

# CORK FOR SUSTAINABLE PRODUCT DESIGN

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**ABSTRACT:** Sustainable Product Design is currently accepted as one of the most promising trends in the “Sustainable Development” movement. It is often seen as a facilitation tool to implement Sustainability in practice, by improving the life cycle and eco-efficiency of products, by promoting dematerialization and by proposing completely new innovative sustainable solutions, services and products which encourage and communicate new “Sustainable Life Styles and Scenarios” and that can both stimulate the economic competitiveness of local industries and promote a more sustainable consumption [1]. In this context cork, a natural, recyclable, non-toxic, renewable resource, with outstanding environmental qualities, incorporating a high potential of innovative technological characteristics, can play a relevant role. Cork is a versatile raw material which adopts different technological transformation processes which can be used in different applications. Among the most noteworthy groups of cork materials available on the market are natural cork, granulates, composite agglomerates and expanded agglomerates. In addition, extensive ranges of new composite agglomerates have been patented and are at the implementation stage. This article presents an overview of: 1) the environmental, social and economic aspects of cork; 2) the cork materials, processes and technologies including a portfolio of cork materials available for sustainable product design; 3) a reflection about the current cork applications along with a discussion centred on the gap between the research and development of cork materials and its application in new products. The article concludes by stating that cork offers industrial designers a number of product-technology options that can generate potentially new sustainable product design solutions not yet tested on the market.

**Keywords:** Cork, Design, Sustainability, Innovation

**RESUMO:** O Design de Produto Sustentável é actualmente considerado uma das tendências promissoras para o “Desenvolvimento Sustentável”. Sendo frequentemente encarado como uma ferramenta para implementar a sustentabilidade na prática, melhorando o ciclo de vida e a eco – eficiência dos produtos, impulsionando a desmaterialização e propondo novas e inovadoras soluções sustentáveis de serviços e produtos que promovem e comunicam novos “Estilos de Vida e Cenários Sustentáveis” e que simultaneamente estimulam a competitividade económica das indústrias locais e a promoção de um consumo mais sustentável [1]. Neste contexto, a cortiça, um recurso natural, reciclável, não-tóxico e renovável, com excelentes qualidades ambientais e com um alto potencial de inovação tecnológica, tem uma importância determinante. A cortiça é um matéria prima versátil que adopta diferentes processos de transformação tecnológica capaz de ser utilizada em diferentes aplicações. Entre os grupos mais notáveis de materiais de cortiça disponíveis no mercado estão, a cortiça natural, granulados, aglomerados compósitos e aglomerados expandidos. Adicionalmente, uma série de novos aglomerados compostos foram patenteados e estão em fase de implementação. O artigo apresenta uma visão geral sobre: 1) os aspectos ambientais, sociais e económicos da cortiça, 2) os materiais, processos e tecnologias de cortiça, incluindo um portfolio de materiais de cortiça disponíveis para o design de produto sustentável, 3) uma reflexão sobre as aplicações de cortiça existentes, a par de uma discussão centrada na lacuna entre a investigação e desenvolvimento de novos materiais e a sua aplicação em novos produtos. O artigo conclui que a cortiça oferece aos designers industriais uma série de materiais e opções tecnológicas que representam um potencial de desenvolvimento de novas soluções de design de produto sustentável ainda não introduzidas no mercado.

**Palavras chave:** Cortiça, Design, Sustentabilidade, Inovação

## 1. SUSTAINABLE PRODUCT DESIGN TOWARDS INNOVATION

The concept of “Sustainable Product Design” has taken on a greater role in the last decade. Defined as a cross-disciplinary concept that includes Product Design and Sustainabil-

ity, both of these are oriented towards change and the future. Product Design is concerned with creating new products and services that generate value and innovation. Sustainability is concerned with the well – being of the future, embracing how best to meet consumer needs – social, economic and environmental – at a systematic level [2]. Sustainable Product

Design is a means to develop new solutions and to incorporate eco-efficient aspects into new products, thus signifying an essential contribution towards ameliorating the environmental impact of products, accompanied by an increase in their social value [3]. It is calculated that 75% of the environmental impacts (such as the costs) of a product throughout its life cycle are determined at the design stage. This is the stage when the materials are chosen, the production methods are considered, and the recycling methods may also be selected [4]. The concept of eco-efficiency presupposes “dematerialisation” through the creation of value and the rational use of resources, namely less production of emissions and residues and fewer production costs arising as a challenge to processes of innovation [5]. As argued by several authors [6], the innovation strategies for Sustainable Product Design integration depend on the levels of originality and associated risk in product development as well as with regard to the integrated strategies promoting R&D in companies. One can characterize the levels of product design innovation as follows:

- **Pioneers** are those companies which launch innovative products or ideas, often characterised by strong leadership and R&D capacity; although they are the ones that present a greater level of risk, they also present the best conditions for competitiveness in the long term.
- **Improvers or Modifiers** are those who develop a strategy that is reviewed or partially reoriented, with competitive advantages that challenge the pioneer; risk levels tend to be lower.
- **Imitators** are those who copy the strategies of others, avoid the risk of investing in research, which is normally costly, but do have a high possibility of failure in the type of applications in which they invest and whose actions tend not to yield results in the long term.

## 2. CORK AND SUSTAINABILITY

### 2.1. Cork

Cork is “the suberous parenchyma originating from the suberphelloid meristem of the cork oak (*Quercus suber* L.), that constitutes the covering of its trunk and branches” [7]. It is a light, elastic material, practically impermeable to liquids and gases, a thermal and electrical insulator and an acoustic and vibration absorber. It is also innocuous, resistant to rot, and can be compressed with practically no lateral expansion. Macroscopically, cork is made up of layers of alveolate cells, whose cell membranes have a certain degree of impermeability and are full of a gas usually considered similar to air, which occupies around 90% of its volume. It has an average density of around 200 kg/m<sup>3</sup>, and low thermal conductivity [7, 8]. Cork also has remarkable chemical and biological stability and good resistance to fire. Cork is extracted from the trunk and branches of the cork oak, in the form of semi-tubular pieces, usually in summer, and at legally prescribed intervals (in Portugal) of nine years. Harvesting begins after the tree has attained a circumference of around 70 centimetres at 1.3 metres from the ground. The tree cannot be completely stripped of its suberous covering, because it would not survive this operation. This operation is carried out manually,

with an axe, although mechanical processes do now exist. The first stripping (*desbóia* in Portuguese) produces virgin cork with a very uneven outer surface. Successive strippings produce cork with a more even outer surface, called reproduction cork or *amadia*. The first reproduction cork, still rather uneven, is called *secundeira* or secondary cork, and is used above all, like the virgin cork, for grinding, obtaining granules and afterwards, in the manufacture of agglomerates. *Falca* is obtained from the pruning waste, a mixture of virgin cork, inner bark and wood, traditionally removed with an axe or an adze from the pruned branches of the cork oak trees, or with specific mechanical equipment [7].

### 2.2. Cork and the Environment

Cork, the greatest product of the Cork Oak forest, is a raw vegetable material with exceptional environmental qualities: it is a renewable resource which is recyclable, non-toxic and durable as well as being a great CO<sub>2</sub> fixer, with excellent physical and mechanical properties. Considered as part of the Portuguese national heritage, for centuries the Cork Oak forest has been legally protected in Portugal. It is forbidden to cut them down and there are incentives to plant and exploit them in order to generate clusters of socio-economic activity in those regions where they are planted [9]. The life span for stripping the bark from a cork oak is between 150 and 200 years, the equivalent of 13 and 18 extractions. The cork oak’s capacity for regeneration is enormous, even without using chemical herbicides, fertilizers or irrigation. At the end of nine years the bark is reborn and the cork is soon ready to be harvested once again through a careful manual process, without damaging the cork oak or the environment [10].

Curiously, the old Portuguese popular saying “If you are planting for your grandchildren, plant a cork oak”, has much in common with the Sustainable Development described in the report *Our Common Future* by the World Commission on Environment and Development of the United Nations: “the development, which implies meeting the needs of the present without compromising the ability of future generations to meet their own needs”

#### 2.2.1 “Montados” – the Cork Oak Forests

The Cork Oak is an emblematic tree from the Mediterranean Basin, particularly South-Western Europe and Northern Africa. It is an essential component of a combination of semi-natural ecosystems, of which the *montados* form a multifunctional system of land use, integrating cultural landscapes of high historic and social value [10]. Cork Oaks are reasonably tolerant to drought, have deep root systems that capture water from the soil depths, and are able to face the stress of the dry and hot Mediterranean summers. Their leaves are reactive to drought, with “pores” (stomata) that close, reducing water loss through transpiration during the dry seasons. In addition to cork and its by products, such as hunting or pasturing, the *montados* and Cork Oak forests perform important tasks in regulating the water cycle and in soil conservation, and are important in combating desertification [10, 11]. Since they normally constitute heterogeneous and resilient

habitats, *montados* and Cork Oak forests house high levels of biodiversity. In addition, not affecting the ecosystem processes allows *montados* and Cork Oak forests to be managed as multiple use systems able to perform essential ecosystem services. Careful management and the suitable added value of the services rendered by these systems are essential for the sustainability and benefit maintenance generated for society [10-12]. The cork forest is responsible for making a very important contribution to the economy and the ecology of several Mediterranean countries and Portugal has one of the largest cork forests in the world. The area of Cork Oak in the Iberian Peninsula increased steadily throughout the 20<sup>th</sup> century, and has since stabilized. Living in dry and arid habitats, cork trees have a distribution mainly to the south of the Tagus river [13]. Portugal possesses about 32 per cent of the world's total acreage (2,277,700 hectares), which corresponds to an area of 736,700 hectares, ca. 23 per cent of the country's woodlands, thus the cork oak represents the dominant species in Portugal [13, 14]. The Alentejo region contains 72% of this area, corresponding to 527,200 ha, while Lisbon and the Tagus Valley possess 155,900 ha (21%), the Algarve region 28,400 ha (4%) and the less dominant region is the northern region with 10,000 ha (1%) [13, 14].

### 2.2.2 Cork Forest Biodiversity and Soil Conservation

The Cork Forest is a unique ecosystem made up of cork oaks, which are characterized by their easy adaptation to different kinds of soils, even those that are not very economically viable. The maintenance of the Cork Forest prevents the degradation of the soil, increases the rate of rainwater infiltration and creates habitats for different groups of fauna and flora. The Cork Oak forest has contributed to the survival of many species of native fauna and to safeguarding the biodiversity that exists in this type of habitat, namely various species of ants, bees, butterflies and reptiles, as well as the Iberian lynx, the Eurasian black vulture, the black stork and the Imperial eagle [15]. Increased planting of Cork Oak forests has prevented desertification in the south of Portugal, a dry, arid region with sandy ground, since it helps reduce soil erosion and assures the subsistence of its populations. The importance of the Cork Oak forest can be exemplified in its use as a barrier to the advancing desert in North African. It is known that forests perform a fundamental role in regulating water balance, infiltration processes and superficial water erosion, with isolated trees in the *montado* functioning as rain interception wicks that lead to underground water retention. Soil conservation is a fundamental aspect of the sustainability of the *montados*. In the regions with a Mediterranean climate, soil fertility is dependant on organic matter, resulting from the decomposition of organic waste (leaves, branches, dry grass). The soil richer in organic matter is characterized as possessing better infiltration, water storage, nutrient retention, aeration and root growth capacities. The diverse forms of plants covering the *montados* ensures, through their coverage and above all their root systems, protection against soil erosion, namely in areas of steep slopes. By promoting the infiltration of rain and preventing soil erosion, the *montados* contribute

to water cycle regulation, an environmental service particularly important in Mediterranean climatic areas where water is a scarce resource (a situation that may become more aggravated in the future) [10, 15]. Given this, the Forest Stewardship Council (FSC) certification was established to promote the responsible management of the world's forests [16]. The 100% FSC Cork Certificate No. SW-COC-2008 is the forest management certification for the Cork Oak forest, making it possible to guarantee appropriate business ethics throughout the chain of custody from the forest and preservation of the Cork Oak forest to the end product [16].

### 2.2.3 Cork Carbon Sequestration

In recent years, public awareness of the importance of the Cork Oak forest in contributing to the environment, economy and society has grown, since in addition to forming a natural barrier to desertification, recent studies indicate that it is also an excellent CO<sub>2</sub> fixer, countering current trends in climate change and world pollution levels. Exploitation of the Cork Oak forest has had a significant impact on fixing atmospheric carbon dioxide, the gas responsible for the global warming of the planet, since, as well as being a vegetable element that converts CO<sub>2</sub> into oxygen and carbon compounds through the process of photosynthesis, it also fixes carbon in the actual cork as it grows. According to a study published by the *Instituto Superior de Agronomia* in Lisbon [17, 18], it has been calculated that the Portuguese forest alone (32% of the Cork Oak forest area in the world) in 2006 represented the fixing of 4.8 million tons of atmospheric CO<sub>2</sub>, the equivalent of 5% of CO<sub>2</sub> emissions in Portugal. A cork oak from which cork is extracted will produce between 250% and 450% more cork than a tree from which cork has not been extracted. Knowing that cork extraction stimulates its growth, it is easy to deduce the capacity to fix CO<sub>2</sub> throughout the lifetime of the cork oak. It is estimated that an annual production of 350,000 tons of cork corresponds to a fixing of 182,000 tons of carbon dioxide, which is retained in the cork oak, or products made from this raw material throughout its life cycle, which are only freed when it is burned. Through recycling we can delay the liberation of this carbon dioxide into the atmosphere [18].

### 2.3. Characterization of the Cork Sector

The Cork Oak forest plays a fundamental socio-economic role, not just by extracting the cork but also its fruit (acorn) and leaves, which are used as animal feed, the manufacture of food oils, seed and vegetable compost, hunting, medicinal, gastronomic herbs and mushrooms [7]. Notwithstanding this, cork extraction is the largest economic activity obtained from the Cork Oak forest. Activities such as bark stripping, pruning, growing treatments and working the land provides seasonal work to around 6,000 people. Currently in Portugal more than 9,000 companies transform cork, giving work to around 15,000 workers. It has been calculated that around 100,000 people, directly or indirectly, depend on cork production, a significant volume of employment. The cork sector represents an important part of the Country's GNP (100 mil-

lion euros). It accounts for 900 million euros of Portuguese exports mainly concentrated on the production of natural cork stoppers [14]. However, the cork industry has a very high production capacity that is not fully exploited. There are significant losses in profitability, since national cork production is insufficient for the available industrial capacity and raw cork has to be imported in order to make good the shortfall [19]. Another relevant aspect is the lesser value of the cork sub-products derived from the natural cork stoppers production, which do not compete in terms of economical gains with the natural cork stoppers market. The cork sub-product, such as insulation and building materials, as well as other smaller applications, face strong competition from alternative sectors, such as wood and polymers.

### 2.3.1 Cork Markets

Portugal is the world's largest cork producer and the largest importer of cork, which is processed and subsequently exported as final consumer products. One of the most recent reports detailing the current market for cork products was published in 2009 by The Portuguese Cork Association [14]. It contained the following conclusions: Portugal is involved in transactions involving approximately 67 per cent of the global volume of exports, which makes it the world leader in producing and transforming cork, and also with regard to exports related to cork. On a global production level, 52.5 per cent of cork originates from Portugal (more than 150 thousand tonnes a year from a total of 300 thousand tonnes annually). In 2007, imports reached 131 million euros and 63 thousand tonnes. The main destination sector for cork products is the wine industry (cork stoppers), which absorbs 69 per cent of all production, followed by the building industry (pavements, insulation, flooring, coverings) with 13 per cent. The main destinations for Portuguese production are highly demanding consumer markets such as the USA and EU countries, particularly France and Spain. The main products exported are natural and agglomerated cork, and there is strong competition between different products intended for the same purpose. Approximately 90 per cent of the cork processed nationally is destined for the international market. This is an important source of income for Portugal which increased to 853.8 million euros in 2007, corresponding to 159 thousand tonnes of exported products. The main country consuming natural cork stoppers is France, at a value of 120 million euros, followed by the USA, with 76 million euros. France also leads the consumption of champagne cork stoppers, with 29 million euros, with the USA occupying second place with 15 million euros. Concerning building materials, the main products exported are cubes, blocks and other agglutinant products, representing 72 millions euros and 28 thousand tonnes, respectively. These are followed, with 44 million euros and 26 thousand tonnes, by other similar products without the agglutinant. The USA is the largest importer of agglomerate blocks with agglutinant, with imports reaching 15 million euros in 2007, followed by Russia with 8 million euros. Regarding the second most exported product – blocks without agglutinant – Germany is the main consumer with 15 million euros, followed by the USA with 6 million euros. Since the year 2002 Portuguese cork exports have shown a year-on-year downward trend [14].

### 2.3.2 Cork Industry and main Manufacturing Processes

Following its inception, the cork industry was mainly located close to its markets (such as Port Wine production) and a cheap source of labour, but nowadays most of the preparation sub-sector is located in the south of the country and is responsible for most of the black agglomerates, while the other three sub-sectors, transforming, agglomerating and granulating, are concentrated in the north of the country, mainly in the Aveiro region [14]. This geographical distribution means that costs arise from the transportation of raw material, coming from the preparatory sector, to the centres for the transforming sector. This situation has caused companies from the transforming sector in the north of the country relocate to the south. According to data from the Portuguese Statistics Institute, the Cork Industry is distributed over twelve districts. However, the industry only has a significant presence in the Aveiro (Santa Maria da Feira Municipality) and Setúbal districts. The companies in the cork industry present a diversified structure, depending on their function and activity. There are few medium-sized businesses and company sizes range from one extreme to the other, from small micro-businesses to large businesses. There is a relationship of dependency between the small companies and the larger ones, considering that the larger companies drain off the product from the small ones and supply the raw material and different kinds of financing. The small companies do, however, play an important role, assuring system flexibility, and fluctuations in demand have a considerable impact on them. The cork industry may be divided into 5 branches of activities [7]:

1. Production involves exploitation of the Cork Oak forest, and specifically planting the Cork Oak forest, treating and preserving the cork oaks and stripping the bark.
2. Preparation is the activity where the *amadia* cork is selected and prepared, through boiling, marking, cutting, selecting and packing.
3. Transformation is the activity, either by carving or simply cutting a plank, where a varied range of natural cork products are produced (cork stoppers, disks, cork paper, handicrafts). This is an activity which involves several different processes, namely separating the cork planks by thickness and quality, separating the cork, pre-drying, rectification, further washing and drying, selecting, marking on the body and/or tops, treatment, commercialisation and dispatch. The parings resulting from the cutting processes are destined for granulation. This is connected to the preparatory activity.
4. Granulating the activity based on using the parings that result from the production of natural cork stoppers and cork waste of an inferior quality. The production process is based on the triturating and milling of cork parings, which are then classified according to their volumetric mass and granulometric characteristics.
5. Agglomerating is the activity which consists of agglutinating granulates and other kinds of inferior quality cork which, through the application of heat and pressure in autoclaves, involving steam from superheated water, gives rise to agglomerates.

### 3. CORK MATERIALS FOR SUSTAINABLE PRODUCT DESIGN

Cork is a versatile raw material that can be adapted to different technological transformation processes and applications. Among the most noteworthy groups of cork materials available in the Portuguese industry are natural cork, granulates, composite agglomerates and expanded agglomerates. Additionally, a wide range of composite agglomerates (a combination of cork with other materials) has already been established as business areas (such as rubber cork), and others, which have been patented, are at the implementation stage. This section first introduces the eco-efficient aspects of cork materials and then presents a categorization-portfolio of the most important cork materials and their composites from a product design viewpoint, including the most recent research and developmental findings concerning advanced cork composites.

#### 3.1. The Eco-efficiency of Cork Materials

The cork sector is self-sufficient in its resources, where nothing is wasted and everything is valued. From its forest origins, moving on to its extraction and subsequent industrial transformation with low levels of emissions, then to its optimized recycling process, cork is defined as an eco-efficient material with a complete and closed life cycle, which is practically waste-free. In the cork products manufacturing process, 100% of the material resource is used and the production residues are re-used for cork agglomerates. The part that is not usable (for example cork powder) is used for combustion and energy production, which is current practice in the sector. This industry has low associated energy consumption where a significant proportion of the energy needs of the production process are satisfied by using vegetal biomass waste. The re-

cycling potential of cork is still enormous, if we bear in mind that more than 70% of cork usage is aimed at the cork stopper market and there are few isolated recycling programmes to recover this material. Concerning the life cycle assessment, a study carried out by PricewaterhouseCoopers/Ecobilan [20] of the lifecycle of the cork stopper in comparison with aluminium and plastic stoppers concluded that, relative to greenhouse gas emissions, the production and usage of each plastic stopper releases 10 times more CO<sub>2</sub> than a cork stopper and presented CO<sub>2</sub> emissions for the aluminium stopper 26 times superior to that of cork. It is also possible to reduce the “carbon footprint” of cork products by increasing the recycling of raw material (for example by recycling stoppers), increasing the renewable energy quota, improving the use of energy efficiency and diminishing the consumption of fossil fuels in transport, industrial processing and distribution. According to the above mentioned study, cork stoppers have environmental advantages in comparison with alternative closures if one considers the consumption of natural resources, the emissions of gas and particles into the atmosphere, water pollutant emissions and waste production [20]. When looking at the Cambridge Engineer Selector Database [21, 22] one can confirm that the Eco value cost of Cork compared with many other materials is the best choice (high value and low eco-cost).

#### 3.2. Portfolio of Cork Materials for Design

Despite the considerable availability of cork materials and technologies in the cork sector, product development is scarce in almost all cork industries. To further disseminate the existing portfolio of cork materials for sustainable product design, a selection of seventeen cork materials available in the cork industry or registered as patents is presented below [23].

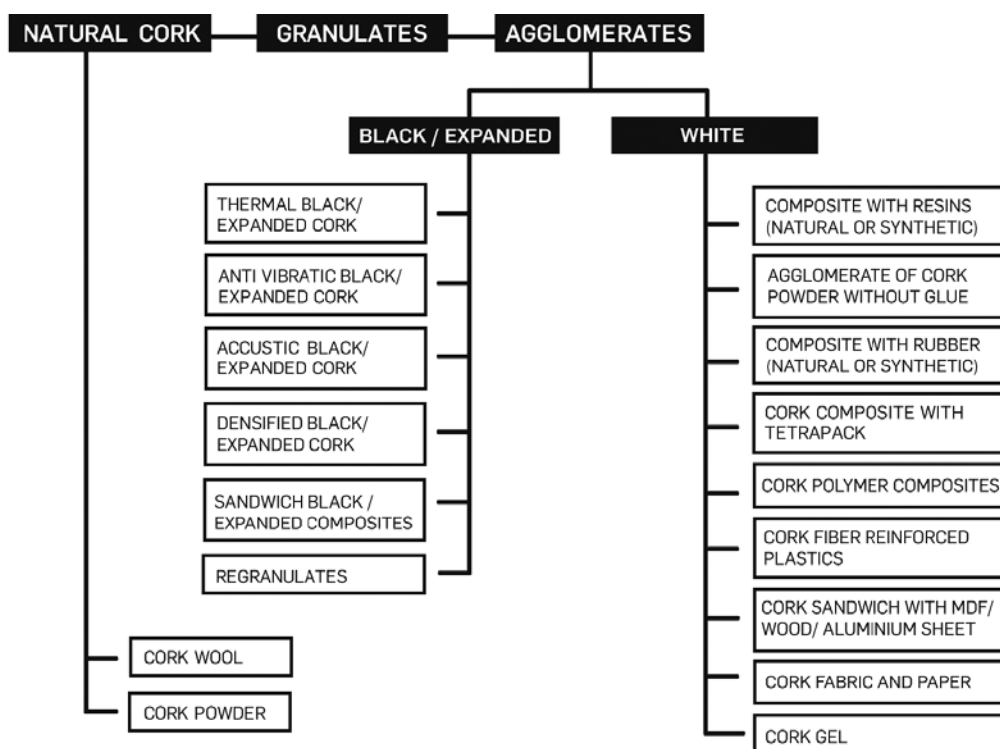


Fig. 1. Schematic Portfolio of Cork Materials

1. Natural Cork – The basic way of using natural cork is through cork planks, resulting from the stripping of the cork oak tree. After they have been extracted from the cork oak, the cork planks are sorted by quality and thickness for different industrial uses, the best known being the use of boiled cork planks in order to obtain products such as cork stoppers for various types of closures (produced by punching and mechanical and chemical finishing operations), cork discs (using the process of scraping and subsequent removal of the interior) or the ends of fishing rods (closures that are perforated and glued). In addition to these applications, cork planks may also be used for many other purposes [7].
2. Granulates – these are made by grinding scraps, parings, virgin cork, cork pieces or stopper production waste and are mainly used as raw material for the manufacture of agglomerates. They are also used directly as products for thermal and acoustic insulation, for filling spaces, mixed with mortar and as a resistant layer under insulating floors. They are further used to reduce weight in certain building elements and for making building blocks. Granulometry (usually more than 0.25 mm and less than 22.4 mm) and apparent density (usually 70-90 kg/m<sup>3</sup>) may vary. Granulates are obtained from different kinds of milling actions, depending on the material to be ground and the type of granules desired [7].
3. Black / Pure / Expanded Agglomerate – Made through a process agglutinating granules of crude virgin cork, mainly *falca* (which has a high extractive level and functions as a natural inter-granular binder) and other types of cork of inferior quality. The agglomeration is carried out by the autoclave process which also works as a mould. The granules are subjected to heat and pressure, with superheated steam. These are usually produced in the form of boards of different thicknesses (though other forms may be obtained), followed by corrections in size and squareness. One or both of the larger sides of the slabs may be sanded. This is a natural product, of vegetable origin. No synthetic agents are used, therefore it is a product with excellent ecological characteristics [7]. The following sub-groups can be found on the market:
  - Thermal Black Agglomerate – Uses a granulometry of between 5 and 22 mm, with a density of around 115 kg/m<sup>3</sup> and a value for the thermal conductivity coefficient of around 0.045 W. m<sup>-1</sup> K<sup>-1</sup>. It is used as thermal insulation in the building industry [7].
  - Black Anti-Vibratic Agglomerate – Has a higher density, usually above 170 kg/m<sup>3</sup>, and a mechanical resistance superior to the black thermal agglomerate. Its elasticity allows it to bear relatively high loads. It is used as anti-vibratic insulation in machinery, building foundations and joints, and for other anti-vibratic purposes [7].
  - Black Acoustic Agglomerate – Uses granules with a typical granulometry of between 5 and 10 mm. It has a density lower than the thermal and anti-vibratic agglomerate, of around 95 kg/m<sup>3</sup>. It has a high capacity for acoustic absorption, decreasing reverberation times. It is used in civil construction for sound correction and reduction [7].
4. Sandwich of Black Agglomerate with Natural Fibres or other materials – A process that uses panels of black agglomerate in a sandwich with other materials, for different purposes, namely to improve thermal performance. Some materials already used industrially are coconut fibre and neoprene.
5. Regranulates – Produced by using the waste from expanded agglomerate, these are essentially used to fill walls, terraces and coverings, and may be mixed with concrete [7].
6. Densified Black Agglomerate Boards – The black cork agglomerate densification is a completely natural (without glues) process and therefore does not have any of the problems of possible toxicity presented by other agglomerates. It involves compressing boards of ordinary black agglomerate in a heated plate press, at a pressure, temperature and pressing time suited to the type of boards used and the characteristics required for the final product. Afterwards the boards are removed from the press and allowed to cool and stabilise in the air, for the time necessary to reach correct dimensional stability. This process allows greater control of the final density (much higher than the existing ones), a better surface finish without extra operations, with different physical-mechanical characteristics and an apparently competitive manufacturing cost, which makes it possible to extend their potential field of use. The process that has been developed is easily adapted to current manufacturing systems and new products for new applications. This makes it possible to diversify production and provide greater added value to the traditional agglomerate [24].
7. Agglomerate Composite with Natural or Synthetic Resins – The composite agglomerate best known and most widely used in industry is white agglomerate. This is made from waste products from the transforming cork sub sector, and represents a means of giving value to waste and an excellent opportunity to recycle (used cork stoppers) or re-use cork products. By maintaining all the properties of cork and being able to acquire extra characteristics, it can take on numerous forms and combinations and therefore occupies an advantageous position compared with other composite materials. Agglomerates are made out of a process of agglutinating the cork granules with a specific, pre-determined granulometry and density, through the joint action of compression, temperature and an agglutinating agent, depending on the final product desired. The most common process uses synthetic resins of polyurethane, phenols (phenol formaldehyde) and melamines, and sometimes also resins of vegetable origin, to give a mixture of granulate and resin. In most industry uses, the agglomerates are usually produced in moulds, which are normally metal (or fibreglass for high frequency systems) for the manufacture of blocks or rolls (the casts are respectively parallelepiped and cylindrical in shape), which it is then possible to laminate. The sheets formed in this laminated process may have various kinds of surface finish: wax, synthetic varnish (acrylic or polyurethane), treated by ultra-violet radiation (UV) or dried in hot air tunnels or re-covered with different films (PVC, for ex-

- ample). White agglomerates can be used in moulding, turning or cutting processes for many different purposes, from civil construction (coverings, insulation) to industry (automotive, aeronautical) or home products (furniture, accessories) [7].
8. Agglomerate of Cork Powder without addition of glues – This is a process of manufacturing agglomerate from cork powder, with the possible incorporation of other components, without using glues in the agglomeration. First, the cork suberin is depolymerised, with basic alternative solutions and acidification, followed by an operation to eliminate the liquid stage until a certain percentage of humidity is obtained in the solid material. Heat compression is then carried out, which also includes various alternative solutions. In this stage various chemical constituents of cork are polymerised, functioning as agglutinating elements. This also allows mixing with other non-cork particles and the adhesion of covering films. It is thus possible to carry out the agglomeration of very small particles, with a wide specific area, without the technical and economic problems associated with the usual processes. This is a material that adds value to the greatest waste in the cork industry and provides an opportunity to create different products [25].
  9. Agglomerate Composite with Rubber (RubberCork) – Rubbercork or CorkRubber is a kind of cork agglomerate that can be formulated in different ways, and is made by mixing and agglomerating cork granulate with natural or synthetic rubber (in powder or small particles) and other agents (vulcanising agents, anti-oxidants, polymerisation accelerants, colourings). These are homogenised, compressed and heated in rotating cylindrical mixers. Finally, the mixture is rolled out until it produces a homogeneous mass that will be cut into boards and placed in moulds, compressed and treated just like the composite agglomerate with synthetic or natural resins, thus giving blocks that are later cut to the required sizes. RubberCork can have a density that ranges between 250 and 950 kg/m<sup>3</sup>. It combines the compressibility and elasticity of cork with resistance to oil and gas and the flexibility of rubber in a product that provides great compatibility with liquids, minimum distortion through compression, reduction of vibration and an excellent capacity for recovery. Some uses are in gaskets, floors and anti vibratic insulation [7].
  10. Agglomerate Composite with Tetrapak® cardboard waste packing – this uses the process for producing composite agglomerates but includes in its composition a combination of fibres and particles deriving from the shredding and/or grinding of Tetrapak® packaging, optionally including other materials, preferably without adding external binding agents, but optionally with the incorporation of glues, by compression and heating, using appropriate operating conditions for the agglomeration to consolidate the agglomerate. This process is preferentially applied to residues of used Tetrapak® packaging but may also be applied to industrial residues. Materials are obtained with a wide range of characteristics for multiple applications, coverings, anti-vibratic insulation, floorings, which are anti-electrostatic and with the possibilities of being used as intelligent materials [26].
  11. Cork Polymer Composites (CPC's) – can be produced with cork powder (50% wt.) and mixed with polypropylene (PP), polyethylene (PE) or Polyurethane gel by pultrusion with the purpose of preparing cork-based composite by compression molding, thus the aggregation of the particles (and in some cases the adhesion of the covering particles) is due to the use of different kinds of thermoplastic binder. CPC have good dimensional stability, lower water uptake, a better acoustic insulation performance, greater rigidity as opposed to the flexibility of the usual cork agglomerates and similar behaviour in terms fire resistance, flexural modulus and impact resistance when compared with traditional solutions, although inferior in terms of mechanical strength [27, 30]. This process is not structurally very different from the competing ones and may therefore be easily adapted to industry which also allows different uses from the normal ones. Thus, the CPC materials have showed important characteristics to be considered as good candidates to be applied in the design of flooring and construction systems [30]. and have extended possibilities of their application (still at an exploratory stage) in the area of comfort and the medical field. Another innovation is the development of cork composites with bio-plastics, contributing to research and development in renewable base cork composites [23].
  12. Cork Fibre Reinforced Plastics (FRPs) – Provide another series of opportunities in the realm of technologies for reinforced plastic composites with fibres, which may be used in industrial applications, such as trains, ships, buses and aeronautics. One example already being commercialised uses carbon fibre and is used in kayaks. In this field, the use of natural loads (in addition to cork) in new composites has been considered, providing the mechanical requirements of the materials and market demands are satisfied.
  13. Sandwich of Agglomerate with laminated sheets of MDF, Wood, Aluminium or others – This process can use a great variety of base materials, namely sheets or panels of wood, MDF and aluminium. The sheets of cork are glued and pressed on to the selected materials. Some tests have been carried out in this area using sheets of cork agglomerate on sheets of wood, MDF and aluminium for various furniture applications.
  14. Cork Gel – A compound of silicone with natural cork granulate. Commercially known and used as tape for bicycle handlebar grips because of its excellent qualities: adhesive, it absorbs shock and impact, is comfortable, resistant to heat, water and sweat and is elastic. It is produced and sold in the form of tape in different colours and finishes.
  15. Cork Fabric and Paper – It is also known as cork leather or cork skin and is produced from very fine laminated sheets of natural cork (usually with a thickness of 50-500 μm) or agglomerated cork glued on a textile or paper base. The grade of the backing varies depending on the use of the cork fabric. This fabric has a long durability and its texture is that of cork, which can be felt on touching it. Vari-

ous types of pattern are produced and used in accessories, namely in decorative leatherwork, fashion and clothing.

16. **Cork Wool** – May be applied for different purposes, as in certain kinds of packaging, but also in filling mattresses, pillows or sofas. There are special inherent properties: absence of toxicity, compressibility and power to recover, durability, lightness, impermeability and insulation, and it is cited as being able to eliminate certain sleep disturbances. It may also be used in association with different aromas for health-related purposes.
17. **Cork Powder** – The residue derived from the industrial transformation of cork, a series of chemical compounds may be obtained from it for different purposes and applications, namely for medical purposes or as an energy source [28]. The valorization of this residue combined with thermoplastics may allow for the creation of new cork-polymer composite (CPC) materials with interesting properties provided by cork. The impact, hardness, water absorption and acoustic properties are being investigated to create new products from cork powder with high added-value [29, 30].

## 4. DESIGNING WITH CORK

### 4.1. Historical overview

The use of cork for everyday objects goes back thousands of years. The first known applications have been found in the Mediterranean basin, where in centuries prior to the Egyptian, Greek and Roman civilisations, cork was already used for objects such as stoppers for amphoras and jugs, in footwear, in building beehives, such as the roof, in making floats for fishing nets, and as insulation from the cold and damp. Many cork utensils from this Era have been preserved. In Portugal one of the most emblematic artefacts is the “cocho” (a small object produced manually from the natural structure of the knots in the cork oak trunk). For thousands of years the “cocho” served as a drinking vessel. Primitive dwelling places are also known, which used cork as thermal insulation. The “tarro” is however the best known traditional artefact in Portugal and was one of the first primitive applications to be widely used. The “tarro” was used for many hundreds of years as a “flask” for peasants, especially in the Alentejo region. It was however following the use of cork as a bottle closure that cork obtained its main markets and became recognised worldwide. From the beginning of the industrial production of champagne in the 17<sup>th</sup> century (and later that of wine), to the present day, cork has been considered the greatest and best closure in the world, and this continues to provide the largest market for the cork sector. The new cork materials, namely cork agglomerates and composites, emerged at the end of the 19<sup>th</sup> century. One example is black or expanded agglomerate cork used as thermal and acoustic insulation, making the most of one of cork’s natural qualities. However, it was only from the 1960s that cork began to be used more widely in new applications. It is acknowledged that the process of researching new applications for cork has, to date, been limited by the aspect that almost all production and transformation of this material is destined for the cork stopper market. The best known

use – not in stoppers or insulation – is in the area of floors and coverings. Since the 1960s various industrial structures have appeared that are dedicated to developing and commercialising this kind of product, which exemplifies the demand for new applications in cork materials. In parallel to these applications, a series of technical applications have emerged, mainly from the 1980s, such as cork composites like Rubber-cork. These have become established, with markets of their own, aimed at new industrial applications in the automotive and aviation sectors, among others [23].

### 4.2. The last twenty years (1990 – 2010): changing the old paradigm

The decade of the 1990s represented a moment of crisis for the cork sector, with the appearance of alternative closures made of synthetic materials which were therefore economically more advantageous than cork stoppers. This was considered the biggest crisis in the sector in the 20<sup>th</sup> century and the moment to rethink the position of the cork market and the ways of approaching and communicating with this longstanding material. After Cork Stoppers (Natural, agglomerate and champagne), the second largest cork market is the building industry, with the most common cork products used in this sector being thermal, acoustic and vibration insulators (walls, ceilings, flooring); suspended ceilings; wall coverings, flooring and ceilings; baseboards; linoleums; granules as fillers and mortar mixtures; insulating, expansion or compression joints; and for industrial purposes: anti-vibration for machinery and insulation for industrial cold storage. In recent years, the sustainability values and eco-efficient nature of cork has started to be used by the sector to create an innovative image of cork in keeping with the values of sustainable development. In the 1990s the large cork companies started to focus more markedly on Research and Development and as a consequence on research into new materials and new applications for cork. One example in the future development of materials is the adoption of densification techniques to the expanded agglomerated cork, endowing cork with different mechanical and physical characteristics whilst maintaining its special ecological traits. This has enabled the diversification of potential applications and an expansion in current market applications [28]. Agglomerated cork for coverings, furniture, other decorative purposes and particularly the close relation with product design processes also has a future given the increased tendency of consumer markets for natural products [23]. Finally, the recent trend towards diversifying patterns and material combinations, can help cork to maintain its market position, although it should be pointed out that these actions should be carried out in conjunction with market studies and communication activities aimed at opinion leaders – namely decorators, designers, architects and civil engineers, who are very often responsible for selection of materials – given that at times these audiences are not aware of these products. What is more, communications activities also need to be perfectly coordinated with sufficient product supply. In the field of cork composites, the industrial manufacture of rigid agglomerated cork has yet to be explored, especially when considering the development of specific molding technologies for product design [23].

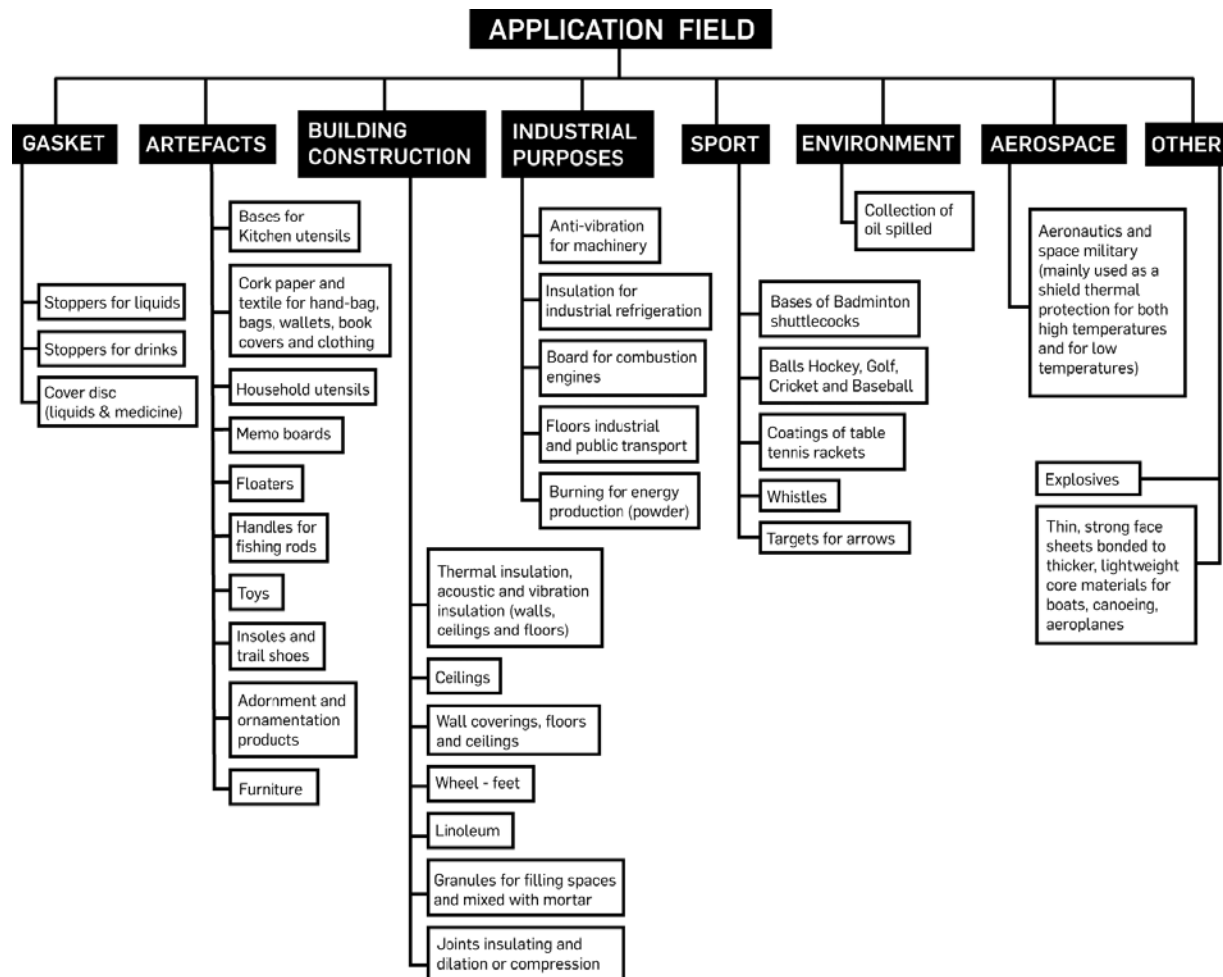


Fig. 2. Standard cork products applications

### 4.3. Cork Product Design

Cork Product Design is a new field in the cork sector, and there have been some isolated experiments; this has not been explored as yet within the context of the R&D undertaken in the cork sector, as an innovation means for new product development. In Portugal some experiments in the area of product design with the use of cork materials and technologies took place from the 1970s onwards, in the form of self-standing proposals presented by designers or design companies. The work of Eduardo Afonso Dias in the 1970s presented the first cork design prototypes, albeit using very simple processes. In 1999 the designer Paulo Parra developed a handmade cork design prototype named “Sela”, manufactured by a cork artisan. Under the coordination of Designer Paulo Bago d’Uva, a project for cork automobile interiors was developed in partnership with the largest cork group in Portugal while another project AUTOCORK, also focusing on the automobile industry, was developed by INETI (now known as LNEG) [31]. In 2005, several cork projects resulted from the initiative “Meaning of Matter in Design” promoted by Susdesign, one example being the “Puf-Fup” seat design by Ana Mestre, which made use of the sensorial aspects of natural cork, and it was the first time the sensorial characteristics of cork were considered as the primary conceptual requirement for a product [32]. The international prominence that the “Puf-fup” seat achieved demonstrates outside interest

in cork as a raw material when allied to a context of creativity and differentiation and altered the cork industry to the need for more extensive research in the field of Cork Design. Other initiatives, such as the “2nd Skin” Project from ESAD have explored the potential of cork in high added-value products, such as in contemporary jewellery [33]. Simple Forms design explored the characteristics of rubber cork in a “Red Dot” design award for the 2008 Rubber Cork washbasin. Besides the Portuguese contributions, the international designers Daniel Michalik and Jasper Morrison explored the potentiality of agglomerate cork, the former using handmade manufacturing processes and the latter taking advantage of the market visibility of a large design brand such as Vitra [23]. These preliminary examples prove that cork has potential innovation characteristics to be further explored in more advanced technological production processes, as well as in the introduction of new product segments in the market, characterized by high value and differentiation. Further testing at the product design stage was presented in the initiative “Design Cork for future, innovation and sustainability” which was carried out by Susdesign in 2008 in cooperation with the Delft University of Technology, INETI and a group of Portuguese cork companies. It sought to increase innovation in the cork sector with a strategic focus on design as an innovation tool. As a result of this, a total of 38 new product prototypes have been generated [23].

#### 4.4. Research and Development for advanced Product Design

Despite being the main producer and exporter of cork in the world, Portugal does not have a long history of Research and Development in the field of cork. The first developments in the sphere of industrial research (involving some industrial secrets) took place from the end of the 1970s, and it was only after Portugal joined the European Union that Research and Development in cork technologies and new materials took on greater prominence. In recent decades the Portuguese Cork Industry has invested heavily in Research and Development, and between 2000 and 2002 more patents were registered (35) during this period than during the preceding 10 years (19). In addition, some of the most advanced cork companies have carried out extensive R&D activities, although it should be noted that no study has been developed yet on the innovation potential of Design in the cork sector. Currently two main types of Cork Research can be identified in Portugal, one with a more academic orientation that takes place in the state-funded Universities and Research centres, and Research with a more practical orientation that is carried out in the largest companies in the sector and is therefore more directed towards the use of materials and new applications. However, the development of new products and applications and the existence of a reasonable range of patents — more than 700 at the national level — in practice faces difficulties regarding implementation by the companies who operate in markets where alternative products at competitive prices already exist, and where the absence of endogenisation of knowledge of production and economies of scale in manufacturing these products is limited. Another factor concerns the absence of a risk attitude in companies in the sector and a certain reluctance to test new developments commercially. The main criticisms levelled at the State centre on the lack of a public body or mechanism to accompany and assure a strategic attitude in the country in the area of cork. Research efforts developed at a national level by public organisations have not followed an articulated strategy focused on solving current problems and challenges, which have arisen with regard to the future of this sector. The National Institute of Industrial Property (INPI) and the National Institute of Engineering and Geology (former INETI) have mentioned the difficulties of integrating R&D into companies and the lack of a concerted global strategy for the cork sector in Portugal [34]. Some of these gaps relate to inefficient interaction between universities, companies and public bodies, the lack of financial means to support an infrastructural strategy, reduced incorporation of R&D into the strategies of cork companies in Portugal (with the exception of the large groups in the sector) and, on occasion, a limited market vision in many companies. Only a few companies in the cork sector have the capacity to conceive and develop, in other words, the capacity to generate and develop totally new products or adapt existing products. For this to take place a group of competencies for innovation and assimilation, understanding and endogenisation of external developments is needed. At the present time, only the large groups in this sector have structures, techniques and means suitable for creating and

launching new products in the market, and the others are all followers, according to the National Institute of Industrial Property, in the work “Using and improving industrial property in the cork sector” [34].

#### 5. DISCUSSION – LIMITATIONS AND OPPORTUNITIES FOR CORK SUSTAINABLE PRODUCT DESIGN

In the context of Sustainable Development, Sustainable Product Design and Innovation is a requirement to create new sustainable solutions, which integrate economic, social and environmental aspects through the whole life cycle of a product or service. When looking at eco-efficient strategies to include sustainability into Sustainable Life Styles and Scenarios, cork is seen as a promising material resource to further implement product innovation. Cork is more than an eco-efficient material *per se*. It is an integrated sustainable system which fully integrates cultural, social, economic and environmental considerations. It is a model for sustainable innovation and therefore a case for deeper analysis. This article has analysed related topics which have highlighted the limitations and opportunities for Cork Sustainable Product Design. Starting with the opportunities, several authors have in recent years studied the environmental aspects of cork, related to the natural characteristics of the material itself through being a natural, renewable, recyclable, non-toxic and durable material which re-generates in the bark of the tree without the need to cut it down. The cork tree is the central preservation point of the Mediterranean forest ecosystem, preserving the natural fauna and conserving the soil, helping to avoid desertification. The environmental ecosystem of the *montados* and Cork Oak forest is the base of a larger economic and social system, which uses cork as the base of regional economic subsistence by creating local jobs. In recent years, the Carbon Sequestration capacity of cork has been emphasised in several research studies published in Portugal [17, 18]. This idea has added to the already inherent eco-efficiency aspects of cork. This context forms the basis to present cork as the largest national resource for sustainable product design and innovation. However, when analysing the current cork markets, one can find the limitations concerning the lack of new product development strategies that are missing in the Portuguese cork sector while the downward trend in the natural cork stoppers market in the last 10 years has been statistically confirmed, although a slight recovery is now taking place. The cork industry has a large technological capacity in terms of materials and processes, but this capacity is completely focused on traditional products and applications, which in the majority of the cases no longer represent competitiveness and differentiation. This situation contrasts with the high level of investment in R&D in the last two decades which has generated a great deal of patent registration which have not yet fully utilised by industry. On the side of Product and Industrial Design, one can observe that only a few isolated experiments have taken place without an overall strategic focus, mainly created by designers who have experimented with the use of the material on their own, in their own workshops without any advanced technological and production support. This situation

has, on one hand, been due to the low strategic relevance of Design in Portugal and, on the other hand, due to the lack of strategies in the sector to fully exploit design as a development and innovation tool. In this aspect, the Project “Design Cork for future innovation and sustainability”, the results of which are not discussed in this article, has generated a base for a strategic discussion by stakeholders in science, design and industry, generating a process which has stimulated the sector to open its horizons towards advanced product design based on creative processes. One of the aspects at the centre of this applied research project has been the preparation and development of a cork materials and processes portfolio for designers and industries, based on the current technologies existing in the industry, as well as in the new patent processes not yet implemented. This portfolio is presented here in this article to further disseminate scientific and academic discussion on this subject, as well as to open the horizons to design and creativity by creating the necessary tools to stimulate a multidisciplinary discussion which can generate real “out of the box” innovation. Research and Development is therefore an essential tool for both scientific development as well as for advanced cork sustainable product design. The efficiency of the chain of knowledge supporting an industrial sector determines the technological and global development of that sector. It is therefore essential that in the context of the growing development of the cork sector, the research and technological development associated with creativity and innovation should act as a force for change [23].

## 6. CONCLUSION

Within the business context, constraints and moments of crisis can be favourable to change and frequently create new opportunities for improvement and diversification. The best way to introduce innovation in the business context is by turning innovation (for example, technological) into something meaningful that responds to real consumer needs. This modulation may be achieved by planning new products where design becomes the driving force in conquering new markets. Taking into account the international decrease in the market for cork stoppers, the great potential of cork materials and technologies for new applications and the growing use of Design as a strategic tool for innovation in companies, the cork sector can establish a new paradigm, which can help the industry to find new commercially successful market solutions. It is therefore the right moment for companies, in conjunction with designers and design companies, to experiment, test and develop proposals using cork materials in alternative innovative applications outside the scope of traditional markets, to obtain significant advantages in external market competitiveness. Creating value is the distinctive strategic mission of Design, to incorporate differentiation and altering a notion of volume to a notion of value. When analysing the existing Design value strategies for innovation in the cork sector it can be concluded that very few companies are positioned as “pioneers” at the product development level and that most companies in the sector, because of scant investment in innovation strategies, remain in the position of “imitators”. There is an obvious context of opportunity for the cork sector, should it open up

to the new contexts of innovation and risk experimentation, to test proposals and promote a strategy based on enhancing and differentiating its products, based on the vision that the industrial sectors with the highest levels of industrial development accumulate experience in promoting Design, and opt increasingly for pioneering strategies. Even though Portugal may currently lead the world in Research and Development in the sphere of cork, there are still several areas that require a commitment to R&D in the sector and thus Design is one of those imperative areas.

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