New Direction

Alternatives in the EU for a Sustainable Architecture: CORK

Founded by Margaret Thatcher in 2009 as the intellectual hub of European Conservativism, New Direction has established academic networks across Europe and research partnerships throughout the world.

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CONTENTS

1

INTRODUCTION

The global environmental crisis, manifested through climate change, land degradation and biodiversity loss, is evidence of the repercussions of the current development model. Human activity, and particularly the construction industry, contributes significantly to this problem, being responsible for a large proportion of greenhouse gas emissions and natural resource consumption. In response, the European Union has designed comprehensive, multi-sectoral strategies such as the European Green Deal, which aims to transform the economy towards climate neutrality and sustainability.

Sustainable architecture emerges as an approach to mitigate the environmental impact of buildings, optimizing the use of resources and reducing emissions throughout the life cycle of buildings. In this context, the EU is positioning itself as a key player, integrating architectural sustainability into its urban and economic development policies. Initiatives such as the "Renovation Wave" and the promotion of the circular economy stand out for their focus on reducing the environmental impact of the construction sector and encouraging the use of renewable materials.

In order to address the environmental challenges of the building sector, it is essential to maintain a holistic sustainability approach to the entire building cycle. In this aspect, two key concepts that are understood in an interconnected way will be addressed: life-cycle analysis (LCA), as a key tool to assess impacts, and the circular economy.

It is also possible to synthesize that the principles of sustainable architecture rest on two pillars: the natural and the industrial. Where the synergistic union of natural elements and industrial processes is essential to achieve sustainability in the construction sector. While renewable materials help to mitigate the carbon footprint, technological innovation makes it possible to industrialize processes in a more efficient and less polluting way, in search of the circularity of production processes.

Regarding natural materials, it is more accurate to refer to materials of biogenic origin, which stand out for their capacity to reduce emissions by capturing carbon during their formation. These materials, in addition to contributing to decarbonization, are linked to the conservation of ecosystems and their biodiversity. It is therefore essential to emphasize their origin, and to analyze in depth the impacts generated by the extraction of natural materials on the environment.

Cork is a unique biogenic material, whose multiple simultaneous properties make it a multipurpose and versatile material. It originates from cork oak forests, and its extraction does not involve felling the tree, which guarantees the preservation of the ecosystem services and biodiversity provided by these wooded areas. Moreover, its production has a low environmental footprint, and the cork industry is an example of circular economy.

Cork is therefore a promising material for sustainable construction. Its thermal insulation capacity, durability and recycling potential make it an attractive alternative to conventional materials with a greater environmental impact. Cork achieves its low carbon footprint by applying circular economy principles at every stage of its production chain.

Although the cork industry has multiple environmental benefits, it is also necessary to know the disadvantages and difficulties that have contributed to its decline. In response, the promotion of cork as a construction material proposes to take advantage of the industry's "waste", which corresponds to more than 70% of the raw material.

In short, cork is a material aligned with the European Union's sustainability objectives, offering an innovative solution to the environmental challenges of the construction sector. At the same time, architecture could be the missing enclave for the cork industry to gain momentum and reverse its decline.

2

SUSTAINABLE ARCHITECTURE

Environmental impact of construction

The current environmental problem, a product of the prevailing development model, has become a planetary emergency. Soil degradation, loss of biodiversity and climate change are symptoms of a system that depletes natural resources and breaks the balance of ecosystems.

These impacts have brought the planet to a critical point of no return, where disruptions to natural systems threaten the ability to sustain life as we know it. To mitigate this situation, it is imperative to implement concrete measures that promote the transition towards sustainable models in key sectors such as construction and industry.

Buildings are the longest-lasting and largest human consumption product, making the construction sector one of the most important industries for the global economy. It is also a relevant sector in terms of the generation of environmental impacts. Throughout its life cycle, this industry is responsible for generating sources of air pollution, land erosion, alteration of ecosystems and, as a consequence, damage to people's quality of life.

Consequently, according to UNEP, the global building sector contributes almost 40% of carbon dioxide (CO 2) emissions, mainly through energy use during the lifetime of buildings. On the other hand, the figures for GHG emissions from building materials are more than 30% of total energy and 40% of cO2 emissions over the entire lifetime of the building, making it the second largest energy demand factor, second only to heating (Zabalza, 2009).

At European level, the construction, use and renovation of buildings require considerable amounts of energy and mineral resources. Buildings are responsible for 40% of the Union's total energy consumption and 36% of its greenhouse gas emissions from energy. In addition, the amount and volume of waste generated during construction and demolition of structures is also a matter of concern. The construction sector is responsible for more than 35 % of the total waste generated in the EU (European Commission, 2020).

The built environment has a significant impact on many economic sectors, local employment and quality of life. It is resource-intensive and absorbs around 50% of all extracted materials. GHG emissions resulting from the extraction of materials, the manufacture of building products, and the construction and renovation of buildings are estimated to be between 5% and 12% of total national GHG emissions.

Therefore, the choice of materials is a relevant decision in terms of sustainability. Under this premise the emissions of different materials have been compared, the study "Energy and the Environment in Residential Construction" by The Canadian Wood Council in 2005 included all life cycle stages of different materials, and concluded:

Steel and reinforced concrete designs emit 34% and 81% more greenhouse gases than a timber design. In turn, these designs release 24% and 47% more pollutants into the air than those built in wood.

While timber construction has tended to be presented as a symbol of sustainable architecture, there have also been warnings about the environmental risks of forestry exploitation, since the excessive extraction of natural resources has had a negative impact on ecosystems and has generated significant losses of biodiversity, putting at risk the main tool for decarbonizing the planet: the forest cover.

In view of the above, it is necessary to promote innovation and sustainability in the construction sector in order to increase quality and reduce costs, expanding the range of construction materials by incorporating those with a lower carbon footprint that do not have an impact on the ecosystem, framed within a circular economy system that does not generate waste.

Sustainable Architecture

In response to the climate crisis, the paradigm of sustainability emerges, seeking a development model that meets the needs of the present without compromising the ability of future generations to meet their own needs.

The concept of sustainability has evolved since 1987, when the World Commission on Environment and Development first defined it, highlighting concern for the future of the planet and the scarcity of resources. Since then, the term has broadened to integrate economic, social, cultural and environmental aspects, while maintaining a commitment to balancing current needs with the preservation of opportunities for future generations.

Sustainable architecture, as a concept and as a practice, did not emerge suddenly, but is the result of a historical evolution that integrates various currents of thought and social movements concerned with the relationship between humans and nature. The interest in sustainability arose to address resource constraints, energy issues and the reduction of the impact of construction on the natural environment.

In general terms, sustainable architecture is an approach that integrates criteria for the design, construction and operation of buildings under criteria that seek to reduce the environmental impact throughout the building's life cycle. This approach aims to optimize the use of natural resources, minimize energy consumption, manage waste and reduce the environmental impact of buildings

and promote the use of materials with a low carbon footprint and high durability. This approach has evolved towards the incorporation of sustainable materials, which minimize the ecological footprint.

It also prioritizes energy efficiency through passive systems and incorporates new technologies that promote water and energy efficiency. Sustainable architecture also promotes the integration of the building with its surroundings, conserving biodiversity and minimizing alterations to local ecosystems.

In 1998 Kim J. & Rigdon proposed the first criteria for measuring sustainability in architectural design: resource-saving, life-cycle design of materials and human design. Since then, various architectural trends that seek to minimize the environmental impact of buildings have been grouped under the concept of "sustainable architecture".

The main trends in sustainable architecture adopt two types of approach, a "technocentric" approach that privileges scientific research and technological innovation to create intelligent, energy-efficient buildings. The second approach is the "ecocentric" one, which values practical execution and the use of natural materials and traditional construction techniques, with a low environmental impact. Some examples of this current are bioconstruction, eco- architecture and natural architecture (Lárraga, 2015).

For example, with an "ecocentric" approach, ecovillages emerge as a radical proposal that seeks to transform the prevailing development model. They are defined as human settlements designed to integrate human life into the natural environment in a sustainable way, prioritizing organic food production, ecological construction, the use of renewable energies and community management of resources. There are also less radical and more widely used approaches, such as passive design.

Passive design has its roots in traditional architecture, where buildings responded naturally to climate and local conditions, taking advantage of resources such as orientation, thermal inertia and cross ventilation to optimize indoor comfort. (Xunta de Galicia, 2017).

This ancient approach, based on empirical knowledge of materials and bioclimatic strategies, has now been rediscovered and adapted, integrating scientific and technological principles to reduce reliance on mechanical air conditioning systems and minimize the environmental impact of buildings.

Current passive design, then, adopts a bioclimatic approach to energy optimization, seeking a design that, based on a correct understanding of the environment, climate and place, manages to maximize indoor thermal comfort and reduce energy demand through bioclimatic strategies.

With the aim of reducing dependence on artificial air-conditioning systems, i.e. reducing the need for heating, cooling and artificial lighting, it achieves superior energy efficiency without active systems. It is an architecture based on two pillars:

- Use of the possibilities of the environment, through constructive solutions.
- Low energy consumption operation.

It also highlights the use of intelligent control and automation technologies for the optimization of passive design, as a frequent practice in current sustainable constructions, mainly in residential buildings (Ghoreishi, 2022), which reflects that a technocentric approach has been integrated into the bioclimatic current, configuring an alliance between the natural and the technological, to achieve housing with the minimum energy demand.

Sustainable architecture, since its beginnings, has been characterized by its diversity of approaches and the constant search for innovative solutions that minimize the environmental impact of buildings. It is important to note that, although there are different approaches, all positions within sustainable architecture share the common goal of creating a more sustainable and environmental y responsible habitat. Even so, it is essential to be aware of the approaches that have become more widespread, in order to understand the main shortcomings in terms of sustainability in construction.

In recent years, cutting-edge sustainable architecture has been dominated mainly by bioclimatic or passive design and the incorporation of "eco- tech" elements. The focus of sustainable construction has been largely on the thermal performance and energy efficiency of buildings. Consequently, it should be recognized that beyond technological and climate control devices, there is still a long way to go to achieve sustainable construction models considering the whole life cycle of buildings.

The promotion of energy efficiency in buildings has achieved significant progress in reducing energy consumption and improving habitability conditions. However, as we will see in the next point, this approach covers only one stage of architecture, omitting the overall vision that encompasses the totality of environmental impacts associated with construction. Therefore, in order to take a broader perspective, and not reduce the impacts of buildings to users' heating costs, concepts such as circular economy and life-cycle analysis (LCA) will be addressed.

Keys to sustainable architecture

The main objective of sustainable architecture is to minimize the negative environmental impact of buildings. In this context, the seven proposed by the IBC for Sustainable Building were (Torgal & Jalali, 2010): Reduction of resource consumption, reuse of resources, use of recyclable resources, protection of nature, elimination of toxics, application of life-cycle analysis in economic terms, and finally, emphasis on quality. In addition, some trends and concepts of today's sustainable architecture are summarized below:

- **Holistic and integrated approach:**
  Sustainable architecture is not limited to design and construction alone, but considers the entire life cycle of the building, from site selection to deconstruction. It also integrates the environmental, social, economic, cultural and institutional dimensions.
- **Environmental awareness and social responsibility:**
  The socio-environmental responsibility of the architect and the citizen's commitment to responsible consumption are emphasized. In addition, priority is given to equity, the protection of occupants' health and the improvement of their quality of life.
- **Use of appropriate technologies:**
  The use of eco-technologies to make efficient use of natural resources and materials is promoted. Appropriate technologies, adapted to local conditions and with low environmental impact, are also essential.
- **Bioclimatic design and energy efficiency:**
  The aim is to make the best use of local climatic conditions to reduce the energy consumption of buildings. This includes the use of natural light, natural ventilation and solar shading.
- **Sustainable materials and life cycle:**
  Priority is given to the use of materials with low environmental impact, recycled, reused and of biogenic and/or local origin. The full life cycle of materials is considered, from extraction to final disposal.
- **Participation community and collaborative design:**
  Community participation in the design and construction process is encouraged to democratize sustainable architecture and create a habitat that is more sensitive to local needs.

Although, redundantly, there is no common consensus on the definition of sustainable architecture, there are three key concepts that broadly encompass the main approaches to sustainability in architecture. Firstly, life-cycle analysis, which provides an in-depth understanding of the impact of construction, has not yet been widely applied. Then, energy efficiency is an aspect that involves the use phase of buildings, to which more attention has been paid. And finally, the circular economy seeks to minimize impacts with an approach that encompasses the entire life cycle.

Life-Cycle Assessment (LCA)

The production of buildings places a demand on environmental resources and generates an output of pollutants into the same system. It is therefore necessary to develop environmental impact assessment methodologies that allow all these processes to be brought together in a single analysis (Jönsson Ä, 2000).

Among the possible methodologies, Life-Cycle Assessment (LCA) is one of the most objective environmental assessment methodologies, providing the ideal framework for assessing the potential environmental impacts of all construction products and processes (European Commission, 2003).

LCA reports the knowledge of the environmental impacts that occur throughout the life cycle of a product, process or system. It can therefore be defined as a systematic, objective and scientifically based procedure that allows the quantification of all resource consumption and emissions associated with a product, from cradle to grave.

This makes it possible to analyze potential environmental impacts using a large number of indicators, during each phase of the life cycle. Thus, the breadth of analysis understands that for each component of a product, a raw material was extracted, there was a manufacturing process, both the raw material and the final product were transported, and finally at the end of its life this set of materials could become waste.

Indeed, the environmental indicators of greatest interest for measuring a given product will depend both on the raw materials involved and on the different phases involved. For example, to produce a T-shirt, the cultivation of cotton involves a significant consumption of water resources for irrigation, and on the other hand, the transport of the material will emit CO2 into the atmosphere and will involve the consumption of fossil fuels, so each indicator will have greater or lesser relevance depending on the phase of analysis.

This not only makes it a complex analysis, but also allows for a high rate of accuracy and a low margin of error in the information obtained, making it possible to make decisions at a higher level of environmental awareness.

Buildings are the largest human product, involving multiple processes, components and actors, therefore, conducting an LCA involves a higher degree of complexity. The concept of a building's life cycle is considerably broader than the current approach, which focuses on the design and construction of buildings. Adopting such an approach makes it possible to analyze all the environmental impacts associated with a building and to determine which are the most relevant, thus making it possible to identify the so-called "hotspots", which are mentioned below.

Use phase

LCAs can be used to find out which phase or component of a building is having the greatest impact. Thus, it became clear that the use phase of buildings was where much of the energy consumption took place, and the first energy efficiency guidelines were

developed, placing the construction sector as responsible for most of the energy expenditure.

The use phase of buildings is a stage of high consumption, mainly due to energy expenditure for heating and cooling. Consequently, efforts have focused on improving the thermal performance of dwellings by incorporating materials with high insulating capacity. With this in mind, the European Commission has set out to raise the requirements of the EU's thermal regulations and has implemented strategies to achieve maximum energy efficiency in buildings and reduce consumption. These include the "Nearly-zero energy buildings (NZEBs)" initiative, and the "Renovation Wave", which will be discussed in more detail below.

Energy efficiency

According to EU forecasts, between 85 and 90% of the building stock that will still exist in 2050 has already been built and constitutes a huge material bank spread across the continent. Existing buildings, as well as constituting a material bank, account for a large part of people's energy consumption (European Commission, 2020).

Currently, 97% of existing buildings are energy inefficient, and need to be significantly upgraded to meet modern efficiency standards, which has led to initiatives to renovate the Union's building stock. Renovation policies are aimed at reducing the environmental impact of these buildings, improving the quality of life of occupants and reducing long- term operating costs.

Life-cycle evidence suggests that by subjecting existing buildings to thorough and highly efficient retrofits, we can reduce the life-cycle environmental impacts associated with energy and water consumption by building occupants and building products by 60-80%. Energy efficiency is therefore a key aspect to be integrated into sustainable architecture, and consequently, authorities have already set targets in this respect.

Materials

The construction of nearly zero-energy buildings has led to a significant reduction in energy costs by moderating the impacts generated in the use phase of the building. Consequently, the most recent LCAs reveal that the critical points of the buildings, where the greatest environmental impact is generated, are linked to the construction materials, to a greater extent, of load-bearing structures, external walls and façades.

Each of these materials and elements is associated with specific environmental impacts, which cannot be addressed by focusing on a single impact category or a single aspect of the design. In this case, the thermal efficiency of the materials is not a priority factor; it is preferable to adopt a holistic approach that addresses the specific impacts associated with the type of material being used. For example, while steel production generates a significant amount of CO2, wood has a greater impact on the land use change variable (LULUC).

The main strategy to mitigate the impact of building materials is to promote the use of materials with lower environmental impact, highlighting those of renewable origin capable of reducing carbon emissions, also called biogenic materials, which will be discussed in more detail in the next chapter.

Also, special attention needs to be paid to the end of life of materials, which involves incorporating circular economy concepts. Furthermore, during the use phase, there may be relevant impacts associated with the construction elements, due to the need for maintenance or replacement of the components, so that the quality and durability of the elements are fundamental aspects.

Consequently, in order to reduce the impact of building materials, it is primarily necessary to integrate circularity concepts throughout the entire life cycle of buildings. Also, the promotion of materials of biogenic origin is a method of converting the built environment into carbon sinks. Thus, the three main phases to consider are: origin or source, use, and end of life.

Circular Economy

The concept of circularity aims to ensure the long-term efficiency of resources already in the design. The circular economy is based on three fundamental principles, which are to eliminate waste and pollution, to keep products and materials in use, and to regenerate natural systems. While it is possible to apply these principles at some stage o f a product development, this does not ensure that the production is framed in a circular economy scheme, this can only be determined by a detailed analysis of each stage of the product life cycle.

Indeed, it is possible to understand that life- cycle analysis and circularity are two interrelated concepts. Thus, the circular economy is the model to be implemented, and the LCA is the method or tool that allows this circularity to be truly effective. In this way, the LCA makes it possible to differentiate between: applying circular economy principles and consolidating an accurate circular economy model.

Therefore, by understanding these linked concepts, all actors involved in a project can contribute to minimizing the impact of a building throughout its life cycle.

The circular economy is an approach that has been around for some time and has proven to be a key tool to address current environmental and economic challenges. Its importance has transcended, and today it is being integrated by authorities and legislators in public policies, consolidating itself as a fundamental pillar to promote more responsible and sustainable production and consumption models. For example, the European Commission has already implemented that:

- To achieve climate neutrality by 2050, preserve our natural environment and strengthen our economic competitiveness, a fully circular economy is needed.
- Today, our economy is still almost entirely linear, with only 12% of secondary materials and resources re-entering the economy (European Commission, 2020).

In anticipation of the EU guidelines for sustainable construction, mention will be made of one of the plans established by the European Commission, which not only proposes guidelines for the construction sector, but also defines the circularity criteria to be implemented in all production chains.

New Action Plan for the Circular Economy

The New Action Plan for the Circular Economy is a guideline driven by the European Green Deal, which aims to ensure that resources used are kept in the EU economy for as long as possible.

A circular economy reduces pressure on natural resources and is a precondition for reaching the 2050 climate neutrality target and halting biodiversity loss. Half of total greenhouse gas emissions and more than 90% of biodiversity loss and water stress are due to resource extraction and processing.

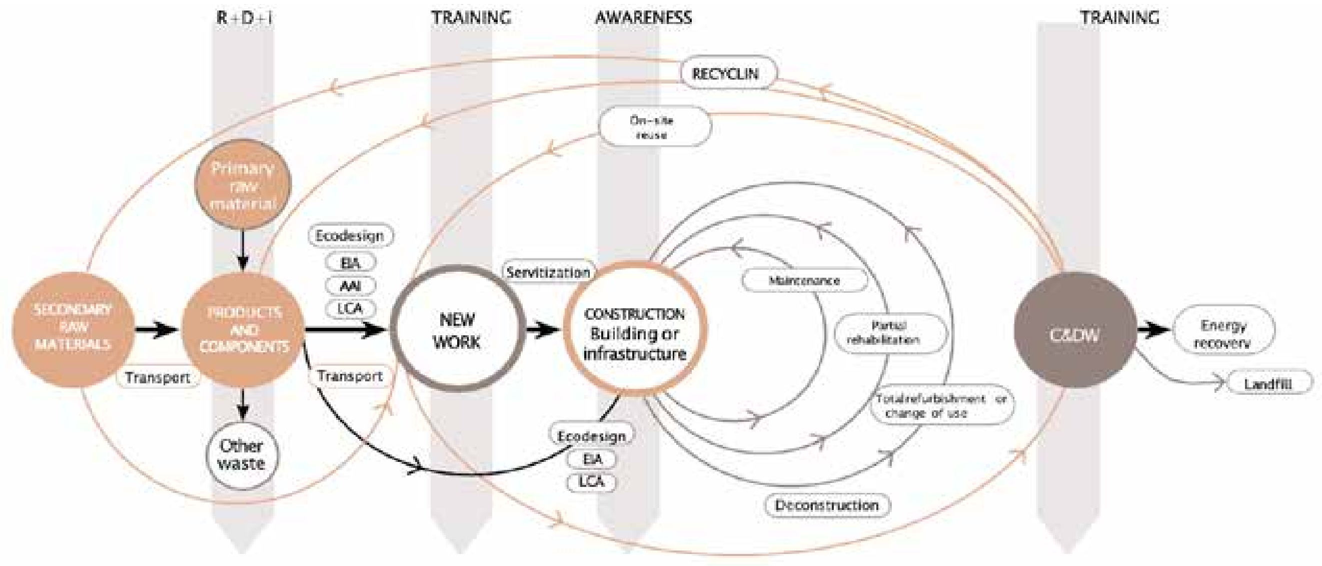
- In general, before referring to the construction sector specifically, this guideline states that it will address the following key issues:
- Improve the durability, reusability, upgradability and reparability of products.
- Increase the content of recycled content in products.
- Enable high quality remanufacturing and recycling.
- Reduce carbon footprint and ecological footprint.
- Limit the use of single-use products and counteract premature obsolescence.
- Prohibit the destruction of durable goods that have not been sold.
- Incentivize "products as services" or other similar models where producers retain ownership of the product or responsibility for its performance throughout its life cycle.
- Mobilize the potential for digitization of product information.
- Rewarding products according to their different sustainability performances.

This plan has already decreed to focus on the most resource-intensive sectors with high circularity potential, including construction and housing, "proposing a comprehensive strategy for a sustainable built environment that will promote the principles of circularity in buildings", in order to ensure that less waste is produced.

In order to realize a conceptual framework for the circular economy in construction, it is necessary to maintain a holistic view and employ a life cycle approach across the entire value chain in the building sector, integrating different areas. Currently within the sector there are areas of the circular economy that are directly in the focus of targets and policies (e.g. waste reduction or material recycling). However, it is essential not to lose sight of the overarching framework that encompasses all aspects as, without them, a successful transformation to a sustainable paradigm cannot be achieved.

Likewise, in order to integrate the concept of circular economy in the sector, it must be approached at different levels, or scales, which are detailed below (Fundación Conama, 2021).

Conceptual framework circular economy



SOURCE: Own elaboration based on Fundación CONAMA, 2021.

Territory

At the territorial level, a society in a specific territory and its management can generate or have an impact on the transition towards a circular economy, where the involvement of all actors and sectors is essential: services and infrastructures, primary sectors (agriculture), secondary sectors (industrial estates and business parks), and tertiary sectors (shops and services), as well as the integration of the natural environment into this circularity.

In addition, the greatest concern currently facing part of the territory is depopulation. The "emptying" affects practically the whole of the interior, whose situation contrasts with the concentration that occurs on the coast and in the large cities. The transition towards a circular economy in a territory can be an opportunity to moderate depopulation and revitalize the rural environment, bring cohesion to urbanized areas and promote new strategic sectors by revitalizing the territory's economy.

City

In the context of the urban circular economy, cities act as large sinks where material resources enter and leave transformed into waste, altering the natural cycle. However, given the high density of activities and population, cities are strategic systems for applying resource efficiency criteria.

Buildings

The building stock has enormous potential as a consolidated structure of materials and living spaces of the future. In this sense, retrofitting will play a key role, the building stock incorporates the concept of durability in its definition, a key aspect in the circular economy. The life cycle approach must be incorporated, considering attributes such as adaptability, flexibility, versatility and multi- functionality to anticipate and meet the future needs of users.

Product

Integrating the concept of circular economy into a product or system tries to convert all resources into nutrients for other cycles, closes the cycle and transforms a product process from linear to circular, avoiding waste as much as possible, reusing it as a resource.

Waste

While maintaining a holistic approach is required to achieve a circular economy model, waste management plays a critical role. Reducing and reusing construction and demolition waste requires adopting life-cycle principles that consider each phase of the construction process, from design to demolition.

This includes selecting recyclable materials, promoting modularity and efficient disassembly, as well as implementing technologies that enable the separation and sorting of waste on site. These practices not only minimize the volume of waste generated, but also facilitate the reintegration of materials into new production cycles, thus contributing to a truly circular and sustainable value chain.

Industrialization

Indeed, in terms of circularity, the industrialization of construction processes represents an improvement in terms of the sustainable qualities of a project. Dry construction reduces and optimizes the consumption of resources during the execution process, which makes for a much more efficient construction process that also minimizes waste and facilitates subsequent reuse or recycling, in line with the principles of the circular economy.

At the same time, prefabricated systems simplify the planning of traditional construction sites, improving the precision of execution and thus reducing time and costs.

However, conventional prefabricated construction has some limitations in terms of sustainability. Generally, this type of system uses standardized modules composed of metallic structures and enclosures made of synthetic materials, which tend to have a high environmental impact during their manufacture. This indicates the need to rethink the selection of construction materials and promote the incorporation of those with a lower environmental footprint in prefabricated or modular systems. Indeed, it highlights the great sustainable potential of manufacturing prefabricated building systems based on natural and renewable materials.

Global sustainability challenges

The construction of buildings involves multiple industries in each of its phases, indeed, the environmental impacts generated by the construction sector extend beyond the construction site itself. Therefore, before addressing sustainability guidelines for the building sector specifically, it is relevant to take a broader multi- sectoral and holistic view, to corroborate the correct cohesion of sustainability objectives.

Climate change is a problem that transcends borders, and combating it requires a global dialogue to take coordinated and equitable action among all countries. For the drivers of climate change and biodiversity loss are global in scope and are not limited by national borders. Only through a global, coordinated and committed approach will it be possible to halt environmental degradation and restore ecological balance.

Sustainable Development Goals (SDGs)

The Sustainable Development Goals or Global Goals, also known as Agenda 2030, are 17 interconnected global goals designed to be a blueprint for achieving a better and more sustainable future for all. These goals define a global consensus to drive the climate transition.

The Nine Planetary Boundaries

In line with climate goals, an international group of scientists at the Stockholm Resilience Centre defined nine interconnected boundaries or parameters that are critical to maintaining the planet's stability. Each of these aspects is important individually, but it is also important to understand them together.

The concept of planetary boundaries presents a set of nine limits, within which humanity can continue to develop and prosper for future generations. An article in the journal Science Advances states that by 2023 the Earth will have passed six of the nine planetary boundaries. In this article, in addition to promoting responsible consumption, it emphasizes the use of tools to regenerate the earth's resources, with forests as the main ally.

The results of our model demonstrate that one of the most powerful means humanity has at its disposal to combat climate change is to respect the limits of land-system change. Returning total global forest cover to late 20th century levels would provide a substantial cumulative sink of atmospheric CO2 by 2100 (Earth beyond six of nine planetary boundaries, Science Advances, 2023).

In other words, forests are the main tool to decarbonize the planet and achieve carbon neutrality, because of their capacity to absorb carbon, but it is also true that "there i s no doubt that the global forest area continues to decline". This relates directly to 15 Sustainable Development Goal, which recognizes that forest-related challenges are inherently global.

European Union and the environment

The world's major powers must lead a transition to an economic model based on energy and environmental sustainability. The European Union is therefore a key player in leading the transformation and development of society towards a new paradigm by having the collective capacity to transform its economy and society towards a more sustainable path.

The first environmental measures of the European Union took place at the European Council meeting in Paris in 1972. At this meeting the leaders of the Member States "recognized the need to establish a Community environmental policy to accompany economic expansion and called for a programme of action".

From this milestone, the European Commission, the executive body of the European Union, began to work with these notions and to materialize the agreement through "multi-annual action programmes" that set out actions, objectives and strategies to fulfil the EU's environmental policies.

Today, the European Union maintains that its environmental policy "protects Europe's natural resources and preserves the health and well-being of EU citizens". But it also recognizes that there are still many challenges to be addressed, such as "climate change, unsustainable consumption and production, as well as different forms of pollution".

European Green Deal

The new growth strategy aimed at transforming the EU into an equitable and prosperous society is the European Green Deal, which integrates the UN Sustainable Development Goals and places sustainability and citizens' well-being at the center of economic policy, and the Sustainable Development Goals at the center of EU policymaking and action, stating that all EU actions and policies should contribute to the objectives of the European Green Deal.

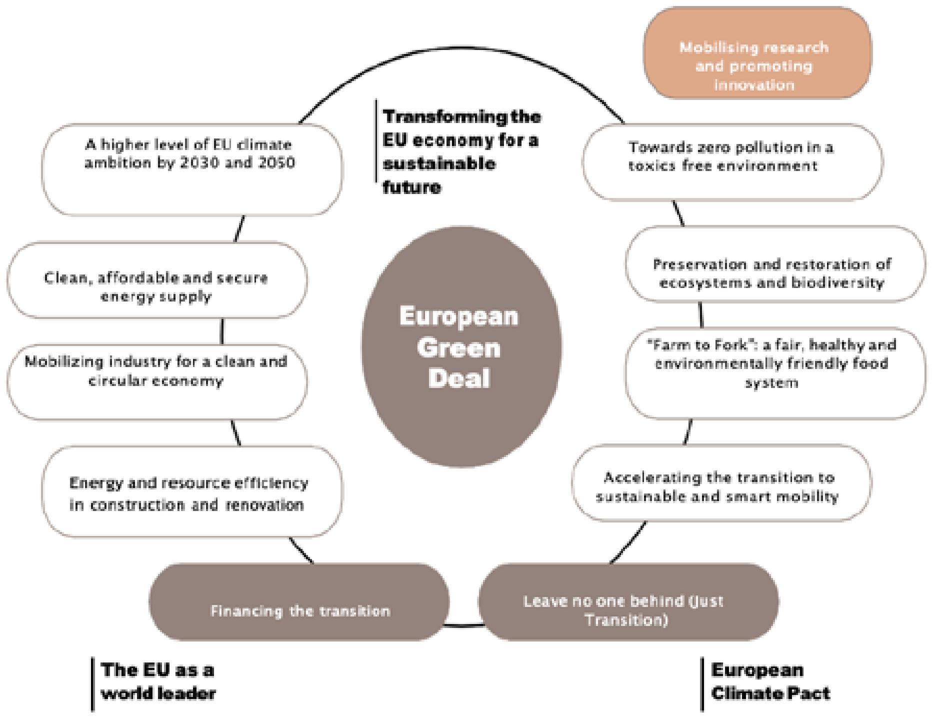
This pact is understood as the connecting axis, or backbone, of all sustainability measures, from which various sectors and their many facets branch out. The challenge, then, is to ensure that the different guidelines are integrated coherently and without contradictions, despite the complexity of a multi-sectoral approach.

This plan aims to transform the EU into a sustainable and climate-neutral economy by 2050. It sets out the roadmap to meet specific key targets by 2030 such as a 55% reduction of GHG emissions, at least 40% share of renewable energy in total energy consumption, energy savings of at least 32,5%, 30% protection of soil and seas, recycling of 60% of municipal waste and 75% of packaging waste.

The action most directly targeted at the building sector is the so-called "Renovation Wave", which will be detailed in the following section, and w h i c h aims to achieve energy efficiency improvements in existing public and private buildings. The implementation of a "New Global Strategy for a Sustainable Built Environment", which takes a broader perspective on sustainability in architecture, has also already been announced and is framed within the Circular Economy Action Plan, already mentioned in the previous chapter.

In parallel, construction will also be a key factor in patterns more closely linked to other sectors, as shown on the following page, where a contradiction between measures that benefit sustainable construction, and guidelines to protect woodland, is evident.

European Green Deal



SOURCE: Own elaboration based on European Commission, 2019.

New EU Forest Strategy for 2030

The "New EU Forest Strategy for 2030", which corresponds to one of the strategies set out in the European Green Deal, also shares the perspective of the planetary boundaries. This guideline recognizes the central and multifunctional role of forests, as well as the contribution of foresters and the entire forest value chain in achieving a sustainable and climate-neutral economy by 2050, while ensuring the restoration, resilience and adequate protection of all ecosystems. But at the same time, it states that:

- The most important role of wood products is to contribute to the building sector's shift from being a source of greenhouse gas emissions to becoming a carbon sink.

This contradiction involves a risk that is stated in the document itself:

- The potential additional benefits from harvested wood products and material substitution are unlikely to outweigh the reduction in the net forest sink associated with increased harvesting. Member States should pay attention to this risk, which is their responsibility under the relevant applicable legislation.

On the one hand, the EU strategy recognizes that forests are a natural ally in adapting to and combating climate change, but, on the other hand, it also proposes to encourage and exploit the use of wood as the main building material to generate a "carbon sink", which could compromise the sustainability of forest ecosystems.

In view of this situation, the main proposal is to encourage more sustainable forest management practices, and also to promote non-timber forest- based economic activities in order to diversify local economies and employment in rural areas. In this way, it will be possible to exploit resources while ensuring the conservation of their source.

Built environment as a carbon sink

The real intention of promoting the use of wood in architecture is to encourage the use of materials that contain embodied biogenic carbon, which in simple terms refers to the cO2 captured by the tree before it is felled, which is contained in the wood or other forest product. Consequently, renewable materials have the potential to decarbonize the building sector.

Therefore, before talking about a specific material, it is more accurate to refer to materials of biogenic origin, which, due to their embodied carbon content, could transform buildings into "carbon sinks". In this context, in addition to wood, there is an opportunity to boost the non-wood forest economy, such as cork.

The "EU Biodiversity Strategy to 2030" discussed on this page states that EU forests provide valuable non- timber products such as cork (80% of global production), resin, tannins, grasses, medicinal and aromatic plants, fruits, berries, nuts, roots, mushrooms, seeds, honey, ornamental plants and wild game, which often benefit local communities. They contribute around 20% of the commercial value of forests, and their potential to generate additional income for forest- owning communities can be further promoted and supported in cooperation with national and local authorities and actors.

It is therefore also necessary to boost non-timber forest-based economic activities. This brings multiple territorial benefits, including securing rural livelihoods and supporting a bioeconomy that is underpinned by more sustainable forest management practices.

In conclusion, in line with European objectives, promoting the sustainable harvesting of non- timber forest products for integration into the construction sector is a key strategy for achieving carbon neutrality and preserving forest area at the same time.

European Union Guidelines for Sustainable Architecture

As mentioned above, the European Commission has established several directives and frameworks to promote sustainability in architecture and construction. These directives focus on energy efficiency, the reduction of greenhouse gas emissions and the circularity of materials. While reference has already been made to the European Green Deal and the New Action Plan for the Circular Economy, the main directives and frameworks directly related to the construction sector are presented below.

Energy Performance of Buildings Directive (EPBD)

The Energy Performance of Buildings Directive (EPBD) is the main piece of EU legislation aimed at promoting the improvement of the energy performance of buildings.

Its main objective is to achieve a zero-emission building stock by 2050 with a focus on phasing out fossil fuels in the heating and cooling of buildings, and sets several requirements for different aspects related to the energy performance of buildings:

- Nearly-zero energy buildings (NZEBs): The EPBD sets a target for all new buildings to be NZEBs by 2030 (detailed below).
- Renovation of the existing building stock: Policies to improve the thermal performance of existing buildings are also promoted (detailed on the next page).
- Minimum energy performance requirements: Minimum energy performance requirements are set for new and existing buildings.
- Energy performance certificate: Obliges Member States to implement energy certification systems for buildings.
- Phasing out fossil fuel boilers: The directive aims to phase out fossil fuel boilers from 2025, prioritizing the transition to emission-free heating systems.

Nearly-zero energy buildings (NZEBs)

Nearly Zero Energy Consumption Buildings (NZEBs) are a mandatory measure in the European Union for new buildings from the end of 2020, according to the Energy Performance of Buildings Directive 2010/31/ EU. This directive stipulates that all new buildings must be highly energy efficient, with most of their energy covered by renewable sources generated on-site or in the environment. For public buildings, this requirement was brought forward to 31 December 2018.

The key principles that seek to minimize energy consumption and maximize the use of renewable energies are:

- Energy efficiency: Design and build with a focus on drastically reducing the building's energy demand. Incorporate high efficiency building systems, such as advanced thermal insulation, high-performance windows, airtight seals, and strategies to reduce heat or cooling losses. Implement efficient technologies for heating, ventilation, air conditioning (HVAC), lighting, and appliances.

- Passive design: Maximize passive design strategies to optimize the building's energy performance without relying on mechanical systems. Take advantage of orientation, natural ventilation, sunlight, and elements such as shading and thermal masses to minimize the need for artificial air conditioning. Adapt the architectural design to the local climate and specific environmental conditions.

- Rational use of resources: Encourage efficient consumption of natural resources and minimize the environmental impact during the life cycle of the building. Use sustainable, recycled and low- energy materials in construction. Reduce water use with efficient technologies and recovery systems.

- Intelligent energy monitoring and management: Implement energy management systems to continuously monitor, analyze and optimize energy consumption. Integrate smart sensors and technologies to adjust energy use to real- time needs.

- Indoor health and comfort: Ensuring a healthy, comfortable and efficient indoor environment for occupants through proper control of air quality, temperature, humidity, and natural lighting levels.

Renovation Wave

The Renovation Wave is a European Union (EU) initiative launched in 2020 as part of the European Green Deal, being one of the main building strategies. Its main objective is to double the annual energy renovation rate of buildings by 2030, thus transforming Europe's building stock into a more sustainable and energy efficient one, with a focus on the circular economy and support for vulnerable households. The plan is to make renovation a strategy that benefits both climate neutrality and recovery. This strategy adopts the following key principles:

- Energy efficiency: To ensure that only the strictly necessary energy is produced.

- Affordability: Efficient and sustainable buildings must be affordable for all.

- Decarbonization and integration of renewable energies: Especially from local sources.

- Life cycle analysis and circularity: Minimizing the footprint of buildings requires resource efficiency and circularity combined with the conversion of parts of the building sector into a carbon sink, e.g. through the promotion of green infrastructure and the use of organic building materials that can store carbon, such as sustainably sourced timber.

- High health and environmental standards: Ensuring high air quality, good water resource management, disaster prevention and protection against climate-related hazards.

- Addressing at the same time the dual challenge of green and digital transition: Smart buildings can enable the efficient production and use of renewable energy through intelligent energy distribution systems.

- Respect for aesthetics and architectural quality.

The main measures that have been taken to boost Renewal are:

- Minimum energy efficiency standards: The introduction of minimum energy efficiency standards is expected to drive large-scale renovation, addressing barriers such as split incentives and co-ownership structures. (To be detailed below).

- Financial support and technical assistance: Support measures, such as technical and financial assistance, are needed to facilitate renovation, especially for vulnerable households.

- Renewal passports: Renewal passports will be promoted as a voluntary tool to provide a clear roadmap for deep renewal in stages.

- Long-term renewal contracts: Member States may introduce mechanisms to establish long- term renewal contracts during the different stages of a phased renewal.

Minimum energy efficiency standards

These standards set energy efficiency thresholds that buildings must meet within a specific timeframe or by a specific date, are part of an overall plan to renovate a building stock, and provide for the following:

- Non-residential buildings: The EU has set minimum energy efficiency standards for non- residential buildings. They focus on the renovation of the most energy inefficient non- residential buildings, as these have the greatest potential for decarbonization and additional social and economic benefits.

- Residential buildings: For dwellings, Member States are free to decide whether to introduce minimum energy performance standards at national level, adapted to their specific conditions.

- Renovation trajectories: Member States should establish national trajectories for the progressive renovation of their residential building stock to achieve a zero-emission building stock by 2050.

- Financial and technical support: Already mentioned on the previous page.

The introduction of minimum energy efficiency standards is a key instrument to boost large-scale renovation of existing buildings and help overcome barriers to renovation with the aim of phasing out less efficient buildings and continuously improving the national building stock, contributing to the goal of a decarbonized building stock by 2050.

Level(s)

The Level(s) tool is part of the European Commission's Circular Economy Action Plan. It is a virtual platform that functions as a "database" based on information from different sustainable building projects. The greater the amount of data, the more efficient its results, serving also as an agent of cohesion, dialogue and convergence of the construction and architecture sector. In this way it acts as a common space in which to share and gather knowledge.

Level(s) helps to measure the environmental impact of every decision made on a construction site. It thus determines the best solutions to have the least possible impact on the environment. It therefore stands as a common EU framework for assessing the sustainability of buildings throughout their life cycle. In this way, it serves as a roadmap for creating a new paradigm of sustainable construction, serving as an element for learning and identifying areas for improvement.

In other words, a tool has been created to promote the application of Life-Cycle Analysis in the European construction sector, which despite being a complex subject, the creation of a database allows the handling of a large amount of information in a short time, boosting the massification of these analyses on the continent.

The key points of this tool are:

- Sustainability indicators: including material use, waste management and greenhouse gas emissions.

- Circular economy: by promoting the reuse and recycling of materials.

- Life cycle approach: Level(s) considers all stages of a building's life cycle. This allows for a holistic view of sustainability.

- Common language: Level(s) provides a common language for building sustainability, facilitating communication and collaboration between building professionals.

- Alignment with EU policies: Level(s) is aligned with the European Union's sustainability policies and objectives.

New strategy for a sustainable built environment

To exploit the potential for increasing material efficiency and reducing climate impacts, the Commission will adopt a new comprehensive strategy for a sustainable built environment. This strategy will ensure coherence between all policy areas, such as climate, energy and resource efficiency, construction and demolition waste management, accessibility, digitalization and skills. It will promote the principles of circularity throughout the life cycle of buildings through the following actions:

- It will address the sustainability performance of construction products and, particularly the possibility of introducing requirements on recycled content for certain construction products.

- Promote measures to improve the durability and adaptability of built assets in line with the principles of the circular economy.

- It will use the Level(s) tool to integrate life cycle assessment into public procurement and the EU framework for sustainable finance, analyze the desirability of setting carbon reduction targets and explore the potential of carbon storage.

- Consider reviewing the material recovery targets set in EU legislation for construction and demolition waste and its specific material fractions.

- It will promote initiatives to reduce soil sealing, rehabilitate abandoned or contaminated sites and encourage the safe, sustainable and circular use of excavated soils.

In addition, the "Renovation Wave" initiative announced in the European Green Deal for a significant improvement of energy efficiency in the EU will be implemented in line with the principles of the circular economy, particularly those of optimized life-cycle performance and increased life expectancy of built assets.

In this way, while maintaining a broad perspective of the overall framework, a plan has been created that is able to bring together and unite the different aspects of sustainable construction.

The New European Bauhaus

The New European Bauhaus is an initiative launched by the European Union in 2020 as part of the European Green Deal, and aims to integrate design, sustainability, accessibility and social inclusion to transform the built environment and communities towards a more sustainable and aesthetic future.

Key points of this initiative include:

- Sustainability: Promotes design that minimizes environmental impact and encourages energy efficiency, the use of recycled materials and the transition to circular economies. It is aligned with the climate objectives of the European Green Deal, seeking climate neutrality and the protection of biodiversity.
- Aesthetics: It proposes an approach that combines functionality and beauty. It seeks to unite modern architectural design with cultural and artistic values that reinforce a sense of belonging and harmony.
- Inclusion: Promotes accessible environments for all. Encourages community participation and co- creation in project design, ensuring that the voices of all stakeholders are heard.
- Innovation: States that research and innovation in architecture, eco-design and building materials should be expanded.
- Interdisciplinary connection: It combines disciplines such as architecture, design, art, science, technology, and economics to offer integrated solutions. It rescues the spirit of the original Bauhaus, which integrated design and functionality, adapting it to the challenges of the 21st century.
- Pilot projects and funding: It supports projects and provides funding through European programs such as Horizon Europe, Cohesion Fund and Next Generation EU.
- Education and awareness-raising: Disseminates knowledge on sustainability and supports exchange networks between academic institutions, artists, designers and local communities.

It is possible to see that several of the key points of one initiative can be replicated in another strategy, understanding that each of these plans are part of a common objective. In a reduced and simplified form, the EU guidelines for sustainable architecture are based on the following:

- Reducing the energy consumption of buildings.
- Increase the use of renewable energy sources.
- Improve the quality of the indoor environment.
- Encourage the renovation of the existing building stock.
- Promote the circular economy at construction.
- Promote the implementation of LCAs.

3

BIOGENIC MATERIALS AND THEIR IMPACT ON FOREST COVER

In the European Union's environmental strategies, timber architecture tends to be presented as a tool to decarbonize the planet, and it is proposed to encourage its use. Specifically, the "New EU Forest Strategy for 2030" argues that the most important role of wood products is to contribute to the building sector becoming a carbon sink.

The key points of the "Renovation Wave": Life Cycle Analysis and Circularity are also fundamental:

> *Minimizing the footprint of buildings requires resource efficiency and circularity combined with the conversion of parts of the building sector into a carbon sink, for example through the promotion of green infrastructure and the use of organic building materials that can store carbon, such as sustainably sourced timber.*

At the same time, in the "New European Bauhaus", the argues that research and innovation in architecture, eco-design and building materials should be expanded, particularly industrial improvements to use more low-grade wood.

As mentioned above, while the emphasis is on the use of wood as a traditional building material, it is more accurate to refer to biogenic materials, such as those capable of absorbing carbon from the atmosphere.

Biogenic carbon is defined as the carbon captured by a tree or plant during its lifetime; therefore, it is considered as a positive environmental impact, or negative carbon, i.e. it subtracts emissions, contributing to reduce the environmental footprint of a product.

It is therefore considered essential to delve deeper into the environmental impacts of biogenic materials, especially those of wood, due to its rise as a sustainable material. Starting by understanding the concept of biogenic carbon and how its impact is calculated.

Biogenic carbon calculation

One strategy for developing low-carbon buildings is to incorporate materials of biogenic origin, the impact of which is assessed through a life cycle analysis (LCA). However, there is no clear consensus on how to model the biogenic carbon released or absorbed during their lifetime.

In other words, a wood product is credited with negative carbon because of the tree's capture of CO2, but, as was shown two chapters ago, the extraction of that wood could be damaging the global area of trees. This raises questions about the balance between the positive effects of using materials that sequestered carbon during their lifetime, and the negative impacts of their extraction on ecosystems.

It is therefore relevant to investigate the methods currently used to calculate embodied carbon in renewable materials. A study entitled: "Biogenic carbon in buildings: a critical overview of LCA methods" published in the journal buildings & cities, investigates and compares existing methods used for biogenic carbon assessment. This study identifies two types of traditional LCA approaches (0.0 and - 1/1), which are static in nature, and then more accurate dynamic approaches, which have been developed subsequently.

- **Focus 0/0**
  It is based on the assumption that the release of CO2 from a bioproduct at the end of its life is balanced by an amount equivalent to the uptake of CO2 during biomass growth. As a consequence, biogenic CO2 is not taken into account.
- **Focus -1/1**
  It consists of tracking all biogenic carbon flows throughout the life cycle of the building.
- **Dynamic focus**
  Approach based on time-dependent characterization factors, considers the biomass turnover period.

After a detailed analysis of each of these methods, and the extent to which they have been applied in evaluations to date, the following conclusions were drawn:

- The dynamic approach was identified as the most relevant and transparent, yet the least used.
- The time period of forest rotation is a crucial parameter that is not taken into account in static

approaches. This leads to errors in determining the global warming score, which for the case study was 29%, and for the assessment of the building components was between 35-200%.

- In the -1/+1 approach, the results are misleading when the system boundaries are limited to the product stage.

- The 0/0 and -1/+1 approaches do not take into account the typology of trees.

- The impacts of land use and land use change (LULUC) are not included in most of the existing methods

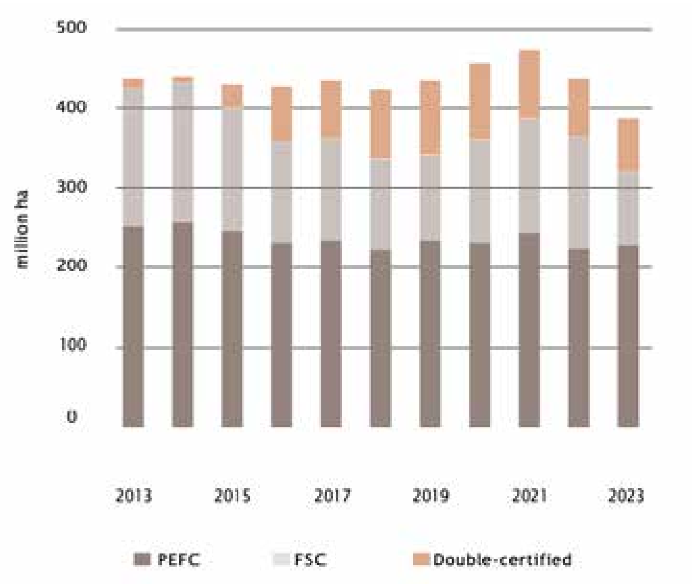
The main shortcoming of traditional LCA approaches is that they do not consider the influence of rotation periods, which results in deviations in the environmental assessment of biogenic products. Studies such as Pittau et al. (2018) show that not all products of biogenic origin can be considered carbon neutral.

Although the dynamic approach is recommended by scientific papers, most current standards recommend the -1/+1 approach (ILCD 2010; EC 2013b; EN-16485 2014; ISO-14067 2018; ISO-21930 2017), while environmental product declarations (EPDs) mainly follow the 0/0 approach (EC 2017a, 2017b; Draft EN-15804/prA2 2017).

Regarding land use (LULUC), it is a crucial factor in cO2 sequestration whose potential has tended to be underestimated. However, Erb et al. (2018) concluded that, under current climatic conditions, if there were no human-managed land, potential vegetation could store 49% more carbon relative to today. Therefore, timber extraction reduces forest biomass stocks compared to their potential.

As already evidenced, the environmental impacts of building components have significant discrepancies being assessed with different methods. Therefore, it is considered essential to understand the inaccuracies in biogenic carbon assessment methods when designing sustainable architecture.

Certified forest area 2013-2023



SOURCE: Own elaboration based on FAO, 2023.

Timber forestry industry

It has already been shown in the previous point that the idea of promoting the massive use of wood in architecture may not be the right way to achieve sustainable architecture. However, it is true that among conventional building materials, wood is distinguished by its low environmental impact. In fact, it is not advisable to cancel its use, but it is advisable to measure it by considering two fundamental aspects: its origin and its end of life.

The main recommendation is to limit the use to certified timber, which comes from sustainably managed forests and has been assessed to meet specific environmental, social and economic standards. This certification guarantees that the wood was obtained without compromising biodiversity.

The two main forest certification systems correspond to two certificates: the FSC (Forest Stewardship Council) and the PEFC (Programme for the Endorsement of Forest Certification). Both assess aspects such as the protection of endangered species, the reduction of the environmental impact of logging activities and the guarantee of adequate forest regeneration.

According to FAO data in its "Forest Products Annual Market Review" report, by mid-2023, the FSC and PEFC reported a combined total of 450.6 million hectares of certified forest, which is equivalent to 384.7 million hectares of real forest after accounting for double certification. Therefore, if the total area of forests managed for production is around 1.15 billion hectares, then the percentage of certified forests would be approximately only 33.45%.

It is important to note that this percentage has decreased in recent years due to the suspension of certificates in Russia and Belarus. In addition, deforestation-free policies, which focus on company due diligence rather than third-party forest certification, may be influencing this trend.

Continuing with the end of life, it should be noted that the objective of attributing embodied carbon in wood is to keep that cO2 captured in the wood, and thus, preventing it from returning to the atmosphere. However, wood that is not reused at the end of the building's life will eventually decompose and return to the atmosphere in the form of methane.

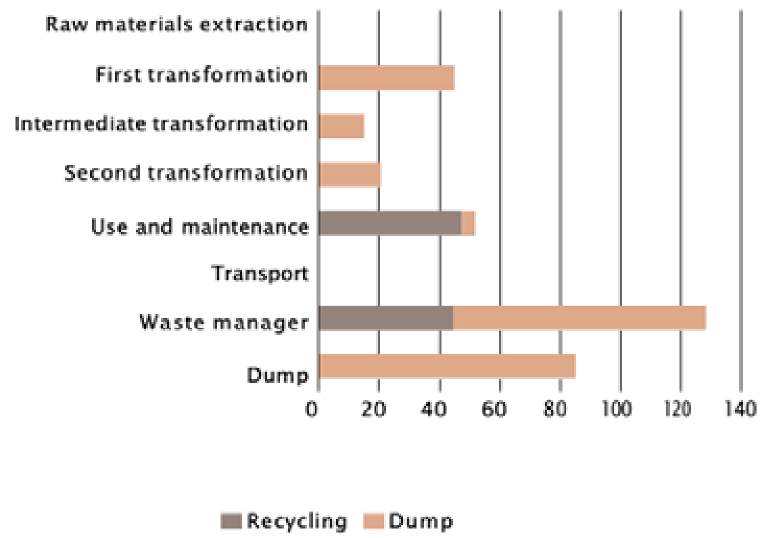
The final stage of the wood cycle involves three main possibilities. The first is that when it is discarded its final destination is a landfill, then there is its possible reuse or recycling and finally, an end of life as a source of renewable energy or biomass through incineration.

Re-use or recycling involves conserving the biogenic carbon embedded in the wood, incineration, however, returns the CO2 to the atmosphere. Unfortunately, currently the most common way to prevent wood from ending up in landfill is to incinerate it. Even so, in Spain, 90.63% of waste in landfills is wood, according to the Life Cycle Impact Assessment carried out by Llorente Díaz in 2011.

Therefore, according to the available data, most of the biogenic carbon attributed to wood ends up back in the atmosphere, either as fuel in the least negative scenario or through decomposition in a landfill in most cases.

This shows that, although efforts have been made to promote the massive use of wood in construction as a tool to achieve carbon neutrality, there is still a long way to go to frame its production in a circular economy model. In order to move towards a sustainable use of wood, it is mainly necessary to promote the expansion of certified forests, and on the other hand, to promote its recycling or reuse.

Wood life cycle analysis



SOURCE: Own elaboration based on Llorente Diaz, 2011.

Non-wood forest industry: Cork

In this context, it is worth mentioning that cork is a material of biogenic origin which, in contrast to wood, has two advantages:

- It is extracted without felling the tree.

- It comes from an agro-silvopastoral forestry system that helps biodiversity, ecosystem resources and soil quality.

This represents a great potential for cork as a sustainable material, which has already been recognized by New York designer Daniel Michalik:

> *Cork is not only the stuff of wine bottles, notice boards and chaise lounges. It is the cultural identity of a country. It is a unique and healthy method of growing and sourcing materials. It is a model of efficiency, reuse and even energy generation on a large scale. What other material offers opportunities like this? (Michalik, 2011)*

Origin of the cork

The cork oak (Quercus suber L.) is an evergreen tree species of the family Fagacea, order Fagales genus Quercus, species suber. It is a tree native to Europe and North Africa.

The long lifespan of the cork oak and the low profitability of its wood means that the economy of the cork oak grove is reduced to the extraction of its non-timber natural resources: mainly cork. “The cork oak is the only cork factory, the rest of us only transform it” (Elena, 2000, p.256). The cork oak is the cork-producing tree because it is the only one that, after cork harvesting, regenerates a specific suberic bark, which it accumulates regularly.

The ecological values of cork lie largely in its origin, which corresponds to the “dehesas” or cork oak forests. “The cork oak is the most generous tree in the Mediterranean, the one that gives the most and demands the least” (Vieira, 1950, p.58).

The cork harvest does not require the felling of the tree, and as a consequence, cork is a renewable and exceptionally sustainable natural resource (Sanchez, 1982). Antonio José Carrero in his study, “El corcho: un producto ecológico” (2009), argues that cork oak forests are a storehouse of CO2, therefore, a great brake on climate change, playing a key role in avoiding and preventing erosion and desertification: “cork oak forests support a great biological richness and constitute a favorable factor in the feeding of aquifers” (Carrero, 2009, p.171). (Carrero, 2009, p.171).

The cork oak forest is considered a Habitat of Community Interest (HIC-9330) by the EU, and the “dehesa” is considered by the FAO as one of the most sustainable farming ecosystems, which allows the maintenance of the diversity of the natural ecosystem while humans can obtain resources from it. The key to the “dehesa” is not to abuse natural resources in order to maintain the cycle between the environment, plants, animals and humans.

This is because cork oaks, due to the characteristics of their bark and exploitation, have a greater facility than other groups of tree species to host microhabitats, given their particular morphology and resprouting capacity, and to generate them at an earlier age (Emberger, et al., 2016).

Ecosystem services are direct and indirect contributions of nature to human well-being. The loss of biodiversity, which underpins various ecological processes, affects the provision of ecosystem services on which we depend. The cork oak forest plays a key role in promoting ecological functions such as soil conservation, carbon storage and water retention, enhanced by its multifunctional characteristics and existing biodiversity (Amorim, 2022). The most recent study by EY in 2019 concluded that, on average, the ecosystem services of a well-managed cork oak forest provide benefits to society of more than €1300/ha/year (Amorim, 2022).

Cork: a sustainable material

The environmental benefits of cork are evident from its origin in the cork oak forests, in its production where it does not generate waste, in its properties as a material, and in its inherent durability.

The most important function of cork in the cork oak is to protect it from fire, since, due to its insulating nature and its low conductivity, it prevents oxygen from penetrating the wood, obstructing combustion. In this way, in the event of a forest fire, the tree can resprout and the resilience of the forests is promoted.

The cork industry is an example of a circular economy model, the cork production process generates almost no waste, as it is possible to reuse the by-products of the industrial process and the rest (cork dust) is converted into biomass that can cover more than 60% of the energy needs of an industrial group. “Cork provides very little waste, as it is reprocessed over and over again, due to the persistence of its characteristics” (Carballo, 1984, p.128).

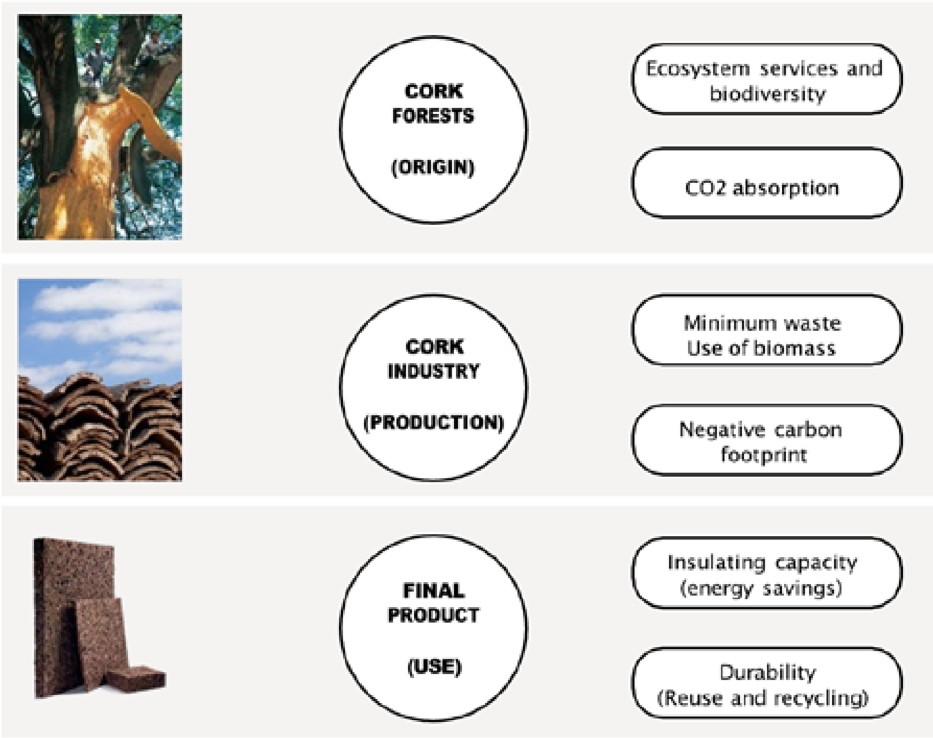
In addition, carbon sequestration by cork oak forests makes cork a product that absorbs more carbon than it emits. According to Amorim’s 2019 sustainability report:

The carbon footprint, including all stages of production and final transport to the UK, represents a total of -342 kg CO2e/ton of product. The study also considered the CO2 sequestration given by the cyclical extraction of cork, providing an even higher result corresponding to a total of -73,342 kg CO2e/ton of product.

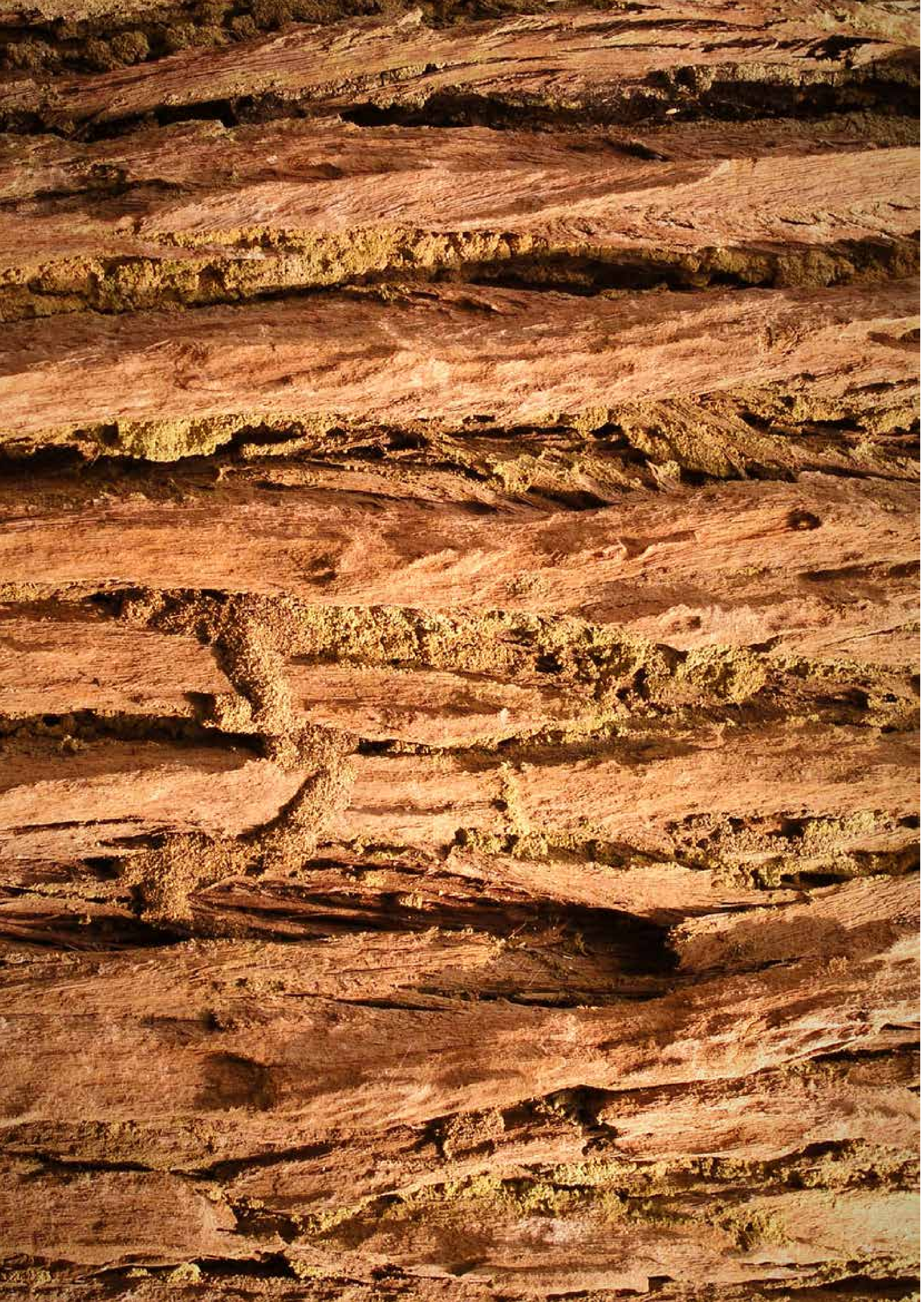
Another contribution to sustainability is given by one of the most unique qualities of cork: durability, since its unequalled capacity to last over time could prevent the product from reaching an end of life.

> *The cork is naturally exposed for hundreds of years to all the climatic influences suffered by the cork oak, which it protects, without suffering any damage. From a branch of cork oak, left on the forest floor, only the hollow cork sleeve will remain as the years go by. Is there any better demonstration of its durability? (Laureano, 1990, p.3)*

Environmental benefits of cork



SOURCE: Own elaboration, 2024.



4

CORK INDUSTRY, A SUSTAINABLE INDUSTRY IN DECLINE

History

The first reference to cork is found in a fossil cork oak located in the "Tajo" river basin in Portugal, millions of years old, presenting an intact cellular structure identical in all respects to that of present-day cork oaks (Oliveira, 1991). This confirms that cork, due to its excellent resistance to weathering, is a product that remains unalterable and rot-proof under the action of humidity.

This material, because of its age, has a long history, and its first applications appeared in ancient times. Cork is a natural material that, due to its unique properties such as lightness, resistance, thermal and acoustic insulation, has been used in various cultures throughout the centuries. Here are some of the first historical references to the use of this material according to Santiago Zapata (2002):

- Egypt: on sarcophagi and vessels
- Greece: in balls of fishing nets, sandals, and the lining of vessels made of vinegar and oil.
- Rome: swarms of bees, covering of rooms with cork planks, fishing nets, covering of pots and shoes.
- Middle Ages: Vessels, fishing gear and ink production
- 1560: in convents to protect from the cold and damp in Sintra and Bucaco
- S. 17th century: capping of beer bottles in England
- S. 19th century: proliferation of the cork stopper.

Throughout history cork has been used for a variety of purposes, which indicated an early appreciation of cork's properties, especially its insulating qualities and impermeability, being commonly used in contact with liquids and moisture.

These milestones reflect the fact that the wine and cork binomial existed even before industrialization, and its value as a multi-purpose material was already recognized.

According to Francisco Manuel Parejo in the article: "El Negocio del Corcho en España durante el s.XX" (2010) of the Bank of Spain, in Agullana, province of Gerona, the first cork stopper plant was created in 1750, marking the beginning of the industrialization of cork, which would have an enormous development from the 19th century onwards, changing the traditional barrel containers for wine used since Roman times, into demijohns covered with cork stoppers (Parejo, 2010).

Since that time, the cork industry has exploited the cork stopper as its main product, and with the growth of the sector, it began to diversify into other sub-industries with the appearance of agglomerates. Agglomerating cork allowed a total use of the raw material, but it also required finding a niche for this lower quality material. At first it strongly supplied the meat processing industry, but later its boom declined with the appearance of synthetic alternatives. This has kept the agglomerated cork industry in the obligation to reinvent itself, which is why already in 1984, José Luis Carballo had proposed to exploit cork for its ecological character:

> *In spite of suffering strong competition from plastic, partly due to the specific location of the cork oak grove worldwide and its limited production, it could be relaunched in an important way, taking advantage of the aftermath of the so-called energy crisis and the impact this has had on the rise in all prices, mainly in synthetic products (Carballo, 1984, p.128).*

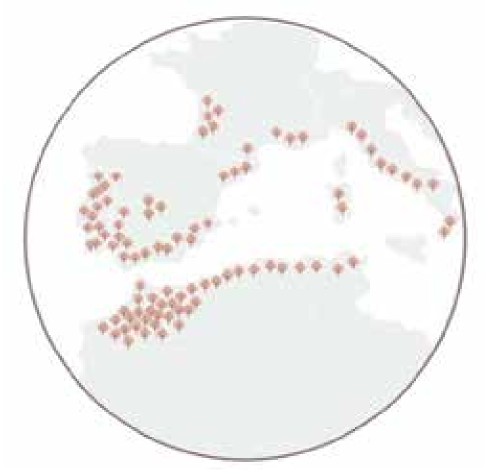
Economic context

Main producing countries

The global area of native forest and Quercus suber pastures is approximately 2,289,000 ha. However, the productive area is estimated at between 1.4 and 1.8 million ha (Salazar, 1998). Of this area, 63% is in Europe, with Portugal and Spain being the main producers. The rest is located on the southern shores of the Mediterranean. Altogether, the Maghreb countries account for 37% of the world's surface area, but they account for less than 10% of trade between countries.

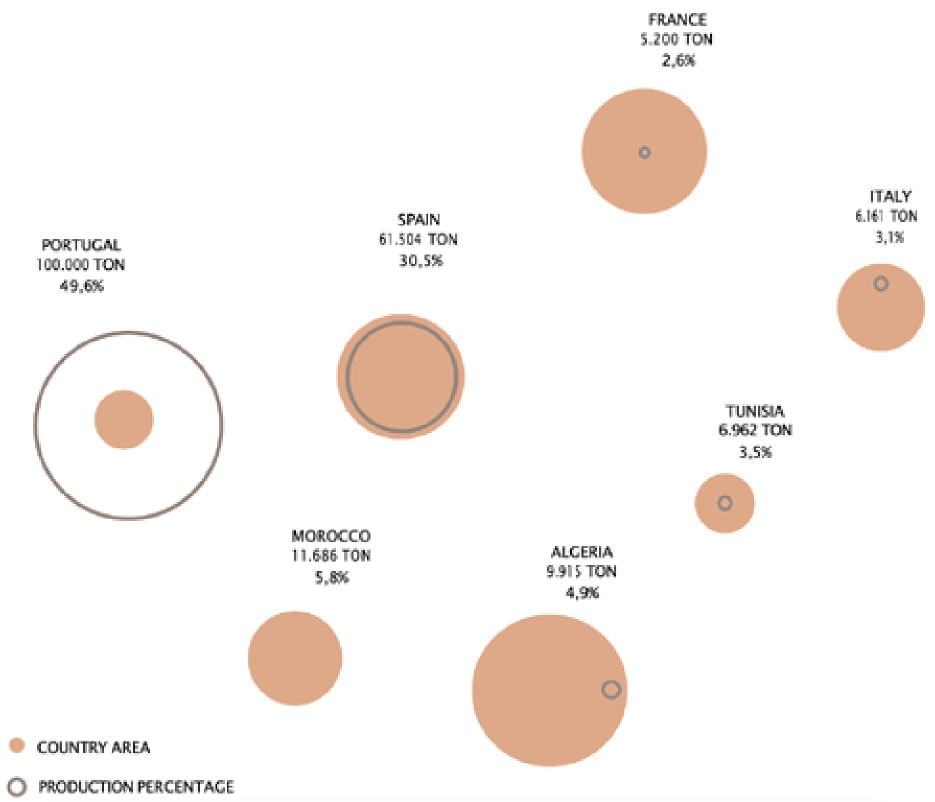
There is, on the other hand, a progressive degradation of cork oak forests in the world, mainly due to the ageing and management of the stands. An analysis of the production history between 1960 and 1990 in Spain shows a sharp fall in cork production (28.5 %) during this period (Montero et al., 1994).

Distribution of cork oak trees worldwide.



SOURCE: APCOR, 2024

Percentage of production according to the country's surface area



SOURCE: Own elaboration based on AMORIM Sustainability Report, 2023.

Market

Cork production in the Mediterranean region is estimated at between 330 and 360 thousand tons per year, with the "Iberian peninsula" producing 76% of the total, North Africa 17% and countries such as Italy and France 7%. Portugal stands out as the world's largest producer and exporter of cork, with a production of 175,000 tons and exports valued at 530 million dollars.

Portugal's leadership is explained not only by the abundance of cork oak forests in its territory, but also by the development of a solid and well- structured industry that has been able to take advantage of this raw material. Thanks to an efficient integration between extraction and industrial processing, Portugal has consolidated its dominant position, satisfying both the domestic market and the growing international demand.

On the other hand, Spain, which is in second place with a production of 85,000 tons, allocates a large part of its production to domestic consumption. In 1998, the country exported 59,680 metric tons, reaching a value of 181 million dollars, according to data from the Cork, Wood and Coal Institute (1998). Likewise, the average value of natural cork is around 3 to 4 US$ kg-1. However, Spain has registered a considerable relative loss in the international market, where its share has decreased.

This is partly due to the loss of competitiveness vis- à-vis Portugal, as Spain has prioritized extractive activity over processing, reducing its capacity to compete in higher value-added markets.

Demand

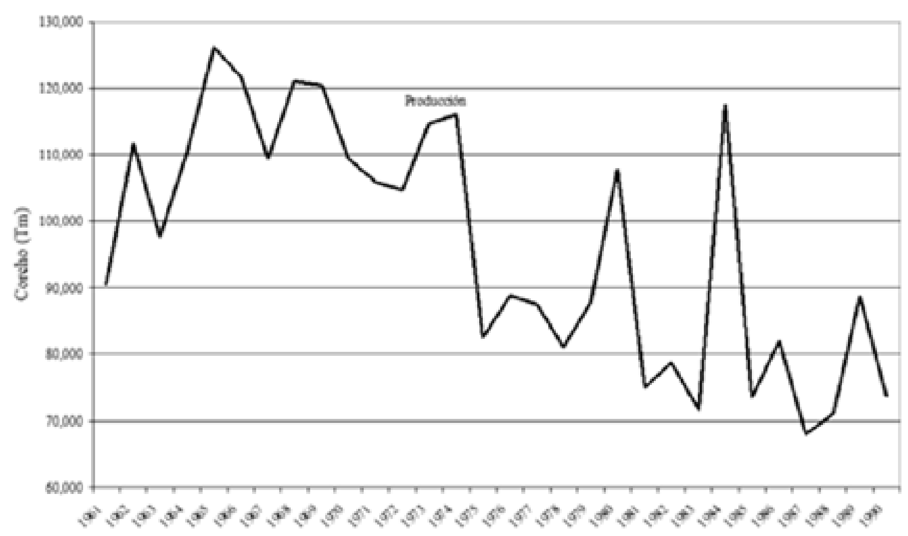
Demand is mainly driven by the wine industry as a key sector, where cork stoppers are preferred for their quality and natural properties. However, supply faces challenges such as the slow growth of cork oak forests, restrictions on the expansion of forest areas, and the ageing of cork oak forests.

In recent years, the price per kilo of cork has increased significantly in both producing and exporting countries. During the 2000 harvest season, prices ranged between 2.4 and 5.8 dollars per kilogram, depending on quality, according to ICMC (2001). This increase, which is two to three times the prices observed in the early 1990s, reflects a growing demand for the product in the face of a fixed or even decreasing supply.

Portugal, with 660,000 hectares of cork oak forests, representing 25% of its forest area and a third of the world's total, has established itself as a leader in the sector. The country not only dominates production, but also ensures an efficient value chain, with 25.4% of the total value of forestry exports coming from cork. Bottle stoppers (54%) and cork boards (40%) are the main products exported. In 1995, Portuguese exports reached about 170,000 metric tons, mainly to wine-producing countries.

For its part, Spain, with exports of 59,679 metric tons in 1998, obtained a value of approximately 180 million dollars, despite remaining in second place in terms of industrial capacity and volume exported, compared to Portugal.

Historical series of cork production in Spain (1961-1990)



SOURCE: Montero et al., 1994.

Variations in the price of cork depending on the quality (US$/kg)

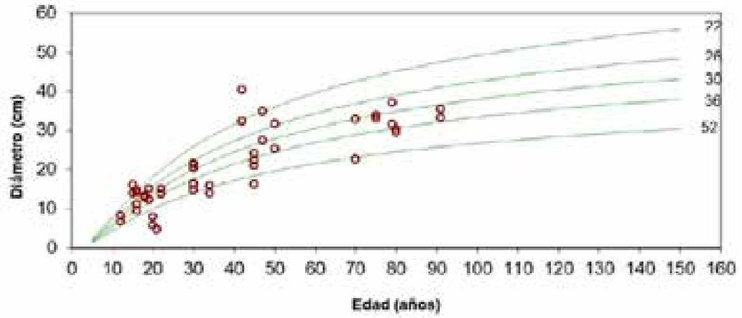
CLASE	1993	1994	1995	1996	1997	1998	1999	2000
19(+) 6ª(+)	1,16	1,16	1,19	1,16	1,16	1,32	3,43	4,22
15-19 5ª(+)	2,06	2,06	2,11	2,00	2,00	2,80	4,48	5,80
13-15 5ª(+)	2,00	2,00	2,11	2,06	2,06	2,80	4,48	5,80
11-13 5ª(+)	1,35	1,35	1,58	1,48	1,48	2,11	3,43	4,22
11(-) 4ª(+)	1,27	1,27	1,58	1,53	1,53	1,85	3,17	3,96
15-19 6ª	0,74	0,74	0,74	0,79	0,79	1,06	1,85	2,64
13-15 6ª	0,69	0,69	0,63	0,69	0,69	1,06	1,85	2,64
11-13 6ª	0,53	0,53	0,63	0,69	0,69	0,79	1,85	2,37
REFUGO	0,16	0,16	0,19	0,18	0,18	0,24	0,95	1,00

SOURCE: ICMC, 2001.

Production

The growth and production of a cork oak forest depends to a large extent on the quality of the site. Naturally and without management, in the first 5 years, growth in height reaches 40-150 cm. At 10 years it reaches 110-320 cm, and at 20, 200-650 cm. Growth is slow due to the extreme drought conditions in some summer months and attacks by insects and herbivores (Montoya, 1980).

Diameter growth of cork oak as a function of the site index in extremadura.



SOURCE: ICMC, 2001.

The cork production of a cork oak forest will depend on the number of trees per hectare, the average size of the trees, the fertility and quality of the site and the silvicultural management during the rotation (González et al., 1993; Montero et al., 1994; Torres et al., 2000). The time of the first topping depends on the time it takes to accumulate a bark or borneizo of 20 cm diameter at breast height (DBH). This diameter is reached in Extremadura between 22 and 52 years, depending on the quality of the site. Generally, after the first harvest, the bark cutting cycle is 9-10 years in the case of the south-west of the Iberian Peninsula, and 14-16 years in the worst years on the coast of Catalonia.

Cork production (kg ha-1) is linearly related to the basal area (m2 ha-1) of the cork oak forest (Tomé et al., 1998; Torres et al., 2000). Evaluations carried out in natural cork oak forests located in Malaga, with 1000 mm of annual rainfall, gave yields of 5,000 and 5,400 kg ha-1 of cork with basal areas of 15-20 and 20-25 m2 ha-1, respectively (Torres et al., 2000). Montero and Cañellas (1999) report yield of up to 5,000 kg ha-1 of fresh cork in natural forest sites.

Demand vs. production

The sustained increase in cork prices represents a positive aspect for the sector; however, the cork industry is currently facing a significant challenge due to the decrease in sales volume caused by the lack of availability of raw material. This is evidenced by Corticeira Amorim's Consolidated Financial Statements report as at 30 June 2024:

Amorim Cork sales (-7.1% compared to the same period in 2023) were affected by lower volumes in all segments, although they benefited from improvements in product mix and price increases.

Despite the difficulties, the Portuguese cork industry has managed to remain a leader in the sector thanks to its capacity to adapt and consolidate itself in the global market. Spain, on the other hand, being the second country with the second largest cork oak forest surface area, presents a different scenario, which is described in more detail below.

Decline of Spanish industry

According to Francisco Parejo, the decline of the Spanish cork industry was due to a complex interaction of economic, political and social factors. While the unfavorable circumstances of the Great Depression and the Civil War had a significant initial impact, it was structural problems, many of them related to the economic policies of Franco's regime, which prevented the industry from recovering and consolidated Portugal's position as a world leader in the sector.

Beyond the political context, other aspects also played a role, including a combination of structural factors, such as the atomization of firms, dependence on labour, anomalous localization and export of raw materials, as well as deficiencies in business management, including lack of modernization, control and an effective trade policy. Competition from other countries and the emergence of synthetic substitutes may also have contributed to the decline.

Among the problems of raw material supply, the Catalan industry stands out, which suffered cork supply problems during the 1940s and 1950s due to various factors:

- Stagnation of cork production in Spain.
- Logistical difficulties in transporting cork from the south-west regions.
- Export of the best qualities of cork.

Among the main points that determined the decline of the cork sector in Spain are the following categories, according to the report entitled "The national cork industry (notes for possible restructuring)":

Business atomization structure

The industry is characterized by a large number of small, artisanal and family businesses. This atomization generates several disadvantages, as it leads to an inefficient commercial network, both for the purchase of raw materials and for the distribution of products. Other disadvantages can be market distortion, unequal fiscal and social burdens, which only affect part of the sector, high production and marketing costs, and lack of cohesion and strength for export.

Also, labour dependency is a crucial factor, staffing problems include an ageing workforce, and high staff turnover due to the difficulty of finding qualified professionals, which is due not only to the difficulty of training, but also to the low attractiveness for young people.

Location and transport

The anomalous location of the industrial concentration of the cork stopper industry in Gerona, far from the cork oak groves in the south, generates a significant extra cost in the transport of the raw material. The extra cost of transport can represent up to 3% of the selling price of the cork stopper.

Low degree of transformation

At the same time, a considerable amount of cork is exported in slabs or with a low degree of transformation. This implies losing the added value that would be generated by transforming the raw material into finished products, as well as creating shortages and raising the price of the raw material for Spanish companies, while encouraging the development of foreign companies that compete with Spanish products.

Shortcomings in corporate governance Companies tend to have a centralized organization, with no delegation of functions and little streamlined administrative work. In addition, there is a lack of control and analysis in the industry, as there is no analytical management accounting or adequate production control.

On the other hand, there is a lack of modernization in this industry, as many companies have obsolete industrial equipment. Also, the Spanish cork industry still uses traditional working methods, and there is little development of more efficient working methods, especially in the more labor-intensive operations.

Other points for improvement in the management of Spanish cork companies relate to the disorganization of warehouses, which translates into excessive and poorly mechanized internal transport and a deficient commercial policy.

Competition and substitutes

Competition from the more efficient Portuguese cork industry, with lower production costs, also contributed to the decline of the Spanish sector.

On the other hand, the development of synthetic substitutes for cork may also have affected the demand for cork products. Synthetic closures have boosted the production of young, cheaper wines, which are usually consumed soon after processing. However, for mature wines, no other material can serve as a closure for as long as cork does. Cork has therefore found an irreplaceable role in the wine industry.

Types of cork and its industries

Raw cork grades by seasonality

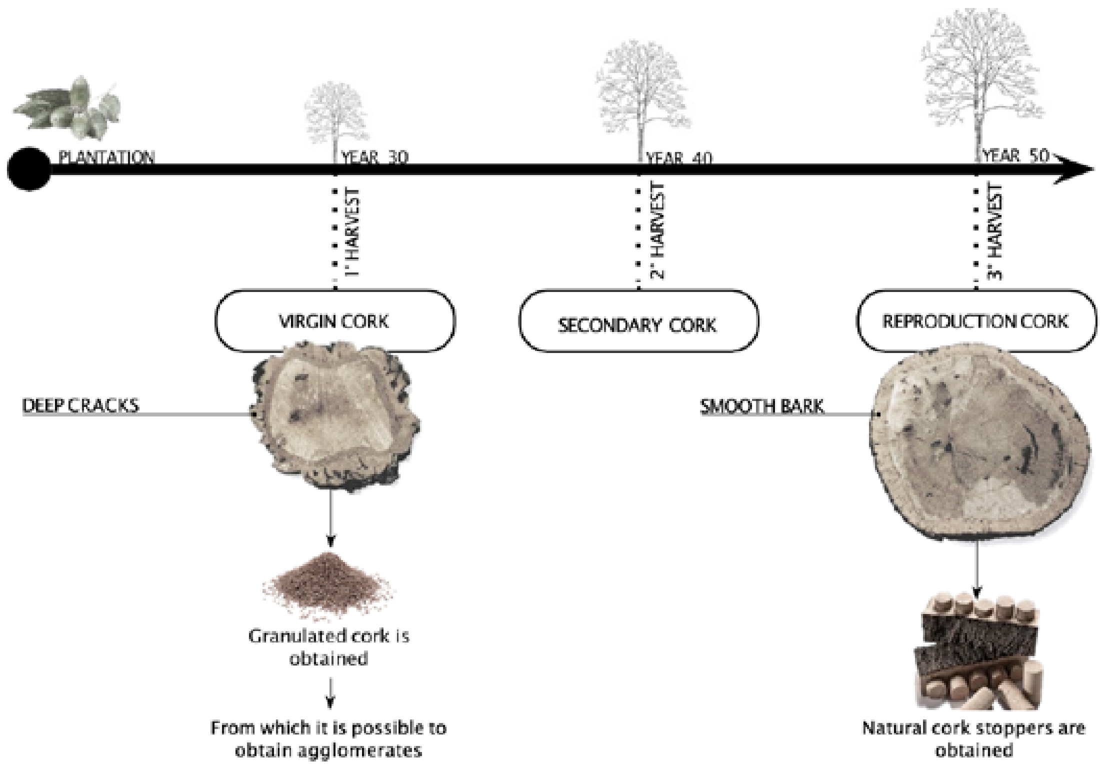
In order to understand the potential of cork as a material, it is first necessary to know its types, given by the different sizes obtained from successive harvests.

The cork oak can be harvested from 9-10 years old to 14-15 years old, depending on the area where it is located. The first cork is harvested when the cork is 25 or 30 years old, and the cork obtained is bornizo cork with deep cracks. At the next extraction, the second cork is obtained with cracks in the rasp or back of the cork. The third harvest is obtained between 45 and 50 years of the tree's life and from this we obtain reproduction cork, which corresponds to a cork of a suitable quality to produce stoppers.

The following is a description of the types of raw cork that are obtained depending on the extraction shift: (Remacha, 2008)

- "Bornizo" or virgin cork: this is the cork that is extracted for the first time. It is only used to make cork granules or agglomerates, as it has an irregular and hard structure and is of low quality.
- Secondary cork: this is the cork obtained from the second corkage of the cork oak tree, which has regenerated it to replace the virgin cork. This cork is of better quality than the bornizo cork, but it is not yet of optimum quality and is not yet useful for cork stoppers, so it is destined for crushing.
- Reproduction cork: smooth structure and homogeneous caliber, suitable for the cork stopper industry.

Cork extraction times

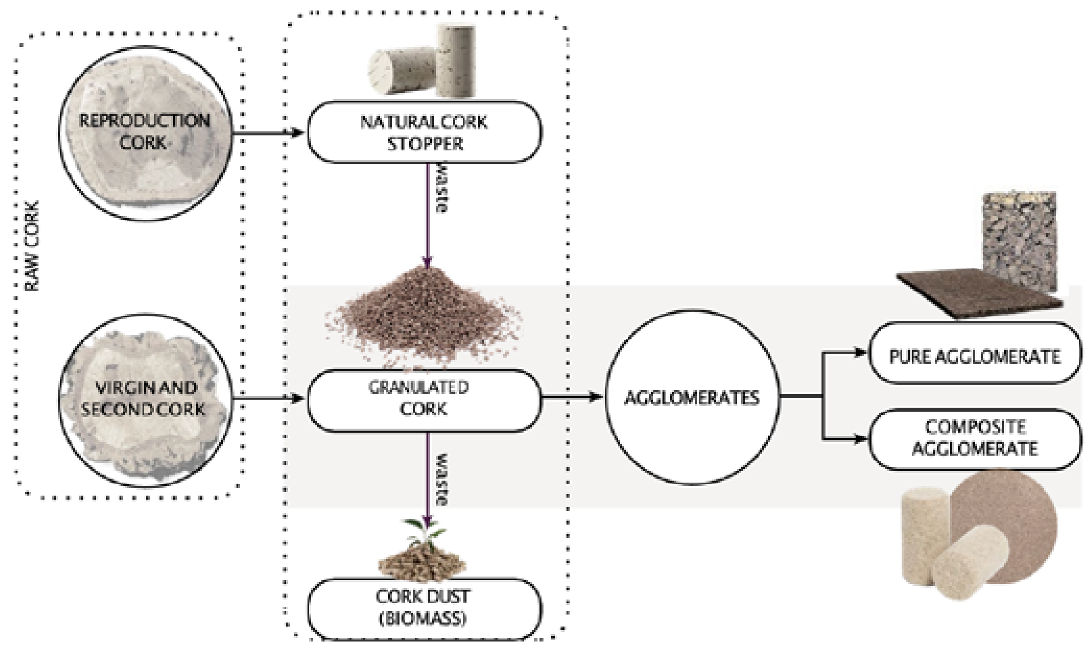


SOURCE: Own elaboration, 2024.

Types of cork

Cork, as a natural product, offers different qualities, from which it is possible to obtain different types of cork depending on the way it is processed.

- **Natural cork:**
  Higher quality cork made from a single piece. It is intended for the manufacture of stoppers from slices or strips of natural cork planks. It is obtained from the reproductive cork extracted from the third sack.
- **Granulated cork:**
  It is produced by crushing the lower quality cork that is not suitable for the manufacture of natural cork stoppers, it is manufactured from the bornizo and second cork obtained from the first and second extraction respectively, as well as from the waste resulting from the production of natural cork, including discarded stoppers. This has led to the understanding of granulated cork and agglomerates as "by-products" or even to their being classified as "waste" from the production of cork stoppers.
- **Agglomerated cork:**
  They are very typical and representative of the cork industry, being the ones that absorb most of the cork produced. They are made from granulated cork and allow two types of agglomerate to be obtained: pure and composite.
- **Pure agglomerate:**
  They are made up of cork grains agglutinated by the cork's own natural resins, which allow the cork to undergo a process of self-agglomeration, which enhances the insulating properties of cork, which is why they are mainly used for insulating buildings or refrigerators. They are not used for the production of cork stoppers and are generally produced from the cork extracted in the first extraction.
- **Composite agglomerate:**
  They are made up of cork grains agglutinated by adding an appropriate glue that is not cork. It is possible to manufacture pure agglomerated cork stoppers or to use them for other purposes and they can be obtained from second or higher quality cork.



SOURCE: Own elaboration, 2024.

Types of industry

We found at least five industries related to cork production, a cork company can be composed of these five, or only one, depending on the size of the company.

In a first stage, a first harvest of virgin cork is obtained, from which it is possible to produce only pure agglomerated cork. To produce pure agglomerate, the raw material is first crushed and then subjected to a physical treatment that produces the self-agglomeration of the cork. In other words, this stage involves first the crushing industry and then the pure agglomerate industry.

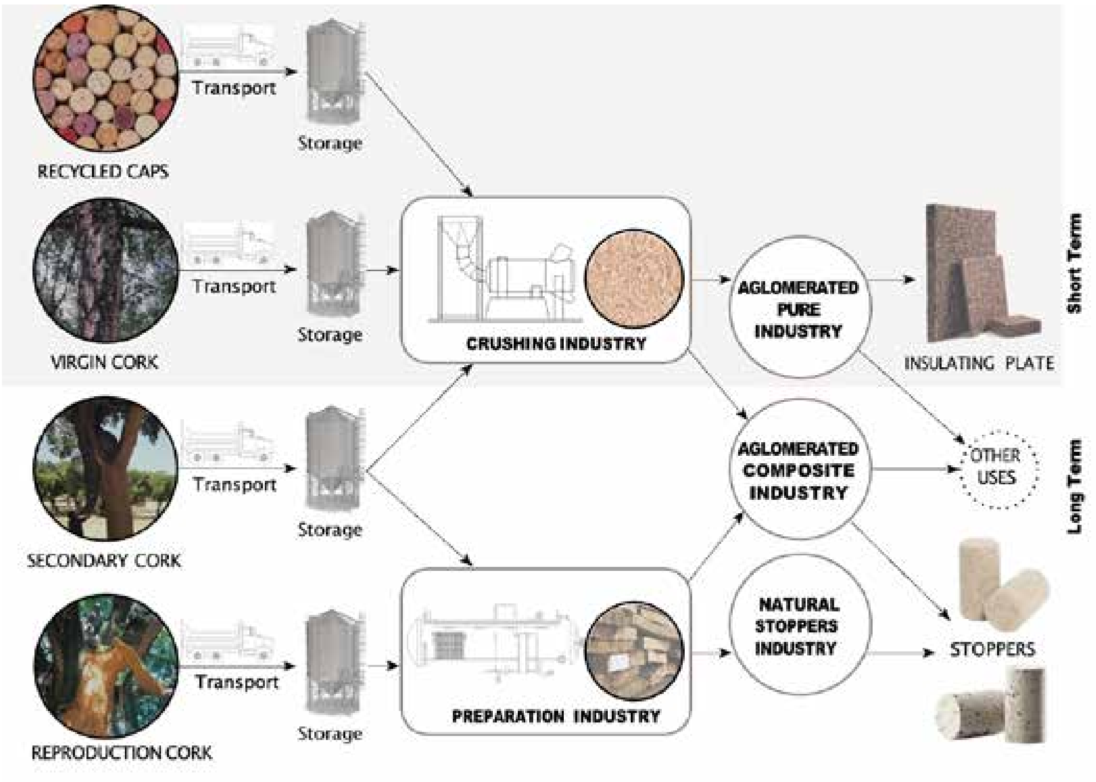
By obtaining secondary cork, it is now possible to produce both pure agglomerated cork and composite agglomerated cork.

Agglomerated composite cork can be used for agglomerated stoppers or for other products. If the raw material is to be used for stoppers, it must first be prepared through a cooking process, then it is crushed and agglomerated, therefore, the cork first goes to the preparation industry, and after being crushed, to the agglomerated stopper industry. For the manufacture of other products, the preparation of the cork is not necessary, and it goes directly to the agglomerated composite cork industry.

In the third extraction, it is already possible to manufacture natural cork stoppers from the reproduction cork, so that the cork, once prepared, is sent to the natural cork stopper industry.

Recycled cork stoppers are destined for the cork crushing industry, offering the possibility of producing pure agglomerated cork or composite cork.

Types of industry



SOURCE: Own elaboration, 2024.

Innovation as a driver of sector growth

Cork is a scarce material worldwide. On the one hand, the wine industry has not been able to replace the cork stopper, so the increase in the supply of wine, at the same time implies an increase in the demand for quality cork. On the other hand, the cork oak is a tree whose geo-climatic limitations limit its production to the Iberian Peninsula, and added to this, the time involved in growing the tree makes it a long-term investment.

The economic profitability of the cork industry depends to a large extent on the high caliber cork stopper, a product of great value in the market, but its long production time requires diversification of the industry in combination with other products. By other products we mean both the by-products of cork itself, i.e. agglomerates, and other products obtained from other sources within the same cork oak forests also called “dehesas”.

Starting with the “dehesas”, usually, the combination of cork oaks with the exploitation of Iberian pigs or other types of livestock allows the investment in cork oak groves to be amortized in the short term. This allows an economic benefit to be obtained from the forest ecosystem itself, while the cork oaks are still in the growth phase, or in the phase of regeneration of their bark.

Although the tree has already grown, the time it can take to obtain quality cork can exceed 40 years, as at least three extractions of cork are necessary for it to perfect its caliber.

In fact, the low-quality raw material obtained in the previous extractions corresponds to most of the raw material, and even in the bags of quality cork, around 70% cannot be destined for the cork industry, due to insufficient thickness or other reasons.

For this reason, in order to promote the growth of the cork industry, it is necessary to focus on the agglomeration industry, which, unlike the cork industry, offers a by-product capable of generating medium-term profitability, serving as an enhancer of the cork industry in broad terms.

Consequently, exploiting low-quality cork in construction products constitutes a latent opportunity to take advantage of a material with unique qualities that is currently not being exploited. The industrialization of cork and its processing as agglomerate has been going on for hundreds of years, and we can find references that have described it for more than fifty years:

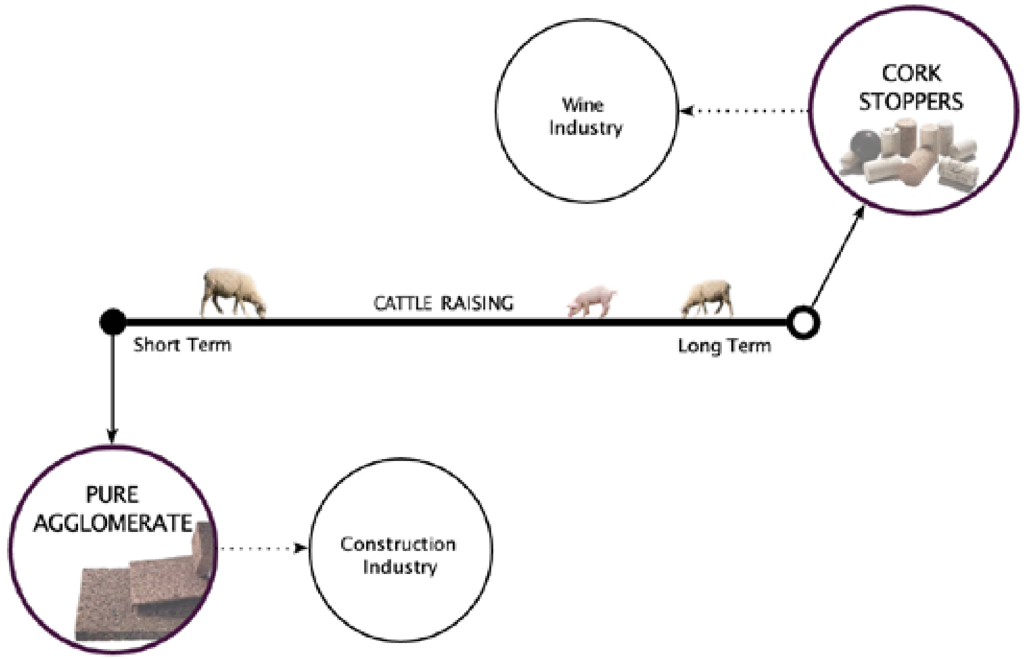
> *The natural cork waste, also called shavings, are passed to mills or crushing machines where they are separated into different types. They are then dumped into mixing machines, where special binders are added and then pressed into the desired shape. Finally, they are taken to drying sheds where they must remain for varying lengths of time depending on the thickness of the sheet produced (Saba, 1967, p.21).*

Although it is not a recent development, as already mentioned in point 3.1, the rise of agglomerated cork in the refrigeration industry has been overtaken by synthetic materials, and then the same thing happened with insulating panels for buildings, which, although their ecological character is recognized, plastic-based insulating materials offer much more competitive prices on the market, against which cork is not able to compete.

Despite the positive aspects of cork, García argues in 2015 that fewer and fewer Spanish companies are managing to make a living from the cork business. This shows us the need to propose ways to exploit the potentials of cork and expand its use, in order to reverse the decline of the industry.

> *There is a dichotomy when it comes to its use. Although the arguments in favour of so-called sustainable development, so frequent in the media in recent years, promote greater use of natural materials such as cork, fewer and fewer Spanish companies are managing to make a living from this business. (García, 2015, p.09).*

Diversified industry



SOURCE: Own elaboration, 2024.

Therefore, the question of how to optimally introduce agglomerated cork into the market is still open. The challenge is to create a product that, despite its high value and high cost, can be positioned as a unique product on the market. Or a product that involves a cost reduction in manufacturing or another phase of the production cycle, which allows the material costs to be amortized. So that it would be feasible to position the product with similar prices of what is available on the market.

Therefore, the valorization of cork through its application in innovative construction systems could encourage the growth of the cork industry and the expansion of the cork oak in the territory, if this material can be positioned in a more competitive way in the market, compared to its traditional use as an insulating product.

The main distinguishing feature is that cork is a material that, like no other, offers measures to improve the environmental impact at every stage of a building’s life cycle. Therefore, the focus on sustainability can constitute a differentiating factor and give value to a product whose potential is not being sufficiently exploited at present.

> *Cork agglomerates have the important virtue of preserving their goodness over a very long period. This circumstance is well known and contrasts with the negative implication of time on the integrity of the structures of synthetic materials (Velasco, 1972, p.3).*

5

CORK IN ARCHITECTURE

Cork is an optimal choice in sustainable construction as it provides thermal and acoustic insulation, improves air quality, has a unique appearance and has obvious sensory qualities. As an ancient material, its applications date back to ancient times, where its insulating qualities were already being experimented with. Its use became more widespread in the 19th century, as in the case of Antonio Gaudí's Sagrada Familia, which has a cork floor.

> *No other material brings together, as cork does, so many simultaneous virtues within the field of its applications, due to its specific and unequalled constitution, obtained by nature in an evolutionary process of specialization over millions of years (Velasco, 1978, p. 05).*

Also, in Lisbon during the 1940s, cork was used in architectural projects related to leisure, such as hotels and cinemas. The choice of cork in projects such as the Hotel do Império, designed by Cassiano Branco, or the Cinema São Jorge, inaugurated in 1950, was linked to the search for an image of modernity, comfort and innovation in leisure architecture. The use of this traditional material, but with new applications and technologies, made it possible to solve problems of insulation and aesthetics in a new way. However, its use was limited to the category of finishing, as cladding or flooring (García-Pereda and Pesoa, 2021).

Cork, due to its versatility, is able to contribute to architecture in a multitude of ways, as the architect Álvaro Siza states: "Architecture and design can take advantage of cork's unique set of properties, knowing them and using imagination". (Amorim News, 2013, p.11).

Structure, composition and material properties

The first plant tissue described under the microscope by Robert Hooke in 1665 was cork (Carballo, 1984). He called the cells of cork cells because of their resemblance to the cells of a honeycomb. The content of the cell cavity, which is between 87 and 89% of the volume, is gaseous (Saccardy, 1938) with a composition very similar to air and according to Morell Villette (2002) the percentage of gas reaches 89.7%.

Cork is a plant tissue formed by dead cells that protect the living parts of the trunk and branches of the cork oak, according to Jose Luis del Pozo Barrón. Cork grows thanks to a layer of cells with meristematic properties called phellogen.

Annual growth in thickness forms a growth ring. Rings are typically 1 to 6 mm (Pereira, 2017).

Cork tissue is very homogeneous. It was long believed that cork cells were isolated, but with the electron microscope it has been observed that between 30,000 and 400,000 magnifications in a radial direction, and in groups, there are perforations that communicate some cells with others, called plasmodesmata, with a diameter of 0.06 um. Their existence contributes to the constant volume of the cork. Their existence contributes to the constant volume of the cork (Remacha, 2008).

Cork composition

In 1920 Klauber gives the following composition:

- Suberin: 58%.
- Cellulose: 22%.
- Lignin: 12%.
- Water: 5%.
- Cerine: 2%.
- Vinylin, phenolic, tannic, diacrylic acids, etc.: 1%.

Guillermonat in 1960 gives the following chemical composition:

- Suberin: 45%.
- Lignin: 27%.
- Polysaccharides and cellulose: 12%.
- Tannins: 6%.
- Waxes: 5%.
- Other (minerals, water, glycerin, etc.): 5%.

Recently, different authors have indicated the following as the elemental chemical composition:

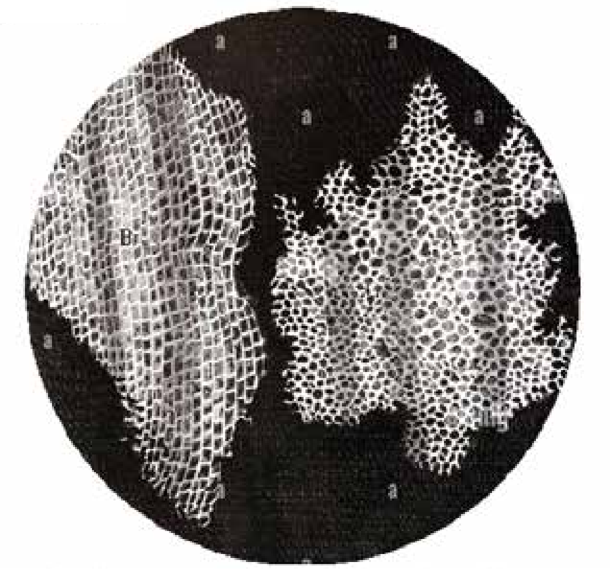
- Carbon: 67%.
- Oxygen: 23%.
- Hydrogen: 8%.
- Nitrogen: 2%.

The most frequent component in cork is suberin, a mixture of fatty acids with great flexibility that gives cork its properties of compressibility and elasticity. Lignin, on the other hand, is the component that allows the cell walls of suberin tissue to be rigid, thus ensuring the maintenance of cell structure and morphology.

Cork

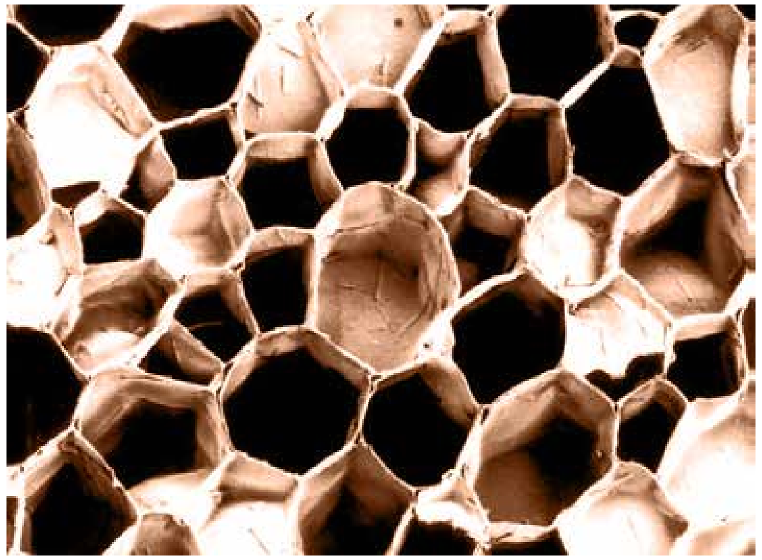
SOURCE: Retrieved from: https://www. sabatcorchos.es/ciclo-de-vida-del-corcho/, 2024

Cork cells



SOURCE: Retrieved from: https://icsuro.com/es/ descubrimos-las-propiedades-del-corcho-en-la-semana-de-la-ciencia/, 2024

Cork cells



SOURCE: Retrieved from: https://www.vinetur.com/2019030449455/what-is-the-cork-sack.html, 2024

Physical-mechanical properties of cork

The cellular structure of cork and its composition mean that this natural product has physical and mechanical properties that make it unique, including the following:

- **Lightweight:**
  88% of its volume is air, which translates into a low density of between 0.12 and 0.24 kg/liter.
- **Buoyancy:**
  Due to the large amount of air present in their cells and their impermeability.
- **Elasticity:**
  Ability to recover the initial volume after undergoing deformation, which justifies, among other things, its use in capping.
- **High friction coefficient:**
  Ability to recover the initial volume after undergoing deformation, which justifies, among other things, its use in capping.
- **Highly waterproof:**
  The surface of the cork is covered with micro- suction cups, giving it adherence and making it difficult to slide.
- **It rots with difficulty:**
  The existence of tannins in cork complements its inalterability. Cork does not absorb more than 18 to 20% water, which influences its conservation and its rot-proofing.
- **High calorific value:**
  Its ability to generate heat is similar to that of charcoal.
- **Aeroelasticity:**
  Shock absorber.
- **Poisson's ratio 0:**
  When the volume of cork is reduced i n one direction, no deformation occurs in the perpendicular direction. This allows it to absorb the deformations of other materials and integrate with them.
- **Low water content:**
  The equilibrium humidity of cork with the environment is normally 6%, making it impossible for microorganisms to proliferate and giving it great durability.
- **Thermal insulation:**
  It has a heat transfer resistance 30 times higher than concrete, thanks to its honeycomb structure, low water content and lack of conductivity of its compounds. Its thermal conductivity is between 0.030 W/mk - 0.040 W/mk for a density of 120 kg/ m3.
- **Sound absorption:**
  Very high (high absorption coefficient) due to its own porosity and elimination of reverberation. Very high impact sound insulation due to its high elasticity.
- **Excellent vibration isolation**
- **Non-toxic, odorless and tasteless**
- **Durability:**
  It is a material that is difficult to alter either by chemical substances, natural or artificial, the fact that it does not contain cells with protoplasm makes i t hygienic, and it can be said that it is resistant to the action of humidity and atmospheric changes. It does not oxidize due to the action of air or humidity.

Traditional uses of cork

The multiple virtues of cork, explained by its physical properties, make it a very versatile material, capable of adapting to a wide variety of uses. Due to this, the value of cork can be understood, Luis Velasco Fernandez in 1978 points out:

> *The combination of so many qualities in the same material enables it to be used in many cases, among which the most relevant are those corresponding to the thermal insulation of buildings, roofs, terraces, doors, transports, pipes, conduits and cold rooms; those corresponding to the acoustic correction in buildings; those corresponding to the damping of vibrations, as an anti-vibration support for moving machinery; and also those corresponding to interior decoration (Velasco, 1978, p.33).*

The following are some examples of the uses to which cork has been put.

In the aerospace and electrical industry:

- Thermal and vibration insulation and acoustic corrector.
- Products to prevent fluid leakage in modern transformers.

Liquid clogging:

- Stoppers: wines, champagne, cava, cider and sparkling wines (agglomerated)
- Natural cork discs and washers

General machinery

- Machinery stands
- Sealing gaskets

Textile industry

- Discs and thread spools with high friction index.

Chemical and pharmaceutical industry

- Suberin, waxes
- Plugs
- In laboratories, for protective bases for work surfaces in entomology, dissection and for flasks.

Footwear

- Heels, soles, insoles, shoe bodies

Fishing industry and sporting goods

- Freshwater fishing tackle
- Cane handles
- Buoys and Floats
- Balls and balls.

Household goods

- Placemats or placemats
- Coasters
- Decorative boxes in beverages and food
- Paintings and frames

Construction

Traditional Uses

- Thermal insulation in walls, partitions, ceilings, floors, slabs, doors and terraces.
- Impact sound insulation and acoustic correction
- Vibration isolation and vibration damping (machines, rails, beams)
- Decoration, wall coverings in various shades
- The bond between rubber and cork agglomerate for flooring combines anti-slip and sound absorption properties.

Non-Traditional Uses

- Recycled cork ceramics
- Acoustic panels
- Domed structures
- Assembly systems

These are some of the most common uses of cork as a material, including traditional uses for architectural applications. Outside the traditional applications of cork in construction, there are references that combine this material with new technologies, managing to express the properties of cork in unique ways.

Cork in Architecture - Temporary Cork Pavilions

Cork is an outstanding alternative for sustainable construction thanks to its thermal and acoustic insulation properties, as well as its ability to improve indoor air quality. Its unique texture and sensory qualities make it a versatile and attractive material. Its use dates back to antiquity, when its insulating properties were already valued, and it achieved greater prominence in the 19th century, being applied in emblematic works such as Antonio Gaudí's Sagrada Familia.

At this time cork re-emerged as a construction material in a new way, offering architecture a modern and innovative aesthetic, although its application was mainly limited as a finishing material.

There are limited historical examples of cork planks playing a structural role in walls, and previously expanded cork blocks have been used for internal self-supporting partitions. In recent years, expanded cork has been used structurally in a number of small temporary pavilions. Below are some examples of cork applied in architecture.

Serpentine Gallery Pavilion / Herzog & de Meuron and Ai Weiwei, London, 2012

This semi-buried pavilion invited visitors to go beneath the Serpentine lawn to discover the hidden history of the previous structures that occupied the site. The roof was raised 1.4 meters above ground level and supported by eleven columns representing the past pavilions, and one column characterizing the current structure.

The interior was clad entirely in cork, a material chosen for its sustainability and texture, which visually evoked the excavated earth and reinforced an archaeological approach. According to architects Herzog & de Meuron, "Cork is a natural material with obvious tactile and olfactory qualities whose great versatility allows it to be sculpted, cut and molded". (2012)

SOURCE: Retrieved from: https://amorimcorkcomposites.com/ en-us/about-us/blog/cork-a-sustainable-realm-of-visuals-and-performance/, 2012.

Gharfa Pavilion, Edoardo Tresoldi, Saudi Arabia, 2019

With a concept inspired by local ruins, Edoardo Tresoldi uses his classic "absent matter" approach using the wire mesh technique. However, this was the first time he used a material to fill the structures and form cork masses. In this way the work instead of merging with the landscape, formed a structure that is an architectural fortress, offering mere glimpses of what is happening inside it.

SOURCE: Retrieved from: https://www.archdaily.co/co/930405/pabellon-de-malla-de-alambre-y-corcho-inspirado-en-ruinas-reflexiona-sobre-la-arquitectura-efimera, 2019

Portugal Pavilion, Carlos Souto, Shanghai, 2010

This pavilion showcased cork as an iconic material of Portuguese origin, highlighting its recyclability and environmental friendliness. Both the exterior walls and interior cladding were made from this material, showcasing its sustainable potential. The exhibition spaces celebrated Portugal's history, culture, economy and daily life, justifying the choice of a material that is deeply representative of the country.

SOURCE: Retrieved from: https://es.wikibrief.org/wiki/ Expo 2010 pavilions, 2010

Cork domed pavilion Pedro de Azambuja Varela; Maria João de Oliveira; Emmanuel Novo, Portugal, 2013

This project was the result of research conducted at CEAAD 2012/2013, which explored the capabilities of agglomerated expanded cork. The concepts developed included the creation of vaults exclusively with cork, the use of a translucent material derived from cork, and a system of radiation and acoustic optimization. These ideas were materialized in a pavilion whose continuous, organic form reflected this symbiotic relationship.

A parametric algorithm allowed testing different variations of curvature and dimensions, while another algorithm automatically generated hundreds of unique parts cut by CNC technology in VFABLAB. These semantically labelled parts facilitated efficient assembly by Amorim Isolamentos SA.

SOURCE: Retrieved from: https://www.archdaily.cl/cl/02- 317300/pabellon-abovedado-de-corcho-pedro-de-azambuja- varela-maria-joao-de-oliveira-emmanuel-novo, 2013.

Claus Porto Shop, New York, 2018

This project used CNC technology to mold cork blocks into a precise and renewable modular system. Using 1,500 diamond-shaped modules, a 13-metre- long arch was constructed. After an initial test, the structure was disassembled, transported and reassembled back in the shop, completing the process in less than 10 days.

SOURCE: Retrieved from: https://amorimcorkcomposites.com/en-us/knowledge-center/case-studies/claus-porto-s-first-store-outside-portugal-is-in-new-york-and-it-s-made-from-cork/, 2018.

Innovation with cork as a structural material

Cork House, Matthew Barnett, 2019

Cork House, by Matthew Barnett, is a building that demonstrates the scope of cork as a construction material. The project arises from the premise that cork in its conventional formats has proven to be capable of adapting to each layer of a traditional envelope: interior finish, insulation between partitions and exterior cladding. As a result, Cork House is a house in the United Kingdom whose solid envelope is made from a single bio renewable material, cork.

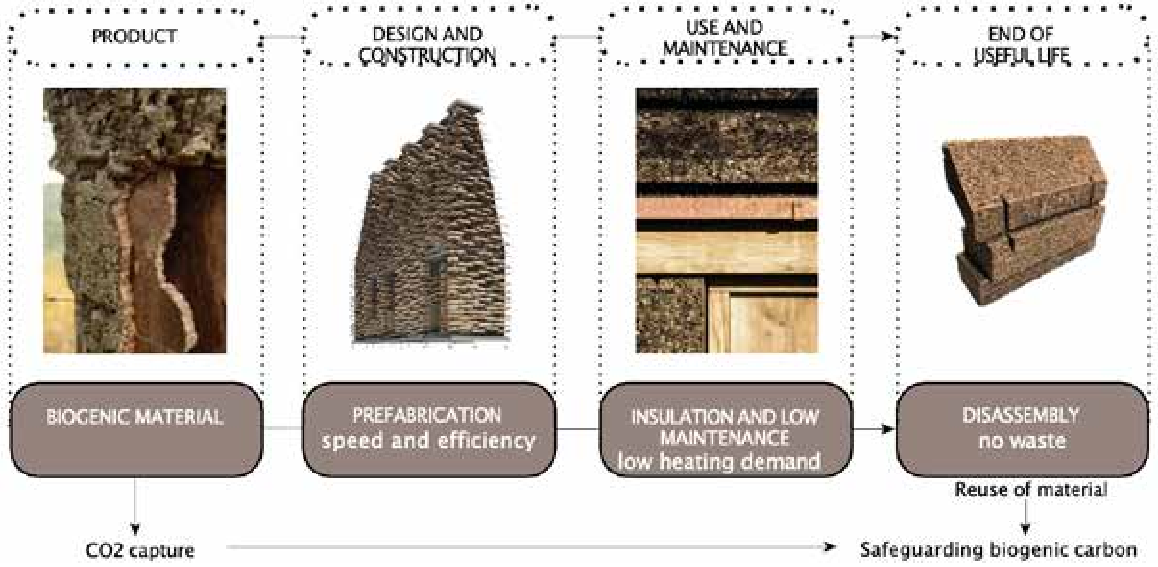
This envelope is constructed from an assembly system, where components are prefabricated off-site and assembled by hand on site, without mortar or glue, so that the 1,268 dry-jointed cork blocks can be salvaged at the end of the building's life for later reuse. (https://www.matthewbarnetthowland. com/cork-house)

The result was an exceptionally low carbon building over its entire life cycle, being assessed by Sturgis Carbon Profiling as negative embodied carbon at completion and 618 kgCO2e/m2 over a 60 year life, the lowest lifetime carbon assessed to date.

The life cycle analysis demonstrates how this innovative construction approach could offer significant environmental benefits in terms of reduced carbon emissions, energy consumption and waste management, which is summarized below:

- **Product stage**
  Cork is a material of biogenic origin that comes from sustainable forest management in favour of biodiversity. Its industry applies circularity principles and absorbs more carbon than it emits.
- **Construction phase**
  The efficiency of the construction system minimizes time and errors, and consequently waste.
- **Stage of use**
  The insulating capacity of cork contributes to the energy efficiency of the house by reducing heating demands, its qualities improve air quality, and its durability means that it requires almost no maintenance.
- **End of life**
  The ability to dismantle and reuse the construction system, together with the durability of cork, guarantees a circular economy model.

Cork house LCA



SOURCE: Own elaboration, 2024.

This project could be considered a turning point in the use of cork in construction, as it proposes for the first time to test the potential of this material as a permanent primary structure. As a result, it addressed previously unknown qualities of its performance, such as weather tightness and structural behavior, and developed a system of tongue and groove geometry and interlocking between each block, allowing for dry assembly. The following conclusions can be drawn from this:

- Cork-cork compression joints, following the principles of the cork wine stopper, were discarded due to the risk of tearing the blocks by creating stresses.
- The tongue and groove geometry makes it possible to position one block in relation to another, due to the elasticity, roughness and non- slip quality of cork.
- The standard formulation, with respect to the density of the cork grains, is adequate to meet the needs of the system. Density between 140 and 160 kg/m3.
- Acetylated wood complements cork.
- The self-agglomeration process of the cork granules cannot be used to give complex shapes to the blocks, making subsequent robotic milling necessary.
- The selection of large block sizes minimizes the number of blocks and the number of joints, which means a more efficient system.
- Slots are incorporated in the blocks for drainage and air equalization.
- The maximum block size is 100x50x22cm.
- The workflow of the construction process was as follows:
  - Modelling of the blocks in SolidWorks.
  - Export of geometries to PowerMill Robot.
  - 5-axis CNC milling.
  - Transport of batches in the correct sequence for assembly.
  - Manual assembly of the walls (by one or two people), ratchet straps were used to hold the walls in position before placing the upper beams that serve as geometrical control points.
  - Roof assembly from a scaffolding platform.

The Cork Studio – Studio Bark, 2018

The Cork Studio was self-funded and self-built by Studio Bark as a low-budget research project. Its intention was to provide a demonstration of how cork could be used in practice and whether it could provide a viable, low-cost, waste-free construction method to be replicated in other projects.

The aim was to test the possibility of extending the application of cork in architecture as a main structure, creating a simple “solid cork” building and eliminating the need for frames, coatings, glues, tapes, breathable membranes and wet work.

In this case, the cork block is used in a more conventional way, stacking the blocks in their original format, without the need to resort to new machining technologies. In this way, it is built with construction elements already available on the market.

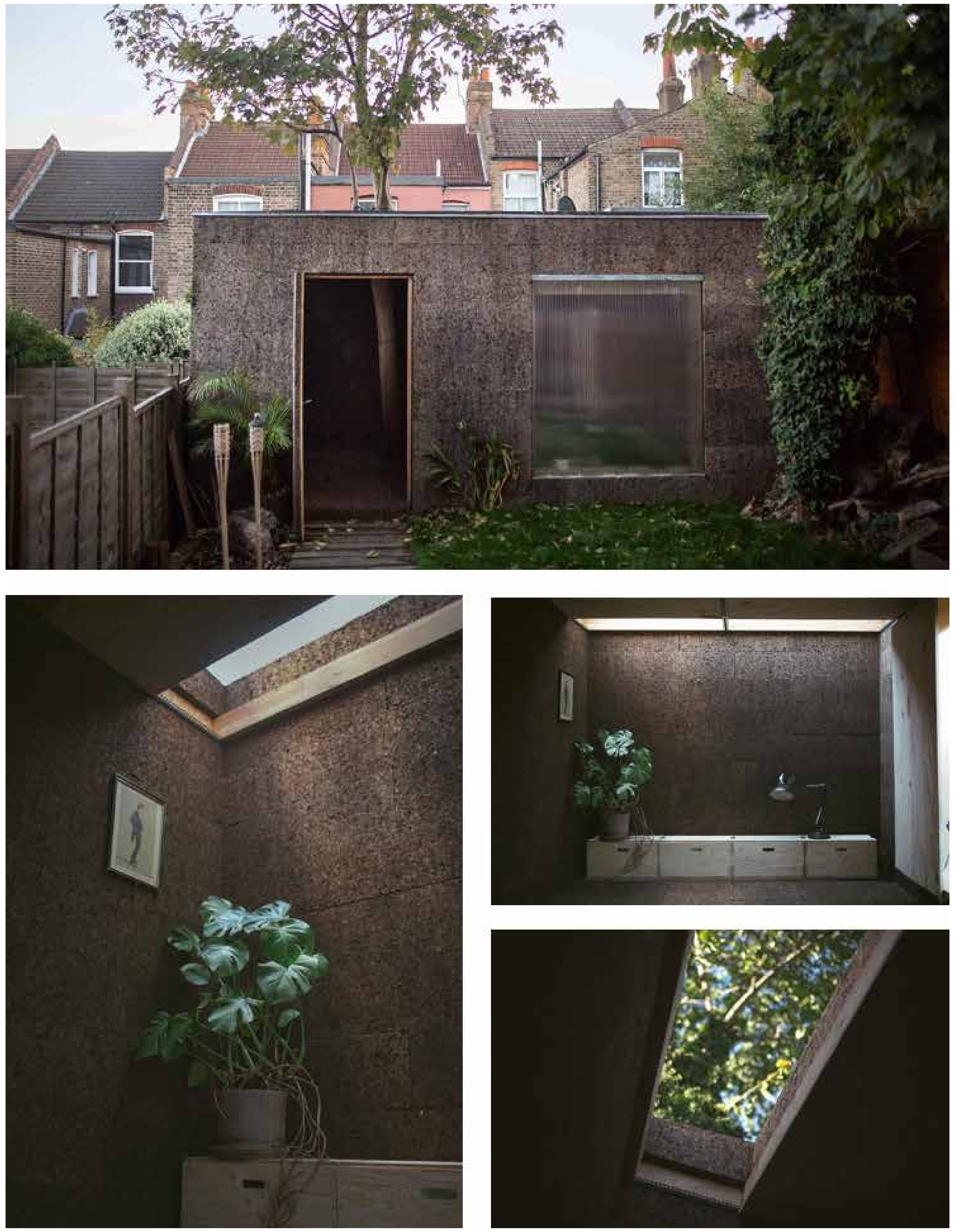
Although this is also a dry system, unlike the previous case, the blocks do not have laser-cut tongue and groove joints, so screws were used as connecting elements, which adds a little complexity at the time of installation. The floor slab is made up simply of cork blocks placed on a uniform surface of sand, testing the cork’s inalterability to external agents to the maximum. Cork blocks placed one on top of the other to form steps were used as scaffolding. In this way, The Cork Studio makes the most of the material to construct an extremely simple building.

This project exemplifies an innovative but simple way of introducing cork in sustainable architecture and gives it a leading role being used as a structure, transcending the classic function of finishing. This study proves that the use of structural cork makes it possible to dispense with non-biodegradable components, highlighting the ecological advantages of cork and its potential to promote a circular economy and sustainability in architecture.

Views of Cork House, Matthew Barnett

SOURCE: Retrieved from: https://www.archdaily.com/938586/cork-house-matthew-barnett-howland-plus-dido-milne-plus-oliver-wilton, 2019.

Views of The Cork Studio, Studio Bark



SOURCE: Retrieved from: https://www.dezeen.com/2018/12/20/studio-bark-cork-studio-recyclable-building-sustainable-architecture/,2018.

Future of structural cork

While these pioneering projects represent an initial step towards positioning cork within the range of building materials, the use of structural cork still has much to be explored. But, although it is still at an experimental stage, the results show that it is a feasible idea.

On the one hand, The Cork Studio proposes an accessible way to build cork structures. The method of building with blocks simply nailed together could easily be replicated in other projects within the EU, using standardized materials already available on the current market. While material availability is not an impediment to building with cork, it also requires initiative on the part of builders.

In this context, the use of cork in architecture still faces some barriers, such as the lack of regulations governing its structural use. Furthermore, despite being an ancient material, the richness of cork is still little recognized by society, including designers and architects. This has been reflected in the decrease in cork production and the decline of the cork industry, which is clearly evidenced by the disappearance of the pure agglomerate industry in Spain.

This lack of recognition can be attributed to a number of factors. The most obvious is the inefficient management of the cork industry, as a result of the complexity involved in coordinating different types of industry. Although, ideally, they should operate collectively, in Spain they currently operate independently, while there is a greater emphasis on the extractive and preparatory industry than on the processing industry.

On the other hand, in the social perception of cork, its role as a packaging material in the form of a wine stopper predominates, which reinforces the idea that it will end up being discarded. This places cork in a linear economic model, in contradiction with the nature of the material, since, for various reasons, the cork industry is not adapted to the linear production scheme that currently predominates, in terms of speed and quantity.

Cork is a product determined by the temporal and geographical limits of the cork oak, which translates into a limited amount of production, unable to match the linear flow of synthetic products. However, the durability of cork and its multiple simultaneous virtues have not been reproduced by any modern material, so being a unique and irreplaceable material, and due to its capacity to last over time, its production scheme is adapted to a circular economy model.

This indicates the importance of using cork wisely, and consistent with its unrivalled durability, to apply it to products with a long-life span, such as architecture. While quality cork will continue to remain in the wine industry, most of the raw cork is still available for a use that corresponds to its essence. Marco Sousa Santos, explains this idea very well:

> *What interests him most are its mechanical characteristics and the correspondence between material and function. Cork should be used primarily for its mechanical aspect rather than for its formal characteristics, because only from this perspective can it be used and valued in a sustainable way. In the perspective of "good design" a material should be used rationally and appropriately, in accordance with its elementary functional purpose (Amorim Cork Composites, 2011, p.21).*

To take advantage of their mechanical qualities and honor their durability, and what a product of greater longevity than buildings, which make up a bank of materials that will accompany us for decades or hundreds of years. At the same time, natural products such as cork, due to the emissions captured by their source of origin, are capable of converting the building stock into real carbon sinks, contributing to decarbonizing the construction sector. Therefore, overcoming the limitations that prevent cork from reaching its full potential would also mean overcoming one of the barriers to achieving carbon neutrality.

Consequently, the limited use of cork in architecture highlights the need to disseminate its values, highlighting both its technical properties and its significant ecological contribution.

In a different vein, Cork House demonstrates the potential of cork in combination with new technologies, proposing the prefabrication of a sustainable system that is quick to install. This proposal adds complexity to the manufacture of cork blocks, due to the need to resort to advanced technological tools. But it simplifies installation and takes nails out of the equation by assembling tongue and groove blocks. Simply put, this solution is less accessible to replicate today, but it is a significant step towards a more industrialized, and therefore more efficient, system.

As mentioned in the first chapter, in terms of circularity, the industrialization of construction processes initially represents an improvement in the sustainable qualities of a project. Dry construction reduces the consumption of resources during the execution process, minimizes waste and facilitates subsequent reuse or recycling. At the same time, prefabricated systems simplify planning, improving the precision of execution, which means a reduction in time and costs.

However, conventional prefabricated construction has been largely focused on the use of metallic and synthetic materials, which have a high environmental impact. Therefore, if a prefabricated system is developed using a renewable material with a low carbon footprint, a significantly more sustainable production model is obtained.

The example of structural cork, as described above, combines the advantages of prefabrication, such as waste reduction and efficient control of resources, with the capacity of biogenic materials to reduce carbon emissions. In this way, a construction model is established that unites an eco-centric approach with the technocentric and is aligned with the global objectives of sustainability from multiple angles.

The idea proposed by Cork House has great potential, because it proposes the industrialization of an ecological building system. However, it is recognized that this system could still be further simplified and standardized. Although its aim was to create a simple envelope, the house has forty-four different types of block geometries.

The key to expanding the use of cork in architecture could be the standardization of a prefabricated system that, with the minimum number of block typologies, allows the construction of the main structural elements to make up a building. This could allow the massification of the use of structural cork in a cork block assembly kit format, which could be adapted to various designs.

On the premise that by using a large volume of material, cork has sufficient capacity to serve as a structural system, from the data obtained in Matthew Barnett's research through Cork House, it would be possible to develop a more standardized and more efficient cork block assembly kit than the example case.

A system made up of a small number of renewable materials makes it less complex than classic multi- layered envelope systems with a variety of elements. Therefore, it is possible to dispense with skilled labour for its construction, if one has the motivation to self- build. The reduction in construction time leads to a reduction in costs, resulting in an economically feasible system.

At the same time, the almost zero carbon footprint that the use of cork allows, adapts to the sustainable paradigm that, due to current environmental problems, will become more and more established in society, making this system a construction method in line with the needs of the future. Likewise, the implementation of a cork construction system can contribute to promoting the growth of the cork industry and the expansion of cork oak forests, bringing with it environmental, territorial and social benefits.

Technically, a cork block assembly kit offers a product with the following advantages:

- Lightweight structure for quick and easy installation
- Detachable and reusable
- Long service life
- Natural and renewable product
- Monolithic and simple envelope
- Thermal and acoustic insulation
- Optimum indoor air quality

To understand the scope of this idea and the market it faces, a comparative analysis with other similar construction systems was carried out. For this purpose, prefabricated systems in block formats were selected, and seven aspects were defined for comparison: horizontal elements, visible structures, dry/dismountable, thermal and acoustic capacity, and healthiness.

The table below lists the selected building systems and the criteria to be taken into account. A check mark is placed in the box if the system satisfies the indicated aspect, and if it does not, the box is marked with an "X". The systems used for comparison are as follows:

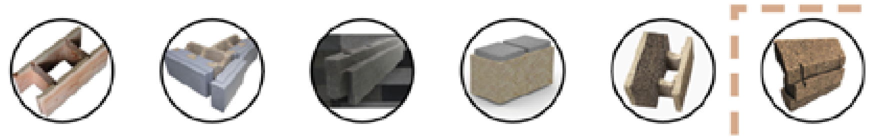
- Gablock, Belgium, 2019
- Bloqueplás, Mexico, 2018
- Brikawood, France, 2017
- Isolabloc, Belgium, 2019
- Isotex, Germany, 1985

The following is an analysis according to each indicator.

- **Horizontal elements**
  Some of the systems are made up of blocks that allow walls to be built, and others go further and include their own system of slabs or vaults. Gablock, for example, includes beams adaptable to the system and slabs that allow building in height, however, with this system the roof is still built in the traditional way. While some systems include horizontal elements, none go as far as forming a roof with the blocks themselves as Cork House does.

- **Visible structures**
  Structural cork forms an envelope that does not require finishing allowing the sensory qualities of cork to be exhibited, in comparison, some of the other systems do not have this level of simplicity requiring both exterior and interior coatings.

- **Dry/dismountable**
  This is an important point from a product life cycle approach, as a dry system allows the blocks to be disassembled for reuse. Isotex or Isolabloc are products that are more advanced, however, after the assembly of the blocks, concreting is required inside them, making them a wet system that can be quickly assembled, but cannot be disassembled.



	Brikawood	Isolabloc	Bloqueplás	Gablock	Isotox	Cork Kit
Horizontal elements	x	x	x	✓	✓	✓
Visible	✓	x	✓	x	x	✓
Dry/removable	✓	x	✓	✓	x	✓
Thermal capacity	✓	✓	✓	✓	✓	✓
Acoustic capacity	✓	✓	✓	✓	✓	✓
Healthiness	✓	✓	x	✓	✓	✓

Comparative table. SOURCE: Own elaboration, 2024.

- **Thermal-acoustic capacity**
  These points prove that the main focus of these systems is on providing energy efficiency to buildings.

- **Healthiness**
  The majority of systems are made up of natural elements, providing optimal indoor air quality in the cases that are visible, with the exception of Bloqueplás, whose health levels could be questioned as it is a highly industrialized plastic material.

As a result, it has been proven that a cork kit could be the only system that meets the established indicators, making it a unique product on the market. In summary, a construction system of pure cork blocks that are dry assembled, forming an envelope with a single natural and renewable material, would imply the following benefits:

- **Waste reduction**
  A prefabricated system minimizes on-site errors and material losses. In short, cork in all its formats is a raw material capable of unlimited reprocessing.

- **Speed of installation and cost reduction**
  The ability of cork to be assembled with a tongue and groove block design without the need to add any intermediate glue means a simple and fast installation process, which reduces construction time and saves resources.

- **Simple**
  Monolithic cork is extremely simple, and because of its multiple properties does not require additional finishes, making it a far cry from traditional complex enclosures involving multi-layered systems and materials.

- **Renewable**
  Pure agglomerated cork is a 100% natural product composed of cork granules that self-agglomerate with their own resin. This means a system that benefits both the indoor air quality of the building and has a low impact on the natural environment.

- **Low environmental impact**
  Its biogenic origin also gives it a low carbon footprint.

- **Reusable**
  Being a dry system, it is possible to dismantle the blocks allowing them to be reused at the end of their useful life.

- **Flexibility**
  The cork blocks are lightweight and can be dismantled and adapted to other projects or designs according to the user's needs.

Cork blocks are still a recent and innovative proposal that requires further practical analysis in order to introduce this product into the regulatory frameworks of each country. In addition, there are still some design issues that could be improved, such as defining a passage for integrated installations in the cork envelope itself, to avoid resorting to visible pipes. Even so, the examples mentioned above have demonstrated optimum resistance over time, which indicates that such a system could be expanded in the future.

In short, the industrialization of a cork system solves the issue of introducing agglomerated cork in an innovative way in the market, a problem detailed in point 3.4. The potential of this system makes it possible to produce a product with unique qualities, with sustainability as a differentiating factor. At the same time, the reduction of labour costs that its easy and quick installation allows, would make it possible to position it within the price range of other similar systems.

6

HOW THE CORK INDUSTRY CAN HELP MEET EU SUSTAINABILITY TARGETS

Cork is an alternative that can combine the advantages of a natural material with the benefits of industrialization, presenting a construction system with low environmental impact that also integrates circularity.

Therefore, the promotion of cork in architecture is a proposal that aligns with global environmental objectives and EU sustainability strategies, both in buildings and in other sectors.

Sustainable forest management

Starting with the origin of cork, cork oak forests are ecosystems considered Habitat of Community Interest (HIC-9330) by the EU, due to their high ecological value, as they are home to a great biodiversity, offer ecosystem resources and protect watercourses.

Although "dehesas" are not classified as native forest because of the anthropic intervention involved, they are an agro-silvopastoral system, characterized by the integrated management of trees, fodder and grazing, as a conservation practice for the use of natural resources. In other words, they are human- managed plantations, which imitate the diversity of nature, to create an ecosystem with the balance of the natural environment.

The extraction of cork corresponds to the bark of the tree, which is then regenerated by the tree, therefore, the exploitation of a non-timber forest industry ensures the preservation of its source of origin. As a consequence, the exploitation of cork oak forests is based on sustainable forest management practices, and contributes to the conservation of forest cover, recognizing the key multifunctional role of forests.

Low carbon footprint

At the same time, cork extraction involves the cork oak accelerating its metabolism, capturing up to five times more carbon, in order to regenerate its bark. As a result, cork brings with it a considerable amount of embodied carbon, making it a biogenic material capable of decarbonizing the construction sector, due to its negative carbon footprint, aligning with the main objective of the European Green Deal: to achieve climate neutrality by 2050.

Indeed, promoting the use of cork as a building material is in line with the plan integrated in the European Green Deal: *"New EU Forest Strategy for 2030"*, since:

- Ensures the restoration, resilience and adequate protection of all ecosystems.
- It helps the construction sector to shift from being a source of greenhouse gas emissions to becoming a carbon sink.
- Promotes non-timber forest-based economic activities to diversify local economies and employment in rural areas.

Circular economy

It is possible to refer to circularity on two scales, one more general with respect to the cork industry, and the other more specific with respect to cork building systems.

Circular economy of the cork industry

Starting with the nature of cork, it is a material that could not be called waste, because it is not polluting, but being a scarce material, it is essential not to waste this valuable raw material, emphasizing the understanding that if a cork stopper is discarded, it will not pollute the earth, but neither will it degrade, it will remain for an indefinite period of time, wasting its unique capacity to last.

Under this premise, the cork industry operates with a circular production scheme, where "waste" is actually a by-product that is used in other sectors apart from the wine industry. And both cork stoppers and agglomerated cork have the capacity to be recycled, being reprocessed as agglomerated cork, although never as stoppers. In this way, all the cork could be reintegrated into the production chain without generating waste.

Biomass

Finally, the final "waste" from the grinding of cork in its granulation process corresponds to cork dust, which can be incinerated to be used as biomass, being able to cover around 60% of the total energy consumption of an industrial group, guaranteeing circularity within the cork factories.

Circular economy of prefabricated cork building systems

As already mentioned, the industrialization of production processes is a key ally in the implementation of circular economy models. The idea of prefabricating the elements of a building in a controlled environment makes it possible to achieve maximum efficiency by eliminating from the equation the common errors that occur on site. In this way, it is possible to produce the precise amount of material to avoid waste.

The prefabrication of cork blocks allows the construction of a dry system, which involves a concept of "assembly and disassembly" instead of "construction and demolition", as the parts could be joined together, without requiring the incorporation of wet elements that prevent the subsequent separation of the components. This ensures the ability to reuse the blocks, and adapt them to the dynamic needs of the inhabitants, which together with the inherent durability of cork, ensures a construction system with an unlimited lifespan.

Indeed, the use of cork in architecture promises to meet several of the key points set out in the *"New Action Plan for the Circular Economy"*, promoted by the European Green Deal:

- Improve the durability, reusability, upgradability and reparability of products.
- Increase the content of recycled content in products.
- Enable high quality remanufacturing and recycling.
- Reduce carbon footprint and ecological footprint.
- Limit the use of single-use products and counteract premature obsolescence.

Energy Efficiency

Cork is a material known for its insulating properties, both thermal and acoustic, as well as for its anti-vibration properties. Pure agglomerated cork, also called black cork, is subjected to a process that further enhances the insulating capacity that raw cork already possesses. The process consists of subjecting the cork grains to a cooking process at high temperatures, causing the cork resins themselves, such as suberin, to self-agglomerate the material with the action of heat, without the need to add other types of synthetic resins.

Indeed, pure agglomerated cork is a 100% natural material, with outstanding insulating properties, making cork the ideal material to apply in the *"Renovation Wave"*, also included in the European Green Deal, being one of its main points:

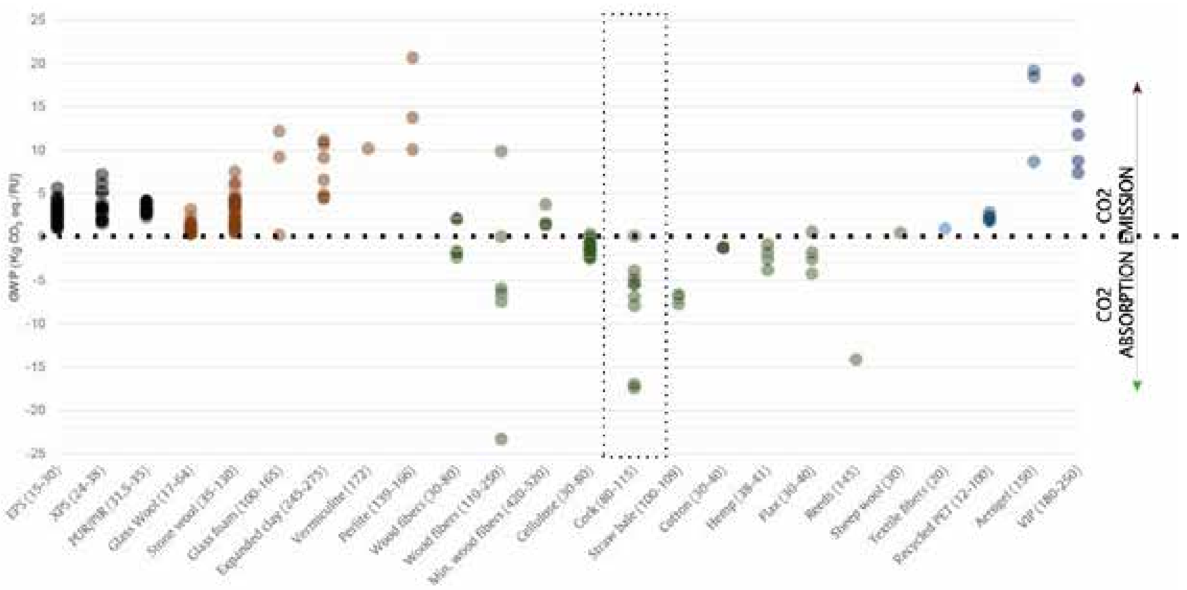
> *Life cycle analysis and circularity: Minimizing the footprint of buildings requires resource efficiency and circularity combined with the conversion of parts of the building sector into a carbon sink, e.g. through the promotion of green infrastructure and the use of organic building materials that can store carbon, such as sustainably sourced timber.*

Certainly, the authorities are aware of the importance of maintaining a holistic sustainability approach, so that renovation should not be implemented independently, but correlated with all the guidelines associated with the European Green Deal, where the improvement of the energy efficiency of buildings goes hand in hand with the circular economy, and the promotion of natural materials.

As a material, cork has a higher thermal conductivity than many other insulating materials, and in addition, as an ETICS it can be applied both between partitions and to the interior or exterior of the envelope, presenting a favorable versatility for the refurbishment of dwellings. Even so, its most significant advantage compared to conventional products is its low carbon footprint.

An article in the journal Elsevier compares the environmental impact of 20 insulation materials. In the graph, it is possible to observe that the cork insulation board in all its thicknesses obtains numbers below 0, i.e. it absorbs more CO2 than it emits, proving that the exploitation of this product can be implemented as an environmental decarbonization measure.

Comparison of CO_2 emissions from insulating materials



SOURCE: Grazieschi. 2021

Innovation and aesthetics

In the case of Portugal, cork is part of the country's cultural identity, which is also present in some communities in Spain, such as Extremadura and Andalusia, where cork harvest is conceived as "an ancestral process".

Yet, outside of cork-producing localities, cork, despite being an ancient material, still has the potential to be further explored and to re-emerge in innovative ways. While socially cork is well known in its stopper format, in architecture it is still perceived as something unusual.

On an aesthetic level, structural cork is built to the same logic as ancient stone constructions, such as Celtic beehive houses. According to Cork House architect Matthew Barnett Howland: Internally, the exposed solid cork creates an evocative sensory environment: the walls are soft to the touch and even smell good, the acoustics are soft and quiet, and the copper pipes glow in the shadows of the ceiling pyramids. (Source: https://www.matthewbarnetthowland.com/)

Therefore, in line with *"The New European Bauhaus"*, which promotes research in ecological materials architecture, an innovative building system is presented that aligns with sustainable objectives, while offering a unique aesthetic, aligned with the following points:

- Sustainability: Promotes design that minimizes environmental impact and encourages energy efficiency, the use of recycled materials and the transition to circular economies. It is aligned with the climate objectives of the European Green Deal, seeking climate neutrality and the protection of biodiversity.

- Aesthetics: It proposes an approach that combines functionality and beauty. It seeks to unite modern architectural design with cultural and artistic values that reinforce a sense of belonging and harmony.

- Innovation: States that research and innovation in architecture, green design and building materials should be expanded.

- Interdisciplinary connection: It combines disciplines such as architecture, design, art, science, technology, and economics to offer integrated solutions. It rescues the spirit of the original Bauhaus, which integrated design and functionality, adapting it to the challenges of the 21st century.

Holistic sustainability approach

The cork oak forest, the cork industry, cork as a material, and the industrialization of a construction system, frame a holistic and integral sustainability scheme that encompasses multiple aspects. This proposal establishes coherence between different actors in the construction sector, energy, forestry and other industries, guaranteeing an efficient use of resources through the application of circularity principles at different scales.

In this way, the promotion of an industrialized cork system is in line with two action points of the *"New strategy for a sustainable built environment"*, which, being also part of the European Green Deal, will promote the principles of circularity in the whole life cycle of buildings:

- It will address the sustainability performance of construction products and, particularly the possibility of introducing requirements on recycled content for certain construction products.

- It will promote measures to improve the durability and adaptability of built assets in line with the principles of the circular economy.

Final reflection

All in all, the cork industry has great potential to support the EU's sustainability goals as an exemplary circular economy chain.

At the same time, the ecosystems involved in cork oak forest management enhance biodiversity, soil quality and ecosystem services, while allowing the exploitation of a non-timber forest industry, which is a crucial factor in simultaneously building carbon sinks and conserving forest area.

Also, cork as a material offers unique environmental benefits, given its biogenic origin, its insulating capacities and its unequalled durability. And the design of a prefabricated cork system proposes a dry industrialized system that eliminates waste, and whose components can be reused, ensuring circularity in its entire life cycle.

Consequently, the promotion of cork in architecture, not only allows to incentivize the growth of a sustainable industry, but also offers an architectural solution aligned with EU strategies to decarbonize the building sector.

Cork oak of Cauquenes, Chile.
SOURCE: Own image, 2022.

7

FINAL CONCLUSIONS

The promotion of cork in architecture is in line with EU strategies to meet global sustainability objectives and constitutes a response to solve the environmental problems affecting our planet. It is also a strategy to address the challenges of the cork industry, which is almost entirely European. Broadly speaking, cork in architecture brings with it an environmental background, subject to a sustainable industry, which unfortunately Spain has not managed in the best way, if compared to the successful case of the Portuguese multinational company Corticeria Amorim.

Promoting the production of a prefabricated cork system could be a crucial factor in encouraging the growth of the cork industry, as it addresses the main shortcoming of the sector: the low exploitation of the product that corresponds to the largest quantity of material (agglomerated cork).

The valorization of agglomerated cork goes beyond an economic motive, as it indirectly promotes the expansion of the cork oak forest, and the territorial benefits that this entails. This is due to the fact that the agglomeration industry offers considerably lower returns than the cork industry. This is because it allows the use of raw material from younger trees, which encourages the cultivation of new species, helping to reverse the ageing of cork oak forests. In this way, the use of cork in architecture contributes to preserving the biodiversity of one of the ecosystems considered Habitat of Community Interest (HIC- 9330) by the EU.

Consequently, the promotion of cork, due to the territorial impact of cork oak forests, involves environmental benefits that encourage the construction of resilient ecosystems and the conservation of the main tool we must capture carbon: the wooded area.

As the above references show, the industrialization of a cork block system offers a unique product whose benefits are incomparable to any other construction system currently available. At the same time, the labour savings implied by a system that is quick and easy to install, makes structural cork blocks an economically accessible product, whose price could be comparable to the value of other prefabricated systems on the market. This makes it possible to define a potential growth niche for agglomerated cork, which does not exist at present.

Indeed, innovation in architecture is presented as the solution to address the decline of the cork industry. While cork as a structural material promises a solution for sustainable architecture. Therefore, the union of cork and architecture constitutes a synergy that ensures a mutual benefit for both actors.

In terms of sustainable contributions to architecture, cork, in addition to its biogenic origin, offers a highly efficient prefabricated and standardized construction method that minimizes waste. The ability of this material to design demountable systems together with the inherent durability of cork makes it possible to reuse it, giving it a cradle- to- cradle sustainable approach.

Circularity allows the maximum use to be made of a reduced quantity of resources. Consequently, understanding that cork is a scarce material, when applied in architecture, it could turn this “defect” into a virtue, by proposing a circular economy model in keeping with the rhythm and limits of nature.

Therefore, this proposal is a clear example that just as industrialization was the cause of the environmental problem we are facing, it will also be responsible for solving it, in synergy with natural resources. “Bringing together craftsmanship and technology is always inspiring. Mixing modern techniques with a material that has a strong heritage can only bring new ideas.” (Studio Corkinho, 2020).

This demonstrates that cork is much more than a material containing biogenic carbon: it is an unrivalled material, capable of contributing to a more environmentally friendly environment, from sustainable forest management to a construction system that ensures a circular economy. By uniting the natural with the industrial, the perfect balance is established, presenting a real solution to sustainability.

In conclusion, advocating the promotion of the development and exploration of cork as an architectural material would imply a holistic positive impact, in favor of maintaining the biodiversity of an agro-silvopastoral agricultural system, which prioritizes the conservation of forest cover, and which encourages the growth of one of the most sustainable industries in the world, while involving a significant advance in terms of sustainable architecture.

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