Introducing eco-ideation and creativity techniques to increase and diversify the applications of eco-materials: The case of cork in the building sector

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Abstract

Cork is an eco-material that has recently been attracting growing interest due to the expanding strategy of sustainable product design, which aims to replace non-renewable materials in the building market. Until now, the cork sector has not taken advantage of the properties of this material and has been fully oriented towards traditional applications such as stoppers for wines and other beverages. The diversification of the cork market, through developing new products with higher added value, is the reason why eco-ideation (using different creativity techniques) can be helpful in creating new products and solutions.

The process of introducing eco-ideation was carried out during two interdisciplinary creative sessions and a product design stage. The results of the process were successful in terms of participation and the quantity and quality of ideas, which were characterised by searching, experimentation, participation and knowledge sharing. The versatility of cork fits perfectly with the creative methods of eco-ideation, as cork's good physical properties allow the diverse generation of new ideas for both applications and markets. The concepts generated in this study are in line with the approach of recognising cork's status as a natural, pure and noble material, taking advantage of the good properties of cork, and giving buildings unique traits due to the singular aesthetic of cork.

Keywords: eco-design, eco-innovation, creativity, cork, building materials.

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1. Introduction

Interest in eco-materials has been growing recently due to the expanding strategy of sustainable product design, which aims to replace non-renewable materials with natural or renewable materials. This strategy aims to decrease the environmental impacts of products during their extraction, manufacturing, use and end-of-life. One eco-material with great application potential is cork (Pereira, 2007). This material is extracted sustainably from cork oak (*Quercus suber* L.) forests, one of the best examples of balanced conservation and development in the world. The cork oak tree is a long-lived species (200-350 years) with high environmental importance due to the key role that it plays in ecological processes such as water retention, soil conservation, and carbon storage (Rives et al., 2013). The extraction of its outer bark, the cork, is a sustainable process because it does not damage the tree, and following extraction, new bark regrows. This process occurs every 9-14 years, depending on the area, until the tree is approximately 180-200 years old (Pereira and Tomé, 2004).

A recent study analysed the production and trade of the Iberian cork sector (Sierra-Pérez et al., 2015). Currently, 85% (161,504 tonnes) of worldwide cork extraction is concentrated in the Iberian Peninsula (Portugal and Spain). However, the production and trade patterns of these countries are very different. Portugal is a producer and a processor of raw cork into end products; it is a leader in the global market and operates a very powerful industry. Meanwhile, the Spanish cork industry is mainly based on raw material and half-manufactured cork, except for Catalonia, which is the global leader in the champagne stopper market. Currently, the Iberian cork market is highly focused on the wine sector, which accounts for more than 80% of its market; and this makes the cork sector heavily dependent on wine market trends (Sierra-Pérez et al., 2015).

Cork has strong potential for use as a raw material for products with high added value, thanks to its unique properties such as elasticity, impermeability and good thermal insulation, as well as its renewability (Pereira, 2007). However, the current cork market lacks product development strategies (Mestre and Gil, 2011) and is fully oriented towards applications that are conventional and of low economic value, particularly wine stoppers of various types and some construction solutions such as insulating building materials, flooring and walls (Mestre, 2015). Curiously, one of these applications, insulating building materials, constitutes a significant portion of Portuguese exports to the northern European countries. However, this volume of exports is only high in terms of mass and is not reflected in monetary terms (Sierra-Pérez et al., 2015). This shows the emerging potential for improvement and diversification due to the current acceptance of cork in the building sector (Gil, 2015). Moreover, there is a large amount of cork that could generate increased economic value and its potential is currently unrealised. On the one hand, the cork stoppers sector produces a high volume of cork waste (e.g., the final cork stopper uses only 20% of the initial raw cork (Rives et al., 2011)). On the other hand, vast areas of cork oak forest are not fully exploited because they belong to private owners who do not want or cannot make the significant investment required to prepare forests for cork extraction. For example, in Catalonia (Spain) cork oak forests are not fully used at present, and it is estimated that 50% of them are not managed in any way (Tusell and Garcia, 2008). By initiating exploitation of these forests, cork extraction in Catalonia could be doubled (Sierra-Pérez et al., 2015).

Although some environmental studies have been carried out in recent years, most were based on raw materials (Dias et al., 2014; González-García et al., 2013; Rives et al., 2012b); on traditional products such as stoppers (Rives et al., 2012a, 2012c, 2011); on building products such as flooring (Demertzi et al., 2015; Jim Bowyer, 2009; Mahalle, 2011) and on insulation materials (de Brito et al., 2010; Pargana et al., 2014; Sierra-Pérez et al., 2016a). These studies evaluate the sustainability of cork by providing detailed environmental impact assessments of products' life cycles, comparing cork products with the most common non-renewable products used in buildings. One of the most interesting conclusions is that the use of natural insulation materials does not necessarily imply a reduction in environmental impacts. In the case of current cork products, the manufacturing processes require large quantities of energy due to their low technological development. This makes it necessary to improve the sustainability of eco-materials throughout their life cycles, and renewable materials offer great potential for intervention. For example, there are many opportunities for the implementation of eco-innovation strategies to produce more efficient and effective products and improve a product's design, thus helping to increase its market share (Sierra-Pérez et al., 2016a).

Eco-innovation is defined as the production, assimilation or exploitation of a novelty in products, production processes, or services or in management and business methods. Eco-innovation aims, throughout its life cycle, to prevent or substantially reduce environmental risk, pollution and other negative impacts of resource use (OECD, 2009). These innovative actions need to involve a broad network composed of firms, associations, suppliers, product advisors, and clients, while aligning and converging the expectations of these diverse stakeholders (Ceschin, 2013). Eco-innovation takes a similar approach to design processes, which aim to conceptualise and generate new ideas for products (Vallet et al., 2013). These processes include key factors to meet environmental sustainability requirements (Mario Fargnoli, 2006) as efficiently and appropriately as possible throughout the product life cycle of consumer goods (Bocken et al., 2011).

Eco-ideation is defined by Bocken et al. (2011) as the generation of the ideas that reduce environmental impact throughout the product life cycle of consumer goods. The process of eco-ideation for new sustainable products is characterised by searching, experimentation, participation and knowledge sharing. This form of knowledge development is significantly more organic than in traditional science because the knowledge developed by the researcher is combined with practice and informed action, which benefit the participants by allowing them to take control of their situations and circumstances (Swann, 2002). In this regard, the Portuguese cork sector developed a project based on design intervention, which aims to incorporate eco-innovation in the cork sector by exploring the potential uses of cork and creating awareness. The project results in a variety of cork design solution prototypes, which exemplify how the functional and aesthetic properties of cork can be implemented in sustainable product design in different markets, among them transport, furniture, lighting or wall and floor coverings (Mestre and Vogtlander, 2013; Mestre, 2015). This could potentially address the weakness detected in the Spanish sector by catalysing the diversification of its market and developing new products with higher added value.

In this sense, this article describes the methodology used in a project conducted in the Spanish cork sector to increase and diversify the applications of cork in the building

sector through the eco-ideation of new product concepts using different creativity tools. In addition, the specific objectives are the following:

· To analyse the potential applications of cork.

· To generate new concepts for cork building products.

· To validate the highest-potential product concepts in the cork industry.

2. Methodology: a creative workshop for eco-ideation.

This workshop consists of a creative process that includes two interdisciplinary creative sessions and a product design stage. Moreover, this process is complemented by some preparation and documentation activities to ensure the success of the workshop. This section describes the steps carried out to reach the objectives established above (Figure 1).

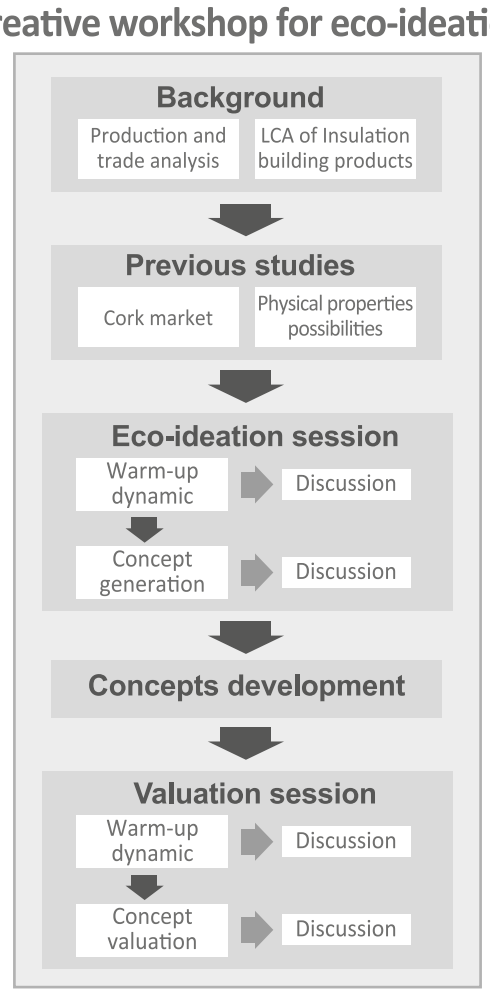


Figure 1. Scheme of the Creative workshop for eco-ideation adapted from Mestre (2015)

2.1. Background

This workshop is part of a project that aims to diversify the Spanish cork market beyond the wine sector through eco-innovation and eco-design. Previously, the Iberian cork sector has been analysed from a production and trade perspective, which identified the building sector as a potential market (Sierra-Pérez et al., 2015). Due to the intrinsic sustainability of cork, its competitors in the building insulation sector were environmentally assessed from a life cycle perspective (Sierra-Pérez et al., 2016b), as

was the main Spanish cork insulation product (Sierra-Pérez et al., 2016a). Next, new concepts for building products made from cork were generated, taking into account the environmental results and conclusions of these studies. The following sections present the process of eco-ideation underlying these concepts.

2.2. Previous analysis of the potential applications of cork

To determine the potential applications and functionalities of cork, the following actions are performed. First, an intensive search of current applications of cork is performed to obtain an overview of the cork market. Second, the properties of cork are contextualised with respect to other similar materials to identify potential applications not yet explored. This information increases the quality of knowledge about cork among those responsible for the project, and the information is transmitted to the participants in successive stages.

2.2.1. Current cork applications

At this initial stage, an intensive and deep search of products made from cork or using cork is performed to develop a database of the current applications of cork in different sectors. This search is mainly carried out based on the initial information provided by cork firms, using the documentation and websites of the following private and public organizations:

· APCOR (Portuguese Cork Association) (APCOR, 2016)

· AECORK (Catalan Cork Association) (AECORK, 2016)

· CELIEGE (European Cork Federation) (CELIEGE, 2016)

· ICSURO (Catalan Cork Institute) (ICSURO, 2016)

· ASECOR (Cluster of Cork from Extremadura, Spain) (ASECOR, 2016)

· REDECOR (Thematic Network of Cork Oak and Cork, Portugal) (REDECOR, 2016)

· RETECORK (European Network of Cork-Producing Territories) (RETECORK, 2016)

All the cork products found have been registered, including commercial name, type of product, sector, components, manufacturer/designer, manufacturing process, country of commercialisation and website (Figure 2). After the data collection, the degree of market penetration is analysed, as are the applications of the cork and the reasons for these applications. Special attention is paid to existing products in the building sector. All this information will be used in preparation for the creative sessions.

2.2.2. Possibilities of cork due to its physical properties

Cork has a very significant and varied combination of physical properties (Table 1). Due to the complete focus on the wine market, these properties are not being fully exploited. To address this problem, materials with similar physical properties have been researched to analyse the possible applications of cork based on its physical properties.

First, the main properties of materials are compared in Ashby graphs (Asbhy, 1992) using the software CES Selector (Granta Design, 2016). These graphs compare a set of materials at the same time by plotting one material property on each axis of a materials selection chart. These graphs condense a large body of information into a compact but accessible form, and they also reveal correlations between the properties

of a material. In this case, the pairs of properties represented are *price – thermal conductivity*, *price – maximum temperature of service*, *price – heat capacity* and *yield strength – density*. Once the correlations between cork and other similar materials are identified, the application markets of these materials are analysed. These markets will be used in the creative sessions to find new market niches for cork.

General properties	Density	120 - 240 kg/m^3
	Price	1.99 - 9.96 EUR/kg
Mechanical properties	Young's modulus	0.013 - 0.05 GPa
	Yield strength	0.3 - 1.5 MPa
	Tensile strength	0.5 - 2.5 MPa
	Elongation	20 - 80 % strain
	Fatigue strength (10^7 cycles)	0.3 - 1.1 MPa
	Fracture toughness	0.05 - 0.1 MPa.m$^{1/2}$
Thermal properties	Maximum service temperature	117 - 137 °C
	Thermal conductor or insulator	Good Insulator
	Thermal conductivity	0.035 - 0.048 W/m.°C
	Specific heat capacity	1.9e3 - 2.1e^3 J/kg.°C
	Thermal expansion coefficient	130 - 230 µstrain/°C
Electrical properties	Electrical conductor or insulator	Poor insulator
Optical properties	Transparency/Opaque	Opaque
Others	Permeability	Waterproof
	Acoustics	Good Insulatior
	Vibration	Good Buffer

Table 1. Main properties of cork (Granta Design, 2016)

2.3. Design and preparation of the creative workshop

The sessions are structured and defined by two specialists in product design, one with expertise in eco-design and eco-innovation, and the other with experience in managing creative methods and groups. The creative workshop is designed with the goal of achieving the above objectives, essentially generating ideas leading to the definition of concepts that can be evaluated for their novelty, technical feasibility, economic viability and potential impact on the market.

The creative workshop is structured in two sessions, the first for generating ideas and the second for concept evaluation. The sessions are developed on two different days separated in time by a few weeks and with different professionals participating in each session. They have been divided into two parts to allow enough time for analysis of the idea-generation session, for the development of concepts and for preparation of the evaluation session.

The success of a creative workshop depends on the dedication applied to preparing for it; the greater the preparation for and anticipation of the possible events

during the sessions, the better the results and the greater the control in managing the workshop itself.

2.4. Participant selection

The sessions are deliberately interdisciplinary, aiming to achieve a holistic approach in which the overall knowledge of the group is greater than the sum of the knowledge of individuals, thus expanding the diversity of ideas and increasing the group's power to answer specific challenges due to different areas of expertise. The integration of two profiles, a generalist profile related to creativity and design and an expert profile in any of the matters related to the subject to be addressed, shapes the interdisciplinary character of the group. The creative profile is divergent, with unfocused thinking and a desire to look for connections; it is not oriented to one final solution but to many possible solutions. The profile of the expert is convergent; its orientation is very specific and focused, eliminating noise and pinpointing solutions or principles based on knowledge-based solutions.

The objectives for each session are different, as are the compositions of the workgroups; the two workshop organizers were involved in both sessions. For the first session of idea generation, a panel of 9 participants was invited, in addition to the two organizers. Product designers composed the creative group and people with different fields of expertise composed the group of experts: environment, energy efficiency of buildings, architecture and building. The invited experts were chosen for their experience and for their professional and research knowledge in different fields related to the topic. For the second session, all participants belong to the cork sector, and so the Catalan Cork Institute hosted the celebration. There were 25 participants with different areas of expertise, including commercial specialists, design and architecture specialists, and marketing or production specialists.

2.5. Description of creative sessions

Creative methods and techniques used in the two-day workshop have been transformed and adapted to meet the needs of warm-up dynamics, idea generation and concept evaluation. Both sessions started with a warm up dynamic (Nash, 1975; Sternberg, 1988) based on "random input" creative methods (De Bono, 2010, 1993) and continued with different techniques based on their objectives, either the generation of ideas or the valuation of concepts.

2.5.1. First session: Generation of ideas

The 1st session started with the introduction of each participant and an explanation of why they were invited to the workshop. Then, organizers provided the participants with context about the state of the art of cork applications, including the building sector. Immediately after this, the 1st session started with a warm-up technique, based on the technique called "forced relationships" or "random stimulation" (De Bono, 2010). The objective of this dynamic is to identify new applications for cork in new potential markets related to cork's physical properties. During the creative dynamic, participants combined two terms, corresponding to a pair of cards from two different decks relating to the physical properties of cork or its potential application sectors. The words were based on the previous analysis of the potential applications.

This method was combined with a forum-style conversation, including a diversity of comments and thus allowing the random mixing of properties of the material with potential applications. During this conversation, it was interesting that group members divided according to their profiles. The creative people were able to identify new applications, while experts were able to assess the suitability of the property to particular situations. The new ideas were registered on a form for further discussion between the two groups.

The next part of the session aimed to define ideas about cork as an insulation product in buildings. A previous presentation on the main systems of thermal insulation in buildings introduced the main results of previous studies developed in the project and related to the building life cycle. In this part, the groups were reorganized, maintaining the diversity in each group. The technique developed for this part of the generation of ideas is based on questions presented by the leader of each group in the form of an interview (Linstone and Turoff, 1975; Osborn, 1963) or conversation with experts. With the creative focus defined, a discussion among the group of experts began, and questions were fragments of problems detected in previous studies. This creative technique is based on the antithetical method (Torre, 1995), first using problem fragmentation in the analysis phase (or divergent phase), and then using reconstruction and recombination in the synthesis phase (or convergent phase). All the generated ideas were registered on a form by the leader, as were the difficulties or requirements of solving it and the elements that differentiate this solution from others. In addition, for each idea a number of pros and cons were recorded, along with comments. Finally, the two groups shared ideas, again in a debate during which ideas were criticised, mixed, transformed and combined to improve, enrich or generate new ideas.

2.5.2. Development of concepts

All information generated during the 2 dynamics was processed using forms where the leader registered ideas and comments, as well as using audio and video recordings. Each specialist registered the information from his or her groups and the subsequent discussion between the two groups. Next, the transcriptions were exchanged between specialists to complete the information.

Focusing on the concepts of cork building products, and based on the documentation of ideas and comments from experts, the most relevant ideas were developed by the two experts in product design. Products were developed using computer-aided design and rendering tools (to specify and to make communication easier in the second session of the creative workshop).

2.5.3. Second session: Validation of concepts

The 2nd creative session began with a brief presentation of the current situation of the cork industry. There was also a warm-up dynamic, and due to the high number of participants the technique of "forced relationships" (De Bono, 2010) was mixed with the technique of 4x4x4. The characteristics of the dynamic still remained the same; the objective was to identify new applications of cork in new potential markets related to its physical properties, using the same words as in the 1st session. The main difference was the distribution of the participants. First, the group worked in couples that would later join with other couples to create groups of 8 participants. In each round, they had

to generate 4 ideas, and in subsequent rounds they joined together with another couple and discussed the ideas and then generated 4 new ideas. The process was the same for each group of 4 participants, who then joined together in a group of 8 for the final round of the process. At the end of the dynamic, the last 4 ideas of each group were explained to all participants and comments or remarks on each idea were registered. The organizers asked a few questions of the group to highlight the most interesting ideas and to obtain feedback from the participants

After the break, the valuation of the concepts generated in the 1st session of the creative workshop took place. Concepts were presented in detail, using rendered images, after which all participants discussed the concepts using the following criteria: technical feasibility, economic viability, novelty and innovation of the concept and potential market impact. For the evaluation of the concepts, a hybrid version of the technique Positive-Negative-Interesting (PNI) (De Bono, 1994), along with the "Evaluation Grid" technique, was used. The evaluation grid, also called checkered, is a method where each idea or concept can be evaluated using certain criteria; the concepts are set in the rows and the criteria in the columns, and the criteria can be weighted. The PNI technique allows a more detailed assessment of the most important ideas, discriminating between and highlighting positive and negative aspects of each concept and highlighting some aspects that are important but that cannot be classified as positive or negative and that can have both effects. The PNI method discovers the potential of each idea, identifies potential elements that make it successful, and prevents the neglect of possible adverse effects, weaknesses and elements of the idea that may not be valid or must be treated with caution. Each specialist can write his or her valuations on 3 cards of each colour (sticky paper): positive in green, negative in red and interesting in yellow. All cards are placed on a table to be evaluated visually based on colours and the numbers of cards; the best- and worst-rated concepts are thus perceived.

The session ends with some general comments as a summary. Comments are presented among the group based on the outcome: the best or worst concept, the most valuable, the most prominent criteria, etc. Moreover, comments are evaluated by each criterion and by concept to obtain a final valuation. Summarising, comments and annotations will improve concepts and will let participants identify strengths and weaknesses based on criteria justified by an expert or someone who knows particular details.

During all sessions, the audio from each group is recorded and the sharing of all ideas is videotaped. The audio recording serves to make a transcription of broader ideas that complete the tables with the comments that have failed to be scored. Videotaping serves to record comments and gestures that are used to explain ideas that are lost if only audio recording is used. The drawings or sketches arising from the generation of ideas are recorded in the tables of ideas, thus all the details of the ideas are recorded.

3. Results and discussion

This section presents the results obtained through each step of the creative workshop and discusses the evolution of the first ideas into new concepts for cork building products.

3.1. Potential cork applications

The process of searching for new market niches for cork has resulted in diverse information about types of cork products, current cork markets, common manufacturing processes in the cork industry and cork's similarities and interrelations with other materials. All the information generated in this part will be used in the creative sessions to improve the quality of the transmitted information.

3.1.1. Current application of cork

The wine sector represents the majority of cork firms in the Iberian cork sector. This implies that the technological development of the cork industries has been exclusively focused on the wine sector's needs. Moreover, this sector requires raw cork of the highest quality because it will translate into greater efficiency in the manufacturing process (Rives et al., 2013, 2012b). The intermediate products, white and black cork granulates, are the cork wastes from the manufacturing of end products, and are reused from the raw cork. Currently, they are mainly transformed through an agglomeration or expansion process, which is the first and most common manufacturing process in the remainder of the cork markets.

On the one hand, the manufacturing of agglomerated products consists of the agglomeration of large blocks of cork, followed by machining processes, such as cutting and milling systems, which transform these blocks. This process represents a very traditional method of working and supposes a reliance on a workforce, which increases the price of products. Therefore, the design and manufacture of these products should be directed to mass production, allowing large numbers of sales and more competitive prices. On the other hand, the manufacturing of expanded cork allows the design of products with organic forms due to the uses of moulds in the cork expansion, which can control the final form of the block. The moulds can be used repeatedly, allowing for mass production, which will reduce production costs. However, for the moment, the initial investment required for these processes will hinder their extensive use.

The most innovative market in the introduction of cork material is the home furniture and decoration sector (Figure 2). Products in this sector include tableware, ceiling and table lamps, hammocks and sofas. On the other hand, cork textiles also represent an interesting market. They are used in cases for technology products, coverings, shoes and bags. The great majority of the firms making these products are located in Portugal, which shows the importance Portugal attributes to this natural material. Moreover, most products belong to a few companies, especially to the absolute leader in the sector. Regarding cork building products, there is not a wide variety of products and applications. Fundamentally, insulation boards are the most common cork product used in building. There are two types of boards, depending on the manufacturing process: white agglomerated boards or expanded cork boards. Moreover, these products are also used in flooring and covering products to increase the insulation of dwellings. The majority of the producers of cork building products are also Portuguese.

						
Product	Whistler	Float	Corqui	Corqui	Puf string	Wallcork
Sector	Home	Lighting	Furniture	Home	Furniture	Home
Materials	Cork + Ceramic	Cork	Cork	Cork	Composite of cork with natural rubber + Steel	Cork fabric + Ink
Producer/designer	Matceramica /Amorim	Benjamin Hubert	Corque/Pedro Silva Dias	Corque/Fernando Brizio	Corque/Ana Mestre	Corque/Sofía Dias
Manufacturing process of cork	Agglomeration + cutting	Agglomeration + cutting	Agglomeration + cutting	Agglomeration + cutting	Production of rubber cork	Print of natural cork laminated
Country	Portugal	United Kingdom	Portugal	Portugal	Portugal	Portugal
Website	www.corkway.com/	http://layerdesign.com/	http://corquedesign.com/	http://corquedesign.com/	http://corquedesign.com/	http://corquedesign.com/
						
Product	Cork chaise longue	Place mat	Ricardo Rollbag	Pinha	Corkybowl	Boat
Sector	Furniture	Home	Fashion	Lighting	Home	Toy
Materials	Cork	Cork	Cork fabric + Cotton	Cork and electric components	Cork	Cork + Ceramic
Producer/designer	Daniel Michalik	Escofet	Lena Hasibether	Materia/Raw Edges	Vícara/ Tiago Sá da Costa	Materia/BIG GAME
Manufacturing process of cork	Agglomeration + cutting	Agglomeration + cutting	Adheration of thin cork slices and coagulation with PU	Agglomeration + cutting	Agglomeration + cutting	Agglomeration + cutting
Country	USA	Spain	Germany	Portugal	Portugal	Portugal
Website	http://danielmichalik.com/	http://escofetcork.com/	http://lenahasibether.de/	http://www.materia.amorim.com/	http://vicara.org/	http://www.materia.amorim.com/
						
Product	Lagarta	Wash basin	Bench	Corkers	Mobile cover	Car dashboard
Sector	Furniture	Sanitary	Furniture	Decoraction	Electronic	Automotive
Materials	Cork	Cork	Cork + painting	Plastic	Cork	Cork fabric
Producer/designer	Corque/Ana Mestre	Simple Forms Design/Alzira Peixoto and Carlos Mendonça	Daniel Michalik	Reddish/Monkey business	Ryan Frank	Mercedes Benz/Villani
Manufacturing process of cork	Agglomeration + cutting	Agglomeration + cutting	Agglomeration + cutting	Plastic moulding	Agglomeration + cutting	Adheration of thin cork slices and coagulation with PU
Country	Portugal	Portugal	USA	Israel	United Kingdom	Germany/Italy
Website	http://corquedesign.com/	http://www.simpleformsdesign.com/	http://danielmichalik.com/	http://eu.mnkbusiness.com/	http://www.ryanfrank.net/	www.villanileonello.com

Figure 2. Example of the table form for the registration of the current products made of cork

3.1.2. Interrelations between cork and other materials

Figure 3 shows the combination of four Ashby graphs comparing cork with other materials. It can be seen that the most similar materials are Flexible Polymer Foams (FPF), Rigid Polymer Foams (RPF), Natural Rubber (NR) and Neoprene (CR). This demonstrates that the applications of these materials can also be potential applications for cork, and they will be used in the creative session to strengthen the generation of ideas.

Flexible Polymer Foams (FPF) use the same manufacturing process as rigid polymeric foams, being based on polyurethane (PU), latex (natural rubber) and sparkling elastomers. FPF have a softer texture and a more flexible structure. This makes them suitable for the manufacture of padded textiles (medium density) as well as for the manufacture of packaging and protective elements (low density). Rigid Polymer Foams (RPF) are manufactured by controlled expansion and are made of Polystyrene (PS), phenolic, polyethylene (PE), polypropylene (PP) or polymethacrylate derivatives. They are lightweight and rigid, and their mechanical properties make them a material intended for packaging applications or lightweight structures. The most widespread application of this type of foam is as the core of sandwich panels, and more specifically, as a thermal insulator (low density, medium density), as packaging for food (high density, medium density) or as insulation for noise and vibration (high density). Natural Rubber (NR) is the most elastomeric product used. It comes from latex, the rubber tree's sap, when it is vulcanized through a heat increase with sulphur. Its most common applications are as vibration insulation, tyres, hoses and tubes, footwear, foam mattresses, toys and articles for use in the medical and health sector. Neoprene (CR) is particularly characterised by a high chemical stability, and by resistance to water, oil, petrol and UV radiation. Its properties can be modified by copolymerization well as in combination with other polymers to improve their properties. Among its most used applications are in the wire and cable industry, automotive Industry, orthopaedic and sport support products, water sports and diving suits, boots, gloves and accessories.

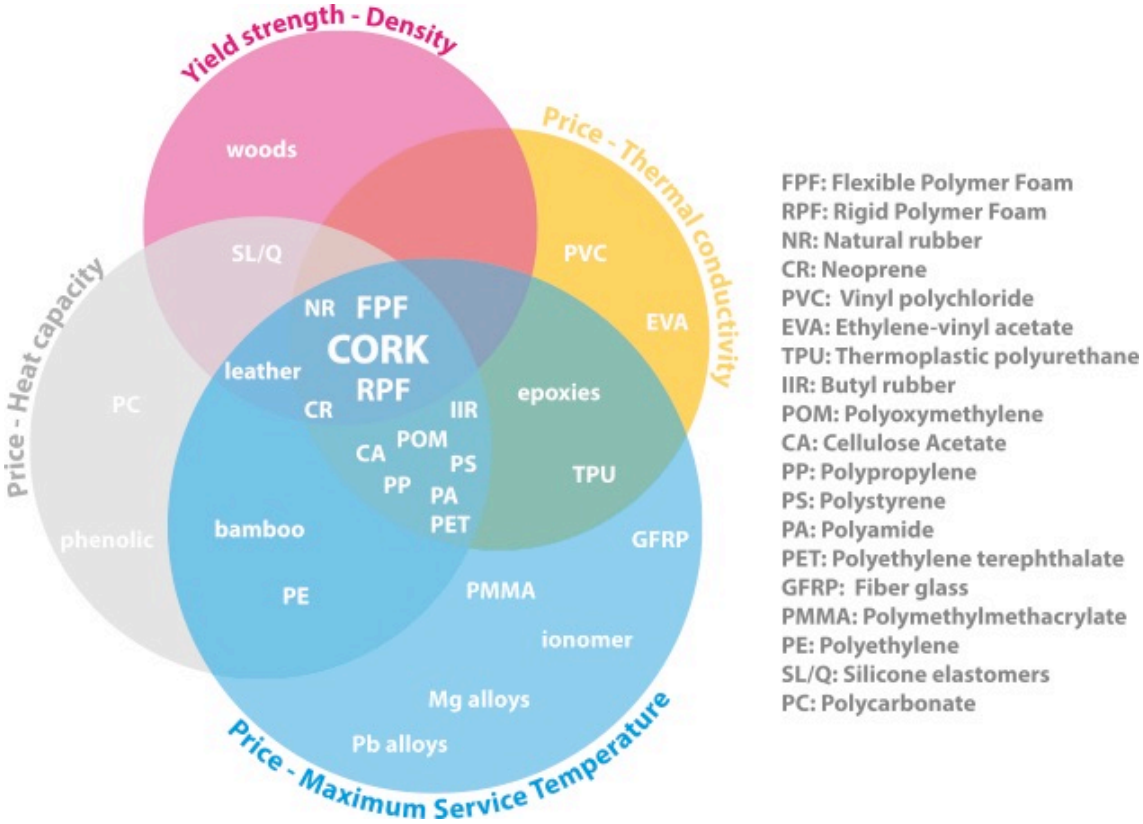


Figure 3. Ashby graphs comparing physical properties of cork with other materials

3.2. Results of the first part of the creative workshop

This section presents the results of the first session of the creative workshop held in the Defence University Centre located in Zaragoza (Spain) on 26 January 2016.

3.2.1. Warm-up session

First, to introduce the possibilities of cork in general terms, the new ideas for cork products were opened to all markets, not only the building sector. The conclusions of the previous analysis served to make pairs of words – pairing physical properties of cork and markets of application – using the force relationship method. Table 2 presents the words used during the session. As noted above, during this session participants took a pair of different coloured cards and proposed a new product made of cork to be used in this application sector.

Physical property		Market of application
Acoustic and thermal insulation		Automotive
Buoyancy		Building
Chemical agent resistant		Defence
Compressible		Fashion
Elastic		Leisure
Hydroponic		Machinery
Impermeable	&	Packaging
Lightness		Physical therapy
Mechanical strength		Sanitary
Non-toxic		Security
Shock absorption		Sports
Sustainable		Toy
Thermal inertia		Wellness

Table 2. Terms used in the force relationship method during the warm-up session

This session resulted in a great variety of different applications; there were 20 pairs of words that produced at least one idea, leading to a total of 53 products or new applications (See Supplementary data). There were a total of 11 ideas that included the building sector. “Acoustic and thermal insulation”, “Elastic“ and “Lightness” were the physical properties used most (9 ideas). A remarkable new market application proposed by the participants was “Physical therapy”. The interesting new physical properties were “Hydroponic,” with two ideas related to green roofs and façades, and “Thermal inertia”, all of them related to buildings. These results give a global view of how powerful it can be to introduce creative techniques in eco-innovation and how important it is to involve interdisciplinary groups of experts.

3.2.2. Concept generation session

The objective of this part was synthesising well-defined and detailed ideas for the application of cork in the building sector. The debate began with a series of questions related to problems encountered in the insulation of buildings. Experts answered the questions and the group suggested solutions; the product concept was specified during the group discussion. The questions were very specific and were developed based on the previous session of the project. According to the methodology used in these studies, the questions had a specific format and referred to situations related to the life cycle of insulation products. The following were some of the questions asked:

- What are the main problems in the insulation of buildings?
- Regarding the installation, how could we decrease the number of elements in installation systems?
- Can you easily recover the insulation material so that it can be recycled/reused after demolition?

Moreover, another batch of questions was related to the specific topic of the use of cork in buildings. The following were some of the questions asked:

- Does cork configure better complex surfaces than other materials (organic design)?
- Is it possible to configure new formats of products (such as paste or tongue and groove blocks)?

- Does cork present potential improvements for installation? Could it be configured as interchangeable boards? Does it offer improvements in replacement or maintenance over other materials?
- What is the potential for recovery/separation of cork in a demolition?
- Is its natural character an argument for marketing? How can it be promoted?

The use of cork in buildings resulted in a very interesting discussion and a great diversity of ideas was proposed. However, above all, its significance is due to the properties that distinguish it from other insulation materials. These properties were: 1) its self-supporting capacity that allows it to need fewer structural elements during installation; 2) its permeability to water vapour that avoids the creation of internal condensation and allows the release of humidity; 3) its combination of lightness and impact strength that provide an opportunity to increase the robustness of lightweight systems; 4) its good resistance to climatological phenomena allows the installation of cork with fewer coating materials or perhaps without them; 5) its intangible quality of being a natural, pure and noble material.

The main ideas summarised at the end of this session served as the scaffolding used to build the subsequent concepts. All the details from the audio and video transcriptions were used to develop the concepts further and to explain three concepts for the next workshop. The main ideas of the new products for the building market can be reviewed in the Supplementary data.

3.3. Concept development

Table 3 presents the final three concepts developed by the specialists in product design. After the conceptualization phase with experts, the development of concepts began with the drawing of sketches, integrating the requirements established in the creative session. Then, product concepts were modelled with computer-aided design software, defining their formal and functional development.

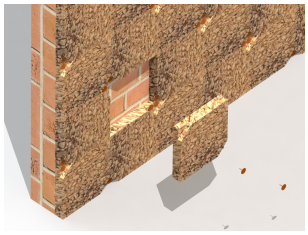
	Concept 1	Concept 2	Concept 3
			
Problem or need detected	Treatment of irreversible moisture in the rehabilitation of internal walls in historical buildings	Making use of the advantage of the cork sustainability in the retrofitting of building façades	Improve the noise pollution in environments with high transit of people
Justification	· Decrease the intensive use of existing dry lining systems of walls. · Cork has good hygrometric and self-supporting properties that allow the substitution of plasterboards. · It can be minimised the metallic structure installing cork boards.	· The external system of building insulation has a good price-features relationship. · Cork is the unique insulation material that can support adverse climatological phenomena without coverings, although its appearance changes. Moreover, its self-supporting allows decrease the intensive of elements of fixing.	· There is a need for improves the acoustic pollution in crowded environments. · Public and work places have to be usually flexible regarding their arrangement and organisation. · Use of cork in these elements improves both identified problems: acoustic and lightness.
Description	· The proposed product is a cork dry lining system consists of vertical continuous boards from the floor to the ceiling. · The structure for installation consists into a unique part separated from wall, more robust than existing ones. · Boards are attached with punches, and they have bevelled edges to get a continuous final surface.	· The proposed product is a board for being installed without external coverings that makes easier the materials separation in the end-of-life. · Due to the fixing elements are exposed, this can affect to the aesthetic of the proposal. · It is proposed to create geometric textures with the combination of boards to improve the aesthetic aspects.	· This product consists in a room or environmental partition made of cork and plastic or metal profiles. · The modular system, without screws, allows to obtain a great diversity of products. The lightness of cork does not require physical effort to site. · Textures have been include improving the acoustic insulation and the aesthetic acceptance.

Table 3. Main concepts generated from the first session and evaluated in the second one

3.4. Results of the second part of the creative workshop

This section presents the results of the second session of the creative workshop held at the Catalan Cork Institute located in Palagrugell, Girona (Spain) on 16 March 2016.

3.4.1. Warm-up session

As in the first warm session, the warm-up session had a divergent approach, not focusing only on the building market but extended to cork applications in every market. At the end, three groups commented on their ideas and expressed their opinions about the proposals, asking for specialists' answers.

This session resulted in a great variety of different applications, combining 10 different sectors and 9 physical properties, with 62 ideas in total (See Supplementary data). Some of these ideas were more evolved than others due to the technique's own process – generation and discussion in several rounds. The ideas show the diversity of the participants and their knowledge.

The most innovative ideas were the floating quays for ports, the 3D printed Lego parts, and modular tents to assist with humanitarian emergencies or terrestrial catastrophes. On the other hand, experts commented that the main problem with introducing eco-innovation in the sector is the lack of knowledge about new industrial processes with cork and the difficulty of developing all generated ideas. This requires research on the material itself and its transformation processes. The majority of the new products coming onto the market are manufactured using existing processes, they do not take advantage of the raw material, which has to develop or adapt a new. Introducing design into the sector (and to its products) can serve as a catalyst for the needs of specific processes or specific characteristics of the material itself. This may not necessarily require the development of advanced technology; it may require adjustments to the size of the machinery.

3.4.2. Concept validation session

The objective of this part was the evaluation of the three concepts based on different criteria: technical feasibility, financial viability, innovation and market impact. Figure 4 presents the results of the valuation method. In this table, each valuation has a colour and a letter, depending on the expert that performed the valuation. Despite there being 25 people in the session, not all participants voted on all the product-concepts because they may not have had a defined opinion about some concepts or because they had nothing to say. There were a total of 94 comments (40% of the total), and every concept had a minimum of 28 comments. Therefore, every concept had been evaluated equally. At the same time, every criterion had been commented upon with at least 20 comments.

Regarding the validation results, in general terms concepts 1 and 2 received the majority of negative evaluations for technical feasibility. The main reason for the negative comments on concept 1 was, on the one hand, the stability problems because of the large size of the boards. On the other hand, due to the large quantity of cork required to manufacture each board, the market price would be much higher than other similar products. Regarding its impact on the market, it was noted that the potential market niche of this solution would be very small because it would be aimed at

customers with greater environmental awareness. Moreover, concept 1 received significant interesting evaluations, highlighting, among other factors, interest in the design applied to such products to improve their aesthetics. Negative valuations were mainly from participants with commercial and technical profiles. Meanwhile, less critical evaluations came from designers and architects and researchers. This fits with the previous comments about the concept.

Concept 2 had the best evaluations regarding product innovation, as well as regarding its impact on the market. Its main positive quality was the high potential for application in different environments. In addition, participants highlighted its easy installation and its differential aesthetics with respect to other constructive solutions. Expertise profiles that appreciated this concept were design and production. Its negative evaluations, as mentioned above, focused on the technical feasibility criterion. On the one hand, the contraction of boards with temperature changes could lead to a variation in the final appearance of the facade. On the other hand, the installation was considered to require a high investment.

As for concept 3, it had the best evaluations in terms of technical feasibility. This was because the participants considered its manufacture very simple and versatile. Due to its simple parts, its technological difficulty is very low, so it is very easily produced by current manufacturing processes. It was also considered interesting because, from a visual perspective, it could have high potential for use in contract projects and interior design, where cork is not yet widely used. This was the concept with fewer negative evaluations, and the most relevant referred to the need to study whether it meets fire regulations.

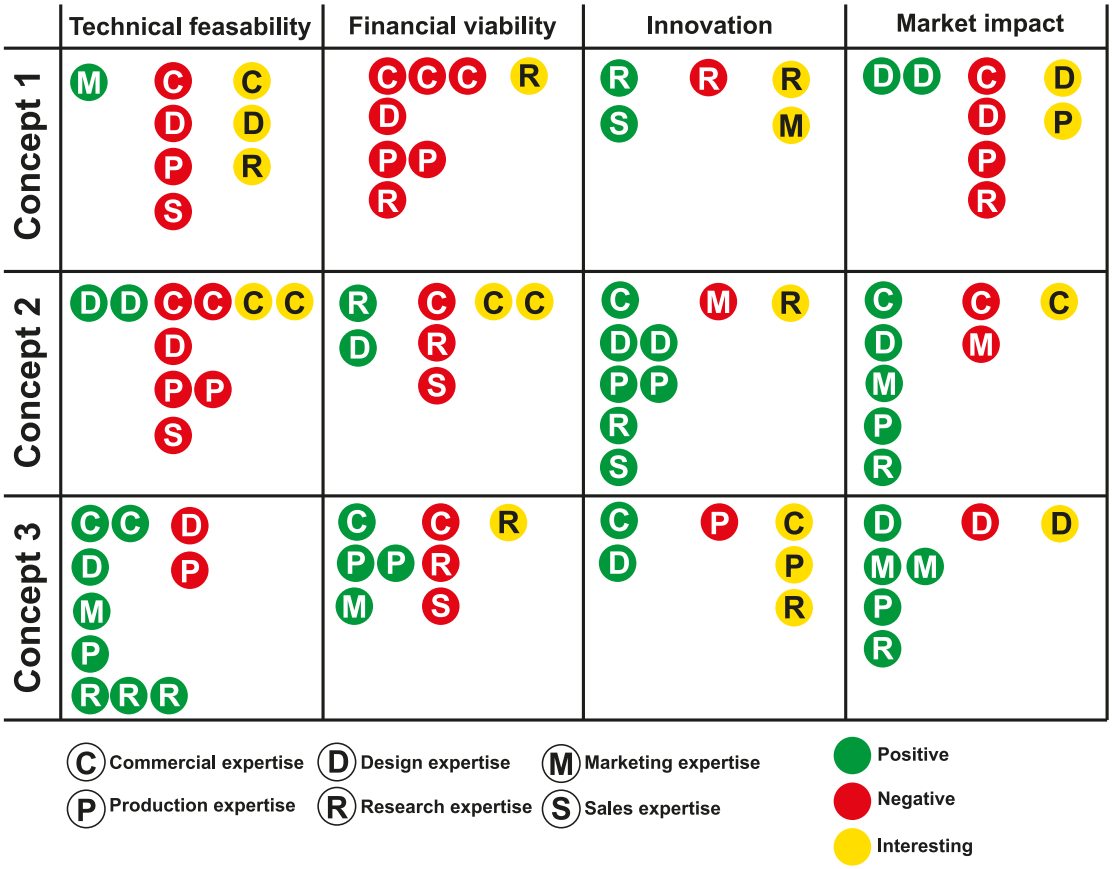


Figure 4. Validation of concepts by the participants with different expertise using PNI method

4. Discussion

The versatility of cork fits perfectly with the creative methods of eco-ideation. Due to its good physical properties, the new ideas generated for both applications and markets are very diverse. The interaction of knowledge among specialists produced the desired results – a high number of ideas in the field of construction, some of which show improvements over existing ones and others that facilitate the generation of new concepts. The creativity workshop can be considered successful in terms of participation and the quantity and quality of ideas; the evaluation workshop far exceeded the expected number of participants and the evaluation method was participatory. The hybridization of creative techniques enabled the adjustment of methods to the needs of the workshop, objectives and participants, thus producing the most out of each session. Thus, the creative workshop places the experts in a situation conducive to creativity, very different from their daily work. The evaluation workshop revealed a technique for participants to assess ideas quickly and effectively using a series of well-controlled criteria, providing useful information and closely linked to the know-how of the cork sector. The identified weaknesses of this creative method are, on the one hand, the reluctance of participants to share their knowledge; and on the other hand, the aspects of authoring and managing the possible new products to be developed.

The main objective of the diversification and promotion of cork in the building market is to recognise cork's status as natural, pure and noble, thus improving the status of cork in the building sector, which does not correspond with its status in the wine sector, where cork is known to be the finest material for stoppers. Because of the cork shortage and its endemic origin in the coastal regions of the western Mediterranean basin, diversification in the building sector does not aim to make cork the leading insulation material. The objective of this diversification is not to substitute cork for common insulation materials but to develop a new range of insulation products at a high level. Cork availability is limited, so the potential for substitution in volume terms is very low. However, the potential for substitution from a market view is higher. In this regard, cork can substitute for other materials, not only for insulation materials but also for external cladding on buildings.

From an aesthetic approach, it cannot be ignored that the use of cork supposes an important decision. So its gradual introduction and acceptance in the world of architecture and construction should be driven by use in iconic, prestigious and unique buildings. This recommendation that, a priori, could be considered an aggressive aesthetic, has been widely accepted with other materials such as Corten steel, as seen in a large number of historical interventions (Hernández Martínez, 2012).

The introduction of these products in the building market has to be accompanied by a strong component of aesthetic innovation and design that enhances their use, and not only for the most eco-friendly professionals. This requires an important investment in design or eco-design, taking into account environmental criteria. And as mentioned above, the introduction of new designs will improve and update current manufacturing processes, which are characterised by low technological development. For this reason, the cork industry cannot currently meet drastic changes in market demand, except in the stoppers sector. This has to be taken into account in future manufacturing processes.

The three final concepts, as examples of this philosophy, aim to respect and demonstrate the pureness of cork. All products are placed directly into buildings, without coverings that hide them. There are many production issues that have to be solved and also manufacturing processes have to be adapted and created, but these needs will serve as stimulus for this to happen. Further steps will be to develop prototypes of each concept, on which we can test them in the market. Moreover, subsequent deeper technical development will be needed and implemented through prototypes. Thus, prototypes will be essential for a better assessment of the presented concepts.

5. Conclusions

· The versatility of cork fits perfectly with the creative methods of eco-ideation. Due to cork's good physical properties, the new ideas generated for both applications and markets are very diverse.

· The creativity workshop can be considered successful in terms of participation and the quantity and quality of ideas; it placed the experts in a favourable situation for creativity due to both the very different natures of their daily work and the exchange of knowledge among other specialists with different areas of expertise.

· Hybridization of creative techniques enabled the adjustment of methods to the needs of the workshop, objectives and participants, thus making each session highly productive. The evaluation workshop revealed a technique through which participants could quickly and effectively assess ideas using a series of well-controlled criteria, providing useful information closely linked to the know-how of the cork sector.

· The main objective of the diversification and promotion of cork in the building market is to recognise cork's status as a natural, pure and noble material. The strategic introduction of cork to the building sector, through its use in iconic and singular building projects, is necessary; this requires an important investment in design or eco-design.

· The concepts generated in this study are in line with this approach; they are examples of the noble use of the material, they take advantage of the good properties of cork, and they give buildings a unique character due to the singular aesthetic of cork.

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