The timeless cork design in Portugal; on the cutting edge of sustainability

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ABSTRACT: Cork is a natural, recyclable, non-toxic and renewable resource obtained from the bark of the cork oak (*Quercus suber L.*). Its unique properties make cork one of the most versatile and mind-blowing materials and an excellent choice for designing sustainable products and creating new spaces. This paper looks at the efforts of the Portuguese cork Industry (PCI) to change the paradigm of cork use. From the traditional and ancient use of cork to an era where sustainability is the future, sustainable cork products are now emerging with brand new designs following a circular economy model (CE). Interviews with CEOs, designers, architects and academic experts from the PCI mainframe provided a fruitful discussion on the benefits of using cork products for a sustainable future already. Despite being considered a 'green' sector, the results showed that PCI does not fully utilize the CE model. Furthermore, the results identify CE drivers and barriers to rethinking eco-design in the PCI and show that the PCI sector benefits from a CE paradigm because the cork industry is sustainable and can innovate and develop new products. However, the implementation of CE is difficult as most companies focus on cork stoppers and lack the financial resources to acquire new Industry 4.0 (I4.0) facilitating technologies for a productive and creative paradigm shift. The work of Ramos (2021) served as background for this paper.

Keywords: Cork sustainability, Circular economy, Cork eco-design, I4.0. Portuguese cork industry

1 INTRODUCTION

The need for a sustainable society, meeting the present demands without risking the capability of future generations to meet their own needs, has a strong relevance nowadays (Brundtland, 1987). Social-economic and environmental trends are changing radically, along with technological progress, population growth, and increasing awareness of resource scarcity. The consumption- driven economy based on the cradle-to-grave[1] concept (Braungart & McDonough, 2002) model uses limited resources to create new products systematically discarded in unsustainable landfills after being used. The "take-make-dispose" oriented Linear Economic (LE) model generated interest in a new Cradle pattern. Consequently, the cradle-to-cradle[2] approach is central to the idea of a Circular Economy (CE) model (Braungart & McDonough, 2002). In this context, Portugal has a sustainable raw material (the cork), used for centuries, which can be transformed, manufactured, recycled, and reused, and an industry (PCI) where "Sustainability and Future" are the main keywords (Ferreira & Sousa, 2019).

In addition to a strong relationship with the wine Industry, PCI also expanded its applicability to other product ranges, ensuring a reference position in the world market (Gil, 2015). Cork, the outer bark of the cork oak tree (*Quercus suber L.*), is a versatile raw material that adapts to different technological transformation processes and applications. The production sector seeks materials whose focus is sustainability and products that can convey the values of ecology. Cork extraction does not damage the cork oak. Moreover, the cork regeneration process promotes an increase in

1. The full Life Cycle Assessment from resource extraction ('cradle') to use and disposal phases ('grave').

2. The full Life Cycle Assessment from resource extraction ('cradle') to use and disposal phases ('grave').

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the absorption of CO_2 (a greenhouse gas, GHG) by the tree, one of the rare cases in which human intervention is beneficial to the environment. Throughout their life cycle, from extraction to processing to disposal, sustainable materials provide environmental, social and economic benefits, while protecting public health and the environment. Nevertheless, *Q. suber* only survives in exact conditions of temperature, water, and soil characteristics, so climate change is a menace to the cork industry's sustainability since those changes inflict massive damage to the cork oak forest. Thus, preserving this natural resource, decreasing the cork waste from cradle-to-gate[3] (Franklin, 2011), recycling the cork waste/products that achieve their end-of-life, and expanding the Portuguese cork recyclability potential are core decisions for sustainable use (Mestre & Vogtlander, 2013). The sustainable practices used by companies towards a CE paradigm impact people's life and the natural environment. Hence, this study expects to be a valuable tool for the cork industry and designers to understand and apply potential sustainability improvements. In addition, the present research detected a gap in the literature concerning the insufficient knowledge held by entrepreneurs in the cork sector on (i) how to obtain sustainable wealth-generating products within a CE framework; and (ii) to what extent can new I4.0 technologies be adopted and help the industry move towards sustainability. Thus, two research questions, RQ, arise:

RQ1: Does a CE paradigm benefit the Portuguese cork industry in the near future?
RQ2: Are Industry 4.0 (I4.0) Technologies and Digital Transition the drivers for Sustainability and CE practices in the Portuguese cork sector?

This study's dependent and independent variables are (i) the CE model and (ii) the PCI's capacity to implement its principles. Furthermore, some moderating variables (such as the industry's capacity to use I4.0 technologies, its capability to implement a closed-looped supply chain, its ability to develop new products, and its status regarding sustainability policies) will be examined to help evaluate the PCI current sustainable development, compare its policies to CE principles and reach a conclusion of what may be improved.

After a literature review, seven RQ-related propositions arose to support the conclusions reached at the end of each research question (Figure 1), serving as a base for the interviews.

This investigation follows the conceptual model represented in Figure 2. The systematic approach undertaken aims to understand the state of sustainability in small and medium-sized cork companies. Implementing sustainable practices and circularity in

RQ1: Does a CE paradigm benefit the Portuguese cork industry?	RQ2: Are I4.0 Technologies and Digital Transition the drivers for Sustainability and CE practices in the Portuguese cork sector?
P1.1: The sustainability policies in the Portuguese cork industry are already fully related to the CE paradigm	P2.1: The I4.0 Technologies are drivers for the development of new sustainable products in the Portuguese cork sector under a CE paradigm
P1.2: The Portuguese cork industry benefits from a CE paradigm	P2.2: A change towards CE paradigm, using I4.0 technologies, benefits the eco-design in the Portuguese cork industry
P1.3: The Portuguese cork industry benefits from a closed-looped value chain and from cork materials recycling	P2.3: The drivers and hampers of CE in the Portuguese cork industry are political, social and/or economic
P1.4: The Portuguese cork industry benefits from new product development	

Figure 1. RQs with the seven related propositions.

PCI could optimize cork utilization and reduce costs, waste, water, and energy consumption, leading to process optimization, innovation, and improved customer and employee satisfaction.

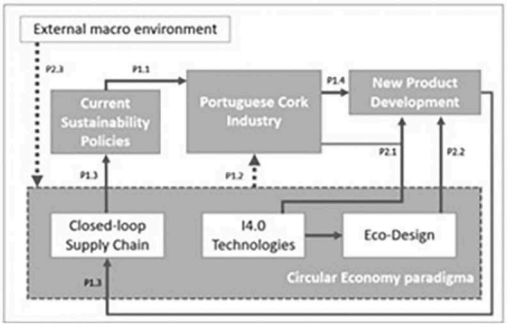

Figure 2. Research conceptual model with the seven concepts addressed.

This work outlines the progress made in recent years toward CE and how I4.0 is revolutionizing the manufacturing, improving, and distributing of products. (Silva & Almeida, 2020). A selection of the most representative cork products and new applications in new objects and spaces follows.

2 TIMELESS CORK MATERIALS & SUSTAINABLE PRODUCT DESIGN

Cork has been used since time immemorial. Indeed, various civilizations found the potential of this raw material from the cork oak tree several millennia BC and used it in a wide array of everyday objects. This is confirmed by countless remnants that have been found in several Mediterranean countries. From Roman Civilization exploring the virtues of cork in footwear to the Discoveries Age, where this raw material was used in the Portuguese caravel ships, until today, the potential of cork continues to be

3. An assessment of a partial product life cycle from resource extraction (cradle) to the factory gate

recognized. In a world where innovation and ecology now go hand in hand, this material is attracting the attention of an increasing number of sectors. Thus, one of humanity's most ancient products in constant use lasts to give life to new products and applications. This includes distinct areas such as construction, sports, fashion, design, health, energy production, and the aerospace industry.

Portugal has a long political history of promoting resource efficiency in managing and recovering specific waste streams, energy efficiency, and green growth. Cork is one of the natural resources on which economic growth relies, and the cork sector shows sustainable growth (Gil, 2015). Moreover, it has been quick to adopt new and sustainable technologies in all production processes. Being highly dependent on natural resources, the PCI has an immense interest in becoming fully sustainable, building long-term resilience, generating business and economic opportunities while providing environmental and societal benefits (Demertzi et al., 2016).

The Portuguese cork industry has launched a new paradigm of industrial management, becoming vertically integrated to guarantee control of the whole chain of value and, at the same time, coming closer to forestry production and end-users. The cork industry is now fully committed to quality, the preservation of the natural environment and landscape, and the satisfaction of its customers.

All designers and corporations wish to fully utilize all raw materials with minimum waste produced in the manufacturing process. Still, established firms generally follow mainly linear models, which is a significant obstacle to the CE transition and, consequently, to resource optimization and waste reduction (Gil, 2015). This problem involves changes from technologies to operations processes and from designers to managers' mindsets. In PCI, the first premise - to attain sustainable use of all raw materials in the manufacturing process with a minimum of waste produced - is unquestionably applicable, especially considering the raw materials' organic nature and biological origin (the cork). One of the main goals is to explore the sustainable potential of cork through the creative vision of designers and architecture studios. Three fundamental objectives can be highlighted from the possible interaction between cork producers, designers, and architects: contributing to expanding the use of natural and sustainable materials in urban contexts; paving the way for greater awareness of sustainability issues, and the development of contemporary urban landscapes; and encouraging innovative and critical thinking, proposing ideas that can effectively contribute to living in a community and with the environment. A new paradigm born out of challenges with cork material: intense competition from plastic and aluminium closures and the retreat of the construction sector with the substantial drop in sales has forced the sector to reinvent itself and constantly invest in Research and Innovation. Focusing on CE, attention seems to be turning to the use of wastes resulting from cork stoppers production (Mestre and Vogtlander, 2013). Cork composites are one of the most promising fields in the cork technological evolution, and all by- products (from cork conversion) have sustainable applications (Ramos, 2021).

When a product is bought, a visual identification creates an emotional connection. The same situation happens when an attractive design is combined with all the sustainability features achieving a winning product. Sustainable product design is considered an interdisciplinary concept, encompassing product design and sustainability towards innovation, adaption, and future crafting/industrial concepts. Product design develops new products and services that create innovation and added value. Designing sustainable products can achieve two main goals: on the one hand, to develop new solutions with more sustainable products that have more excellent added value for both the community and the customer. Also, designing sustainable products integrate aspects related to eco-efficiency (eco- design significantly reduces the impact of these new products on the environment. Thus, innovative and new cork materials must be accepted and thought of by designers, architects, engineers, and other professionals (Maccioni et al., 2021).

Innovation in processes, new products and technologies, research and development in the cork industry sector, universities, and research centers, and the winning of brands that could place the cork on a premium level in all its aspects (architecture, fashion, design, transport), as well as renowned prescribers in the various fields, investment in quality and human value, became research guidelines to address.

3 METHODOLOGY

To gather exploratory data collection, a qualitative multi-respondent study design was adopted. The semi-structured interview form was developed based on the themes emerging from the literature review: Circular Economy, Cork, Industry 4.0, Innovation, New Products Development, Sustainable Design, PCI, and Sustainability. Three experts were interviewed before going into practice to verify that the interview plan covered the full range of questions to address the subject entirely. The key informants that would best address the research questions are industry players in the PCI, other stakeholders of the cork sector, designers and scholars with interesting knowledge in cork materials, and high-tech industry association experts. The justification for conducting interviews is based on interacting with the respondents and assembling in-depth answers generating

a deeper understanding of the area of interest and providing various perspectives. Available company documents were used for data triangulation. All interviewees' names are kept confidential. In total, 10 participants were involved. The collected recorded material was transcribed and compared with the notes taken during the interview to give the researchers a more complete and accurate picture of what was said. In addition, all notes and transcripts from each interview are compared to identify similarities or differences. In the current work, the quotes increase the research's reliability and help understand what is being said in each interview. Categories are used in the form of different concepts in the operationalization to combine them and to be able to analyze differences and similarities. EcoCanvas was a tool used to evaluate the PCI and facilitate data analysis regarding environmental, social, and economic issues. In addition, CE model implementation is addressed. This allows conclusions to be drawn about the knowledge on achieving wealth-generating sustainable products and services in the PCI in a CE framework.

4 EMPIRICAL RESEARCH - INTERVIEWS AND RESULTS

The interview analysis is based on the RQs and related propositions (Figure 1). The interviews were conducted with four university professors (P1, P2, P3, P4), three PCI entrepreneurs (E1, director of the Portuguese Cork Association APCOR; E2, CEO of the company "S", specialized in black agglomerates; E3, responsible for the production in CPF-Cork) and three designers (D1, D2, D3). The interview approach allowed us to go deeper into the RQs and compare it with the information from the literature. Therefore, the following empirical data is presented and analyzed in terms of the theoretical concepts presented in Figure 2.

4.1 *Portuguese Cork Industry (PCI)*

Portugal is part of the EU, and the current practices of this industry are adjusted to European directives and policies, and the PCI cork sector develops its operations within the EU rules. According to E1, The cork sector believes that EU rules are very beneficial goals and orientations"; and "We will grow again this year and maintain our target of 1.5 billion exports by 2030. In turn, E2 stresses the importance of cork oaks to achieve sustainable growth in rural Portuguese regions with scarce conditions for other primary economic activities: It is forbidden to cut them down; There are incentives to plant and exploit cork oaks to generate sustainable clusters of socio-economic activity in those regions where they are planted, mainly in the inner regions of Alentejo"; and "Bark stripping results in seasonal work to around 6,000 people". According to E3: "There is a relationship between small and large companies. Large companies indeed drain off the product from the small ones, keeping the raw material and various forms of financing. However, small companies play an essential role in system flexibility, and fluctuations in demand significantly affect them.

4.2 *Circular economy paradigm*

The feedback is overall positive, with the interviewees mentioning that it could create new jobs, reduce costs and waste, create new products and new business models, thus, increasing the overall value of the industry. PE states that government support could be important, adding that there should be an investment or an encouragement from the government to increase the number of cork oaks and to increase the amount of raw material available, stressing the importance of recycling both cork waste and lesser quality cork. However, legislative changes and creating an Eco-Industrial Park to facilitate the circularity in cork industry operations had opposite opinions. The first was considered irrelevant by E3 and E1 and vital by P4, E1, E2, and E3. The latter is geographically impossible or irrelevant by E1, E2, and something already happening by P1, and E1, E2, and E3. Therefore, the collaboration between the cork industry stakeholders to implement CE policies is essential, and it is already happening (a common opinion of P1, P3, E1, E2, E3, and D3).

4.3 *Current sustainability policies in the cork industry*

All the answers indicated that the industry is very sustainable, with few negative impacts on the environment and that PCI companies use almost entirely its waste, as mentioned by P4, The cork industry, as far as I know, is relatively sustainable. It does not use very polluting processes and does not generate great waste. What is not used in the finest productions (the cork stoppers) is then used to produce other types of products. P3 reinforces this by mentioning that there is an attempt to make full use of the product, so there is practically no waste, and even the powders are used for energy, whether for heating the cork cooking water or for generating electricity. In his turn, D3 admitted, There is room to improve, and that the environmental policy is more focused on the 'No Waste Manufacturing' paradigm than the CE paradigm. To improve, D3 suggested To make an investment in recycled products and further investigation and innovation in this area.

4.4 *New product development and eco-design*

Sustainable Product Design and Innovation are requirements to create new sustainable solutions

which integrate economic, social, and environmental aspects through the whole life cycle of a product or service. In recent years, the cork sector has started to use cork's sustainability values and eco-efficient nature to create an innovative image of cork in keeping with the values of sustainable development, as revealed in the analysis of the interviews. Despite being the leading producer and exporter of cork globally, Portugal does not have a long history of Research and Development (R&D) in cork. The interviewees stated that the industry can develop new products and that Innovation plays a critical role (D2). However, P2 refers to a Gap between the research in cork materials and their application in new products. Coincidently, the ability to create new products and maximize resource usage are seen by E1 as the main competitive advantage of the CE paradigm. E1 considers Sustainable Product Design a promising trend for Sustainable Development. He added that eco-design is like a tool [among others] to implement sustainability in practice, proposing innovative cork products that promote and convey new sustainable lifestyles. P3 mentioned that Cork allows new product development targeting sustainability and simultaneously stimulating the economic competitiveness of local cork industries and helping more sustainable consumption. D3 reveals a similar opinion concerning eco-design, saying eco-design improves the life cycle and eco-efficiency of products, boosting dematerialization. From a practical perspective, according to D1, Cork offers (to designers) a range of materials and technological options that are potential for developing new sustainable products not yet introduced into the market.

4.5 *Closed-loop supply chain*

Theory based on relating the end of a supply chain with its beginning by collecting and processing used (or unused) products, providing them with an economic, social, and environmental value. E1 confirmed that it is difficult for the industry to return used cork stoppers to be utilized by the industry. He mentioned that, in theory, it would be good for the industry to recycle the stoppers, given the necessity to increase raw material availability. So, it is mandatory to conduct a study and understand if it would be economically and environmentally positive for the industry.

Overall, it is believed that only national cork products could be returned, given the financial and environmental costs. Regarding collecting cork-used objects, P4 says this policy would only impact the non-cork stoppers products because recycled cork stoppers cannot be reused as cork stoppers, due to health standards.

4.6 *Industry 4.0 Technologies (I4.0)*

PCI must introduce new technologies to its operations as it creates new business models and brings economic and social benefits. The interviewees pointed out several problems with introducing these technologies: difficulties in obtaining financial partners due to being a small industry and no direct government support (existing tends to go for the larger companies, more able of using the money, with some having an R&D department). Still, APCOR tries to mitigate this issue by sharing knowledge with smaller companies. Too many bureaucracies and lack of technology availability and information are referred. Overall, the technology suggested to the interviewees had positive feedback: (i) 3D printers – a technology owned by APCOR and that some companies use; (ii) Digital passports – essential to ensure maintenance and recycling; (iii) Traceability of products, ensuring sustainable origin and production – according to E1, the sector uses the Forest Certificate, which requires traceability; (iv) Digital waste management; (v) Augmented reality technology; (vi) Smart factories; (vii) Connecting companies in a network to share knowledge – D2 stresses the positive factor for the industry, as long as it does not take competitive advantage. It is hard to implement since one company controls a large portion of the market. However, P3 claims an adequate education is a critical element to implement these technologies, and E1 mentioned that APCOR has an education center and projects to help the companies.

Even so, E1 is very sharp with the following affirmation: The last two or three years have seen an unprecedented technological acceleration in our sector, with a need for heavy investment, not always compatible with the size of our companies. However, APCOR sought to create this stimulus, giving companies diagnostic tools on their positioning concerning Industry 4.0 and new production models to define action and improve plans. Of course, we are amid implementing these issues, but I believe it was a program that created the conditions for awareness of the issues of process automation, digitalization, and everything related to increasing competitiveness.

5 DISCUSSION AND CONCLUSIONS

Many tools summarize results and allow conclusions to be drawn from qualitative studies. The EcoCanvas (Antikainen & Valkoraki, 2016) is the chosen tool to achieve this and bridge the conclusions to environmental, social, and economic issues (the three CE pillar) revealed in our data analysis. It is a Business Model Canvas-based framework to assist companies that wish to become more sustainable and conclude about the established practices and those that will need to be

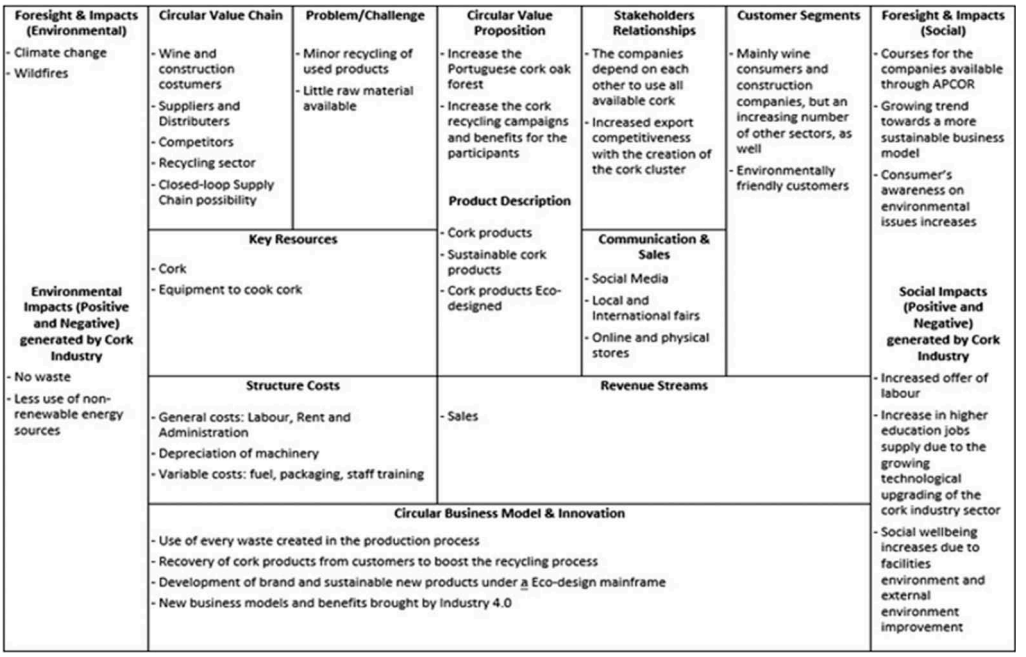

Figure 3. EcoCanvas framework regarding the conclusions about the PCI suitability to CE.

outlined. The framework in Figure 3 resumes our conclusions.

Exploring Ecocanvas, we conclude that the cork industry has outstanding technological capabilities in materials and processes. However, these abilities focus on traditional products and applications that, in most cases, no longer represent competitiveness and differentiation. This situation contrasts with the high investment in research and development (R&D) over the last two decades, which has led to numerous patent applications that the industry has not fully explored (Ramos, 2021).

Also, only a hand full of companies has the financial capability to launch new products. In the PCI, although the technical needs are fulfilled for the proper industry function, implementing the I4.0 technology would be valuable as enforcing a digital passport (Silva & Almeida, 2020). However, the most significant concern is the lack of funds that could assist the PCI in executing these technologies.

In a CE framework applied to industries adopting suitable (I4.0) technology to increase efficiency in manufacturing and reduce waste, the idea of cradle-to-cradle design, as Krajner and Pracek (2019) uphold, applies perfectly in PCI, defining and incrementing the development of cyclable cork made products. To maintain the quality of raw materials over multiple life cycles taking the production processes, the use, and the reuse into account, these products must be developed according to an appropriate manufacturing framework. This means no waste; all cork materials and products are inputs in the productive cycle. The right materials are integrated into defined cycles in PCI at the right time and place. To maintain the quality of raw materials over multiple life cycles taking the production processes, the use, and the reuse into account, these products must be developed according to an appropriate manufacturing framework. This means no waste; all cork materials and products are inputs in the productive cycle. The right materials are integrated into defined cycles in PCI at the right time and place.

On the product design, it is fair to say that there have been few isolated experiments (with no overall strategic direction) made primarily by designers experimenting with the cork in their workshops without any advanced technology and production support (Gil, 2015). It is also possible to conclude the industry's environmental weaknesses due to its high exposure to wildfires (common in Portugal) and climate change. Another weakness is the high dependency on the wine sector, but this industry's environmental and social benefits are clear.

With a suitable CE model, the raw material disposal would increase. Further, the secondary products also increase due to the rise of resource availability not destined for cork stoppers and the adoption of the I4.0 technologies. The central point that emerges from our research is that it is possible to draw a CE model that integrates sustainable

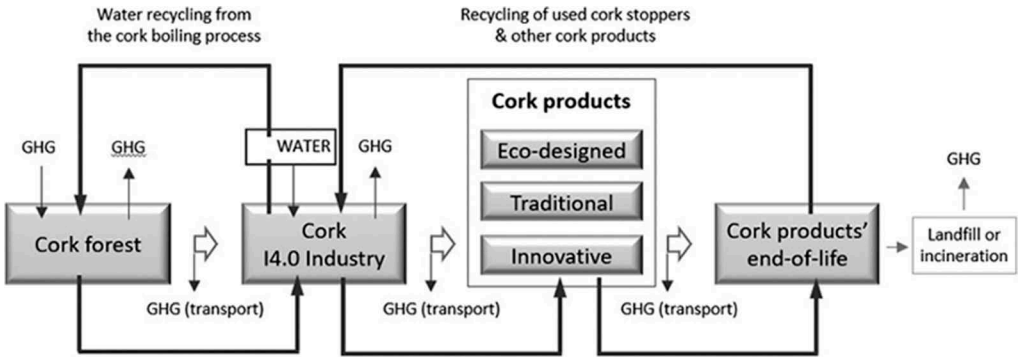

Figure 4. Cork life cycle with the approaches that contribute to developing a CE model in PCI.

approaches in PCI, localizes and mitigates impacts resulting from resources overconsumption and GHG emissions. The model is depicted in Figure 4.

A new paradigm born out of challenges with cork material: intense competition from plastic and aluminium closures and the retreat of the construction sector with the substantial drop in sales has forced the sector to reinvent itself and constantly invest in Research and Innovation. When there is so much talk about the circular economy, attention seems to be turning to the use of waste resulting from cork stoppers production. For example, in the aeronautical industry, a cork-based composite covers space vehicles, protecting them from the heat on re-entry into the atmosphere. Everything that is a by-product, i.e., that is resulting from natural cork conversion, has various applications, most of which are sustainable.

The potential of cork extends not only to wine cork stoppers but also to other sectors such as transport, fashion, furniture, or lighting. The agglomerates and by-products of cork have exceptional potential and the possibility of transforming used products or waste into various new applications and spaces where cork takes center stage.

The growing attention paid to factors such as thermal behavior and decorative aspects leads to a positive response to these solutions. Some automobile prototypes (e.g., from Mercedes) have already been shown at motor shows but have not been mass-produced. In the meantime, cork furniture that bridges sustainable spaces is a concept that has already passed the prototype stage and is gaining importance in the furniture market, combining comfort and attractive aesthetic lines.

The innovation process in the cork sector is closely linked to the environmentally friendly properties of cork and takes advantage of the increasing importance of sustainability in modern society. Moreover, the innovation process in the construction sector was very much in line with European strategic plans to reduce environmental impact and energy consumption. Nevertheless, the cork industry has a great technological capacity in terms of materials and processes, but this capacity is entirely focused on traditional products and applications, which in most cases are no longer competitive and allow differentiation. This means that despite high investments in R&D and many patent applications, the industry does not take full advantage of the new technologies and processes created.

The present work reveals that the production processes in the Portuguese cork industry are oriented towards a "**Zero Waste Production**" paradigm rather than that of CE. However, this model does not include a post-use process, which is a weakness for the Portuguese cork industry, as it is difficult to recycle used products. So, a circular paradigm could help this industry to recover the used cork thanks to its "cradle to cradle" model with the help of Industry 4.0 technologies.

Thus, our study brings us to the following assumption: PCI is sustainable, innovative, and can develop new products. Furthermore, the sector could become even more sustainable with the diversification of its eco-designed cork products and the rise of other PCI segments brought by the CE model. Thus, about RQ1, we conclude that a CE paradigm helps the PCI. Regarding RQ2, we infer that I4.0 Technologies are drivers for sustainability and CE practices in the PCI. Unfortunately, undertaking CE is not easy since most businesses focus on cork stoppers and lack funding to obtain new I4.0 facilitating technologies for a productive and creative paradigm shift.

From the past to the future, today's timeless cork design is on the verge of sustainability and on its way to new spaces.

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