic agents integrated into the symbiosis) and macro (city, regions and governments).

The value proposition must secure both ecological or social and economic value through offering products and services. The business infrastructure must be based on the principles of sustainable supply chain management, the customer interface must make it possible to build close relationships with customers and other stakeholders in order to assume responsibility for production and consumption systems (instead of simply "selling stuff"), and the financial model should provide for the distribution of economic costs and benefits equitably among the parties involved (Breuer et al., 2014; Saavedra et. al, 2018).

Based on the current references and on what was learned from the authors of advanced scientific editors, the following definition of a business model for sustainability could be proposed: a business model for sustainability helps with describing, analyzing, managing, and communicating (i) a company's sustainable value proposition to its customers, and all other stakeholders, (ii) how it creates and delivers this value, (iii) and how it gains economic value while maintaining or regenerating natural, social, and economic capital beyond its organizational scope. Either way, it defines and analyzes business models based on their architecture, the principles of their design, and the components which they rest upon.

Yet, the combination of the technology-driven nature and the relatively early stages of the industry 4.0 technology lifecycle imply and give rise to several concerns which are:

- economy-related, specifically the cost-intensive nature and problems with the assessment of all financial advantages and economic benefits (what could be done with one of Industry 4.0 technologies: computer simulation modelling);
- environment-related, i.e., increased electro-waste, energy consumption growth;
- society-related, e.g., problems of human-robot interaction, unemployment threats, privacy concerns.

2.2 The Evidence from the Industry

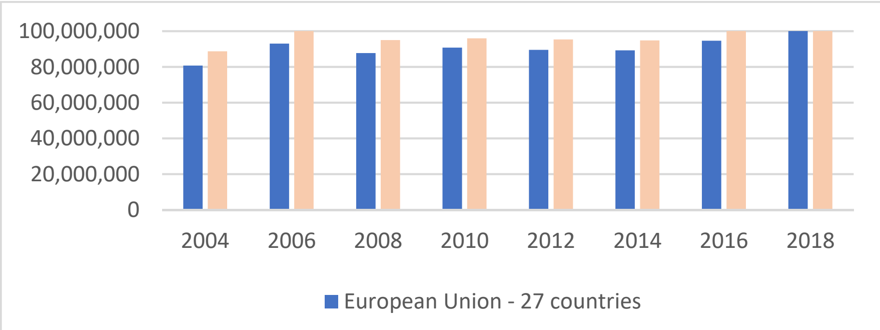
Wastes treatment reports highlight the fixed relation and importance of this topic inside the Circular Economy concept.

Special attention is provided to the inorganic residues, with regard to conversion into glass-based products, can be divided on the basis of the content of glass formers, notably silica. In fact, silica-rich waste materials can be vitrified by themselves or by addition of limited quantities of additives, or lead to glass-based articles, directly by viscous flow sintering, as in the case of recycled glasses.

The main advantages of glass ceramization can be summarized as follows (Rincón et al., 2016):

- flexibility of the process, which allows treatment of many types of waste, such as sludge, contaminated soil, ash, slag from hazardous processing, wet and dry solids in large and variable proportions;
- destruction of all organics (including the most toxic substances such as dioxins and furans) with an efficiency exceeding 99.99%;
- excellent stabilization of hazardous inorganic substances (such as heavy metals, radioactive elements, etc.) within the glassy network in ionic form; consequently, low environmental impact and possibility of landfill disposal without any problem, because any inorganic contaminant is retained permanently (any leakage of contaminants is so slow that no detectable adverse environmental effects are produced);
- substantial reduction in volume of the treated waste (from 20 to 97%, depending on the type of waste);
- good mechanical and thermal properties of the vitreous product.

In order to analyze circular economy conceptualizations in relation to the wastes treatment in Europe (Domenech et al., 2019; Liorente-González et al., 2019), as reported by Eurostat (2023), the total waste generated in Europe-28 at the end of the last decade by all economic entities and households amounted to 2,609 million tons and it showed a clear growth in the years. In the same period considerable variations were also registered across Member States, both in the amount of generated waste and in the activities that mostly contributed to waste generation.



in Europe (tons)

Source: Eurostat.

The most active economic sector was construction with its 33% of the total waste amount (821 million tons), followed by mining and quarrying (29% or 734 million tons), manufacturing (11% or 270 million tons), households (8% or 213 million tons) and energy (4% or 96 million tons). The remaining 15% was waste from other economic activities.

If not managed and disposed of safely, hazardous waste may pose a risk to human health and to the environment. As far as the Italian situation is concerned, the managed special hazardous waste is 9.6 million tons of which 3.8 million tons, equal to the 39.4% of the total hazardous waste managed, recovered in the form of material. The most common operation is the recycling/recovery of metals or metal compounds, with 1.6 million tons, corresponding to 42.4% of the total hazardous waste sent to material recovery.

The other disposal operations, on the other hand, involved 3.3 million tons of hazardous waste equal to 34.5% of the total hazardous waste managed. Shape most used is the chemical-physical treatment, with 2.4 million tons, equal to 46.3% of the total hazardous waste disposed of (Eurostat).

According to a recent survey conducted by the Assoambiente REF Research Laboratory (2021), Italy represents a real excellence in Europe in the recycling of special waste. In the European scenario, Italy ranks very high on the recycling front, with absolute leadership in the percentage of material recovery that is close to 80% (79.3%) and very close to the absolute first place in France (20%) by circularity rate, that is the percentage share of the material recovered and reintroduced into the economy out of the total material (19.5%). This demonstrates the Italian breakthrough towards the recovery of materials, with a view to the circular economy. Despite this, the production is still too high and an adequate process for their management is still missing.

At the end of the last decade, about 338 production plants co-incinerate special waste, of these 278 use a quantity of waste greater than 100 tons/year, while the remaining 60 treat small quantities of waste exclusively for the recovery of thermal/electrical energy functional to its own productive cycle. The total quantity of special, non-hazardous, and hazardous waste destined when co-incineration is equal to approximately 2 million tons. Compared to 2017, the situation remained almost unchanged, with a slight increase of about 29 thousand tons (+ 1.4%). Non-hazardous waste, over 1.9 million tons (94.4% of the total), recorded in comparison to 2017 a slight increase of 1.2%. Hazardous waste, over 113 thousand tons (5.6% of the total), also showed an increase of 5.4%.

In Italy, the largest quantities of special waste are recovered in the Northern regions (70.7% of the total) followed by those of the South (16.2%) and of the Center (13.1%). In particular, in Lombardy over 586,000 tons (28.9% of the total) were destined for co-incineration, followed by Emilia Romagna (316 thousand tons,15.6%), Umbria (over 174 thousand tons, 8.6%), Veneto (over 165 thousand tons, 8.1%), Friuli Venezia Giulia (almost 157 thousand tons, 7.7%), the Piedmont with almost 121 thousand tons (5.9%) and Puglia with over 109 thousand tons (5.4%).

According to the latest data, in 2018, approximately 1.2 million tons of special waste were incinerated. Almost 772 thousand tons (64.5%) of it are non-hazardous and over 424 thousand tons (35.5%) are hazardous. Such quantities are treated both in special waste incineration plants and in the plants dedicated mainly to the treatment of urban waste, authorized by the competent authorities as plants of energy recovery. In particular, about 722 thousand tons were incinerated with the recovery operation and with the operation beyond 474 thousand tons of special waste. Compared to 2017, there is a decline by 5% in the special waste incinerated, equal to almost 64 thousand tons.

There are 82 operating incineration plants that treat special waste, of which 47 are located in the North, 8 in the Center and 27 in the South. The data analysis shows how, consistently with the distribution of the plant park, most of the special waste is incinerated in plants located in the North (84.7% of the total with over one million tons), followed by the southern regions with 12.7% (almost 152 thousand tons) and those of the Center with 2.6% (over 31 thousand tons).

The use of an incinerator as an energy source for a modular plant by the means of which the hazardous waste (e.g., asbestos) is transformed using the vitrification and glass ceramization processes into final products traded in the market of construction or street flooring constitutes a solid base for innovative sustainable business models (Heuss-Aßbichler - Bayuseno 2021).

According to the European Commission Vice-President, Jyrki Katainen (2018) "The hazardous waste management sector has an important role to play in striking the right balance between recovery and final disposal of materials that become waste. This is because they have the right tools and technologies to remove substances of concern from waste and, if this is not possible, to destroy these materials, obtaining energy during the process".

3. Explorative Study

Our empirical study aims to better understand which conditions and features are necessary for a best realization of a sustainable business model in the field of waste treatment in the light of the potentialities offered by the achievements of Industry 4.0 through an industrial system of glass ceramization. Our intention is to understand how these models are created and how they may be improved.

This section aims to describe one example of the arrangements supported by sustainable enterprises realizing business practices of circular economy.

The company (http://www.scater.eu) operates in the environmental consultancy sector and since its establishment it has researched and developed innovative technologies and processes in the field of waste. Its business idea consists in creating solutions in compliance with the current legislation to the problems related to the increase of waste and the decrease of natural resources. The company intends to transform hazardous waste through vitrification and glass-ceramic processes into final products to promote on the construction market.

The procedure starts with the preparation of a mixture which may be composed of vitrifiable minerals, sands and clays and a percentage of waste such as industrial sludge, fly ash from incinerators, asbestos, cement asbestos, slag containing heavy metals, soil and more up to 70%.

To obtain an inert material the mixtures are heat treated at temperatures above 1,400° C to ensure the fixing of all hazardous materials in the glass-matrix. Ultimately, crystallization heat treatment is performed due to which the manufactured product in the glass- state is transformed into a glass ceramic product with the properties that are far superior to the original glass.

The process (defended by a patent) is realized according to the following phases:

• Storage and preparation of raw materials.

The process begins with the inerting of asbestos and eternit, which, unlike other waste, are only dangerous by inhalation. These substances are discharged and deposited on the ground in the storage area, ready to be inerted by heating at temperatures above 1100 ° C inside a static oven. Once these two types of hazardous waste have been cooked, a mixture is prepared consisting of 30% of vitrifiable minerals, sands and clays and the remainder of hazardous waste, such as asbestos and inertized eternit, industrial sludge, fly ash from incinerators, slag containing heavy metals and others;

• Melting, cooling and vitrification.

After the appropriate dosing of the various components, the mixtures are thermally treated at temperatures above 1400°C, so that all the pre-existing species are completely destroyed and melted, in order to obtain an inertized material. The fusion (vitrification) ensures an incorporation and fixing of all dangerous materials in the glass matrix since it represents the safest way of blocking. The melt is finally cooled to obtain a glass in granular form.

• Transformation of glass ceramic plates.

This phase represents the real innovative part of the entire process. The glass obtained is finely ground and mixed with defined quantities of silica, alumina, calcium oxide and magnesium oxide. The glass ceramic is obtained through a crystallization heat treatment and thanks to it an artifact, produced in the state of glass becomes amorphous and possesses all technical characteristics of glass. It is further transformed into a ceramic and, hence, crystalline product, endowed with properties of much higher than the original glass, through an appropriate initial composition of the mixture.

Its excellent mechanical strength, high consumption and abrasion resistance, good chemical tolerance to the atmosphere and acidic environments make the plates of glass ceramic obtained through this process durable over time. The technical quality is comparable and often superior to natural stone (such as porphyry, marble, granite) and other ceramic materials with high resistance (e.g., vitrified stoneware), usually used for urban flooring.

The competitive advantage of this proposal lies in the creation of a final product that comes from innovation of process and product and ensures the utilization of a technology that will allow in loco treatment of a mixture of waste that is generally subject to ever more and more expensive disposal in international markets (primarily in Germany). In addition, it provides for the conversion of special and hazardous waste into products the use of which is not limited to the perspective of recycling, but allows their connotation as raw material.

Each hazardous waste can be reused as raw material provided that the crystal chemical structure is completely altered. Respecting the principle outlined in the hazardous waste treatment regulations, the application of a waste treatment method is expected that completely changes (via vitrification) the chemicrystal structure, making it possible to obtain a secondary inert raw material that can be used for flooring purposes (final product) with no health risk whatsoever.

According to European sources (2022), the energy recovery techniques using incinerators and biofuels will offer solutions for non-reusable and non-recyclable waste. Thus, it will be necessary to make better use of actual EU capacity, nowadays unequally distributed in its territory, and make efforts to avoid overcapacity.

These measures will create more than 180,000 direct jobs in the EU by 2030, which will be added to the 400,000 which, according to estimates, will result from compliance with the effective waste legislation. These measures will satisfy 10% to 40% of the EU demand for raw materials, facilitating the reduction of greenhouse gases by 40%, a goal that the EU is committed to achieve by 2030.

4. Discussion

The capacity of improving the process of treatment and recycling of special and hazardous waste by the aid of an industrial system of "glass ceramization" and the disposal of tiles of inert material used in the market of public decoration or construction represents the core competence of the described business model. This should make our industrial waste management systems a driving force of the economy and innovation directed to the realizing of the main concepts of sustainable development doctrine.

The avenues of future research include the analysis of policy measures adopted by the European Community in the matter of waste. The proper management of hazardous waste continues to generate problems, and the information related to the actual treatment of part of this waste flow is incomplete. It will first enhance data logging and tracing mechanisms through the introduction of computer records to identify the skills and bottlenecks in the management of this type of waste in the Member States. The collection of data regarding other types of waste could also be helpful, as exemplified by some Member States where this practice has already been adopted.

With a view to address the problems associated with certain types of waste, the Commission plans to elaborate an effective system of registration of hazardous waste. Besides, the various issues related to the architectural approach applications to the design of sustainable enterprises acting on the field of circular economy concept in the frame of "Industry 4.0" notion could be analyzed. Another direction of research can include waste treatment performance analysis and examining the measures introduced for the transition to a circular economy and their representation in the sustainability reports of companies according to modern versions of reporting standards (like ISO, Global Reporting Initiative, etc.). So, the analytical approach towards the procedures of waste treatment could become the source of understanding of competitive advantage of the enterprises in the frame of Circular Economy (Masi et al., 2015; Ruggieri et al., 2016; Fortunati et al., 2020; Colantoni et al., 2020; Schönberger et al., 2021).

5. Conclusions

The renewed technology of glass-based products as an effective solution for the management of inorganic waste but it is very important to address the volume, the quality of that raw material, hazardous and inorganic wastes which are the supply of the process. According to forecasts (Eusostat 2022), even without amending the scenario, the EU should already increase resource productivity till 2030. By adopting appropriate policies that promote the transition to a more circular economy as specified by the European Platform on efficiency in the use of resources, this percentage could double, to the benefit of the sustainable dimension in growth, as well as in employment and GDP. This increase in resource productivity would find expression in the enhancement of competitiveness for companies that need to rely on affordable and predictable supplies which sometimes form an important part of their cost structure. They would obtain not only immediate profits, but also strategic benefits on a long-term horizon, as the increase in world demand raises both the price of the resource and its volatility.

It is true that, institutions, authorities, as well as social peers and all stakeholders also play an important role in the provision of targeted and coordinated support, in form the necessary investments, infrastructure, technology and skills, especially in response to the needs of SMEs. They are also capable of guiding consumers towards more sustainable products and services and propelling behavioral change.

References

Bassi, F., & Dias, J. G. (2019). The use of circular economy practices in SMEs across the EU. *Resources, Conservation & Recycling Advances, 146*, 523-533.

Berg, H., Bendix, P., Jansen, M., Le Blévennec, K., Bottermann, P., Magnus-Melgar, M., Pohjalainen, E., & Wahlström, M. (2021). Unlocking the potential of Industry 4.0 to reduce the environmental impact of production, *Eionet Report - ETC/WMGE 2021/5*, European Environmental Agency, European Topic Centre on Waste and Materilas in a Green Economy.

Bernardo, E., Scarinci, G., & Colombo, P. (2020). Vitrification of Waste and Reuse of Waste-Derived Glass, *Encyclopedia of Sustainability Science and Technology*, Springer Nature Switzerland AG.

Breuer, H., & Lüdeke-Freund, F. (2014). Normative Innovation for Sustainable Business Models in Value Networks. XXV ISPIM Conference. *Innovation for Sustainable Economy and Society.*

Cheah, C. G., Chia, W. Y., Lai, S. F., Chew, K. W., Chia, S. R., & Show, P. L. (2022). Innovation designs of industry 4.0 based solid waste management: Machinery and digital circular economy. *Environmental Research*, 213.

Colantoni, A., Picchio, R., Marucci, A., Di Mattia, E., Cristofori, V., Recanatesi, F., Villarini, M., Monarca, D., & Cecchini, M. (2020). WP3-Innovation in agriculture and forestry sector for energetic sustainability. *Energies*, *13*(22).

Deubenera, J., Allixb, M., Davisc, M. J., Durand, A., Höchee, T., Honmaf, T., Komatsuf, T., Krügera, S., Mitrag, I., Müllerh, R., Nakanei, S., Pascuald, M. J., Schmelzerj, J. W. P., Zanotto, E. D., & Zhoul, S. (2018). Updated definition of glass-ceramics. *Journal of Non-Crystalline Solids, 501*(1), 3-10.

Domenech, T., & Bahn-Walkowiak, B. (2019). Transition Towards a Resource Efficient Circular Economy in Europe: Policy Lessons from the EU and the Member States. *Ecological Economics, 155*, 7-19.

Domenech, T., Bleischwitz, R., Doranova, A., Panayotopoulos, D., & Roman, L. (2019). Mapping Industrial Symbiosis Development in Europe typologies of networks, characteristics, performance and contribution to the Circular Economy. *Resources, Conservation & Recycling Advances*, *141*, 76-98.

Ejsmont, K., Gladysz, B., & Kluczek, A. (2020). Impact of Industry 4.0 on Sustainability—Bibliometric Literature Review, *Sustainability.*

Ellen MacArthur Foundation. (2017). Cities in the circular economy: an initial exploration. Retrieved from https://www.ellenmacarthurfoundation.org/publications/cities-in-the-circular-economy-an-initial-exploration

European Commission. (2019). Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions—On the implementation of the Circular Economy Action Plan; European Commission: Brussels, Belgium.

European Commission. (2020). Sustainable Chemicals for a Circular Economy.

Eurostat. (2023). Retrieved from https://ec.europa.eu/eurostat/databrowser/view/ENV_WASGEN/default/table?lang=en

Farzana, S., Farheen, K., Nagma, K., & Zaid, T. (2020) Waste Profiling and Analysis Using Machine Learning. In *Second International Conference on Inventive Research in Computing Applications (ICIRCA),* https://doi.org/10.1109/ICIRCA48905.2020.9183035

Fici, L., Malyzhenkov, P., Masi, M., & Rossi, F. (2019). International Experience in Business Processes Improving on the Base of Architectural Approach. *Nepalese Journal of Management Science and Research, 2*, 61-73.

Fortunati S., Morea D., & Mosconi, E. M. (2020). Circular economy and corporate social responsibility in the agricultural system: Cases study of the Italian agri-food industry. *Agricultural Economics, 66*(11), 489-498.

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy a new sustainability paradigm? *Journal of Cleaner Production,* 143. https://doi. org/10.1016/j.jclepro.2016.12.048

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleanear Production*, 114. https://doi.org/10.1016/j.jclepro.2015.09.007

Heuss-Aßbichler, S., & Bayuseno, A. P. (2021). Immobilization of Municipal and Industrial Waste. In Richet, P., Conradt, R., Takada, A., & Dyon, J., (Eds.), *Encyclopedia of Glass Science, Technology, History, and Culture*. https://doi.org/10.1002/9781118801017

Homrich, A. S., Galvão, G., Abadia, L. G., & Carvalho, M. M. (2018). The circular economy umbrella: Trends and gaps on integrating pathways. *Journal of Cleaner Production*, *175*, 525-543.

Jabbour, C. J. C., Fiorini, P. C. C., Wong, W. Y., Jugend, D., Jabbour, A. B. L. S., Seles, B. M. R. P., Pinheiro, M. A. P., & Da Silva, H. M. R. (2020). First-mover firms in the transition towards the sharing economy in metallic natural resource-intensive industries: Implications for the circular economy and emerging industry 4.0 technologies, in *Resources Policy*, *66*.

Jamwal, A., Agrawal, R., Sharma, M., & Giallanza, A. (2021). Industry 4.0 Technologies for Manufacturing Sustainability: A Systematic Review and Future Research Directions.*Applied Sciences*, *11*(12).

Khanna, A., Kaur, R., & Hirdesh. (2021) Temperature effect on the glass forming ability of strontium tellurite and lead tellurite melts. *Journal of Alloys and Compounds,* 881.

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. *Ecological Economics*, *143*, 37-46.

Kumar, S., Suhaib, M., & Asjad, M. (2020). Industry 4.0: Complex, disruptive, but inevitable. *Management and Production Engineering Review*, *11,* 43-51.

Laboratorio REF Ricerche. (2021). Non solo rifiuti urbani. Rifiuti speciali la gestione che serve al sistema Paese, Dossier. Retrieved from https://laboratorioref.it/non-solo-rifiuti-urbani-rifiuti-speciali-la-gestione-che-serve-al-paese/

Liorente-González, L. J., & Vence, X. (2019). Decoupling or "decaffing"? The underlying conceptualization of circular economy in the European union monitoring framework. *Sustainability, 11*, 4898.

Malyzhenkov, P., Gordeeva, T., & Masi, M. (2018). IT-Business Alignment Problem Solution by Means of Zachman Model: Case of Woodworking Enterprise. In *Enterprise and Organizational Modeling and Simulation, 14th International Workshop, EOMAS*. https://doi.org/10.1007/978-3-030-00787-4, ISBN 978-3-030-00786-7

Martín Gómez, A. M., Aguayo González, F., & Marcos Bárcena, M. (2018). Smart eco-industrial parks: A circular economy implementation based on industrial metabolism. *Resources, Conservation & Recycling Advances*, *135*, 58-69.

Masi, M., & Malyzhenkov, P. (2015). Sustainable Development Reports Usage in Russia as a Process of Best

Ethics Business Practices Communication. *Proceedings "Innovations in science and education".* International Jewish Institute of Economics, Finance and Law. Moscow: MAKS Press.

Masi, M., Rossi, F., & Malyzhenkov, P. (2016). Technical and Management Innovation in the Process of Treatment of Special and Hazardous Waste in a Perspective of Circular Economy. *Proceedings XXVII Congresso Nazionale di Scienze Merceologiche* "Qualità & Innovazione per una Economia Circolare ed un Futuro Sostenibile".

Millar, N., McLaughlin, E., & Börger, T. (2019). The Circular Economy: Swings and Roundabouts? *Ecological Economics, 158*, 11-19.

Nascimento, D. L. M., Alencastro, V., Quelhas, O. L. G., Caiado, R. G. G., Garza-Reyes, J. A., Rocha-Lona, L., & Tortorella, G. (2019). Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. *Journal of Manufacturing Technology Management*.

Neves, A., Godina, R., Azevedo, S. G., & Matias, J. C. O. (2019). A comprehensive review of industrial symbiosis. *Journal of Cleaner Production*, 247.

Osterwalder, A., & Pigneur, Y. (2009). *Business model generation: A handbook for visionaries, game changers, and challengers*. Wiley: Amsterdam, Netherlands.

Piccarozzi, M., Stefanoni, A., Silvestri, C., & Ioppolo, G. (2023). Industry 4.0 technologies as a lever for sustainability in the communication of large companies to stakeholders. *European Journal of Innovation Management*, 1460-1060. https://10.1108/EJIM-11-2022-0641

Pinheiro, M. A. P., Jugend, D., Jabbour, A. B. L. S., Jabbour, C. J. C., & Latan, H. (2022). Circular economy-based new products and company performance: The role of stakeholders and Industry 4.0 technologies. *Business Strategy and the Environment, 31*(1).

Prieto-Sandoval, V., Jaca, C., & Ormazabal, M. (2018). Towards a consensus on the circular economy. *Journal of Cleaner Production*, *179*, 605-615.

Rincón, A., Marangoni, M., Cetin, S., & Bernardo, E. (2016) Recycling of inorganic waste in monolithic and cellular glass-based materials for structural and functional applications. *Chemical Technology & Biotechnology Review Open Access.* https://doi.org/10.1002/jctb.4982

Ruggieri, A., Braccini, A. M., Poponi, S., & Mosconi, E. M. (2016). A Meta-Model of Inter-Organisational Cooperation for the Transition to a Circular Economy. *Sustainability*, 8. https://doi.org/10.3390/su8111153

Saavedra, Y. M. B., Iritani, D. R., Pavan, A. L. R., & Ometto, A. R. (2018). Theoretical contribution of industrial ecology to circular economy. *Journal of Cleaner Production, 170*, 1514-1522.

Saha, H. N., Auddy, S., Pal, S., Kumar, S., Pandey, S., Singh, R., Singh, A. K., Banerjee, S., Ghosh, D., & Saha, S. (2017). Waste management using internet of things (IoT). In *8th Annual Industrial Automation and Electromechanical Engineering Conference (IEMECON)*, 359-363. https://doi.org/10.1109/IEMECON.2017.8079623

Schaltegger, S., Hansen, E. G., & Lüdeke-Freund, F. (2016). Business Models for Sustainability: Origins, Present Research, and Future Avenues. *Organization & Environment*, *29*(1), 3-10.

Schönberger, N., Taylor, C., Schrader, M., Drobot, B., Matys, S., Lederer, F. L., & Pollmann, K. (2021). Gallium-binding peptides as a tool for the sustainable treatment of industrial waste streams. *Journal of Hazardous Materials*, 414.

Sikora, A., Yahaya, M., & Su, S. (2014). Glass Ceramization as an Alternative Production Route of Forsterite Glass-Ceramics for Possible Multipurpose Uses, *Advanced Materials Research.* https://doi.org/10.4028/www.scientific.net/AMR.1043.138

Stubbs, W., & Cocklin, C. (2008). Conceptualizing a "sustainability business model". *Organization & Environment*, *21*, 103-127.

VanWynsberghe, R., & Khan, S. (2007). Redefining Case Study, *International Journal of Qualitative Methods*.

Yin, R. K. (2003). *Case study research: design and methods* (3rd ed.). London: SAGE Publications.