

CONSTRUCTION HISTORY

International Journal of the Construction History Society

Vol. 35 No. 1 (2020)

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Cork: an historical overview of its use in building construction

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Abstract

*This paper is an intimate portrait of cork used as a construction material, in a history that stretches back over millennia. Cork is the outer bark of *Quercus suber*, the cork oak tree, harvested around once a decade in a process of stripping that does not harm the tree. The unusual combination of physical and chemical properties of cork has led to its exploitation in a broad range of construction materials and components. This paper traces the changing status of cork as a construction material through time and reveals how its use in architecture has evolved. The paper is structured according to three identifiable chronological phases: early uses from Nuragic to pre-industrial times, the Industrial Revolution and the emergence of Modern Architecture, and the mid-twentieth century to the present day. These are illustrated through case studies which are critically appraised and provide a context for addressing the current status of cork as a bio-renewable construction material.*

Key words

Cork, *Quercus suber*, architecture, construction, building, history, manufacture, sustainability.

Introduction

This paper presents an intimate portrait of the use of cork as a construction material, in a history that stretches back over millennia. Cork is the outer bark of the cork oak tree (*Quercus suber*) harvested around once a decade in a unique process of stripping that does not harm the tree. The cork oak landscape (called *Montado* in Portuguese and *Dehesa* in Spanish) is a biodiverse habitat and cultural landscape that has evolved as a farmed system through millennia of interaction between local people and ecosystems. There is currently an increased interest in using cork as a renewable biomaterial for construction and yet the construction history of cork has remained relatively unexplored.

The article seeks to track the evolving roles and status of cork in construction over time both as a historical exercise and as a way of identifying possible developments in the use of cork in future architectural design. Three distinct chronological eras in the use of cork in construction are defined and explored. The first section, 'Cork Oak, Landscape and Craft', addresses the role of the cork oak in its broader landscape and identifies a range of early inhabitational, farming and architectural uses of cork in its natural form, from the Nuragic era to more recent Pre-Industrial times. The second section, 'Cork Industry, Invention and Modern Architecture', documents scientific and industrial advances that led to a plethora of pure and composite cork products being made available for construction following the Industrial Revolution, utilising emerging manufacturing techniques in the nineteenth and early twentieth centuries. The final section, 'The growing interest in cork from the Late Twentieth Century to the present

day', addresses the relative repositioning of cork products in the construction market since the mid-twentieth century due to diverse factors which include the rise of petrochemical plastic products, the mainstreaming of concepts of sustainable development precipitating notions and standards for sustainable building products, and the renewed interest amongst some architects in the tactile and experiential character of cork.

The range of buildings and approaches to construction discussed in this article relate to the evolution of construction applications of cork. These works are discussed in relation to the construction status of cork at the time of their creation and are also subjected to critical analysis with the benefit of hindsight and current building science knowledge.

Cork oak, landscape and craft

The cork oak and its bark

The cork oak, *Quercus suber*, is a slow-growing evergreen oak native to the western Mediterranean Basin. It is relatively long-lived: trees can live up to 200 years or more. Cork, the outer bark of the cork oak, is a unique natural foam that has been harvested for millennia for a multiplicity of uses. Planks of cork are harvested via a process of stripping (Fig. 1), using an axe to cut rectangular panels from the trunk and some branches and then levering these planks from the tree with the aid of the axe handle. This seasonal work is undertaken from late spring to early summer each year. It is skilled work, with great care being needed to ensure that the tree is not wounded during the stripping process. Trees are usually stripped for the first time when they reach an age of around 25 years, and then subsequently in a cycle of once every 9 to 12 years over the course of their lives, the exact timing being determined by when the cork has reached a thickness of 3cm or more. This provides a sustainable biogenic material, harvested without any significant harm to the tree. After harvesting, cork planks are stored in stacks to dry out for variable periods of time before being subject to a range of preparations for use.¹

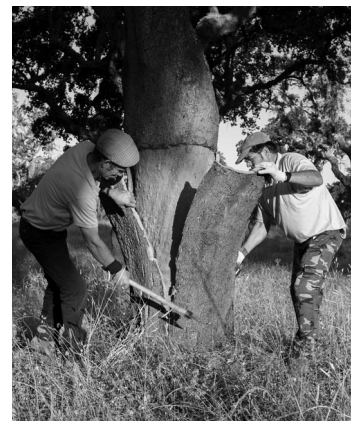


Figure 1. Left: The Montado, Portugal, 2015. Photographer: Matthew Barnett Howland. Right: Stripping cork from a tree. Photographer: Amorim.

The Dehesa and the Montado

The cork oak landscape (Fig. 1) is a biodiverse habitat that has evolved as a farmed system through millennia of interaction between local people and ecosystems, and is the location of early construction

uses of cork. The landscape exists as open woodland, an agroforestry system that includes the growing of crops, livestock farming and forestry in varying proportions depending on the particular local conditions. This gives a character ranging from savanna to forest. This landscape is found in areas of the western Mediterranean Basin, occupying vast areas of Portugal, where it is known as the *Mondato*, and of Spain, where it is known as the *Dehesa*. It is also found in smaller areas in countries including Morocco, Algeria, France and Italy.²

The cork oak landscape provides a livelihood for many people in rural areas of Portugal and Spain and has a unique place in the culture and collective memory of the region. In addition to cork, a range of culinary and cultural products is produced. For example, the Black Iberian pig roams these lands, enjoying the shade of the cork oaks and eating a diet rich in its acorns. These pigs are the source of *Jamon Iberico de Belota* (in Spain, *Pata Negra* in Portugal), seen by many as the apex of the ham world and protected by several denominations of origin recognised by the European Union. In Portugal, these forests were subject to early environmental protection laws enacted in the thirteenth century and the cork tree itself is assimilated as a cultural artifact, recently being formally recognized as the national tree of Portugal, in 2011.

The cork oak plays a significant role in the hydrology of the landscape³; helping to provide stability by drawing on ground water during the hot, dry summer periods, it underlies the broader ecosystem in marginal lands that might otherwise become deserts. The landscape supports significant biodiversity in both plant and animal species, including providing habitat for some critically endangered species such as the Iberian lynx. It is also crucial for over-wintering bird populations, including approximately 70,000 Eurasian cranes.⁴

Early uses of cork

The most frequently cited early account of the use of cork as a construction material is contained in author Pliny the Elder's (23-79 A.D.) 37-volume *Natural History*. This records the use of cork as roof coverings for houses, as well as for nautical floats, bungs for casks, soles for women's winter shoes and medicine (identified in Books 16 and 24). Cork was also used at this time for other purposes such as being included in soldiers' helmets to guard against heat.⁵

Looking even further back there is archaeological and written evidence of cork being used for fishing floats in Egypt and China from around 3000 B.C.⁵ Archaeological records also indicate that cork was used for a range of building and other purposes in Sardinia, Italy, during the Nuragic Civilization commencing around the eighteenth century B.C. This period is named after the Nuraghe, which are stone towers that still number in their thousands on the island today, many being located in cork oak forests. Cork is variously described as being used in the stone village huts where people used it as *chinking* (flexible sealant in the stone walls⁶) and in crumbled form mixed with clay to provide an insulative lining for walls and floors⁷. There is some indication that cork was also used in the towers themselves, traces of cork sheets have been found lining alcoves of a tower at Su Nuraxi.⁸

As an agroforestry product, it is no surprise that cork has been put to a range of farming uses including the making of buckets and milking stools. Cork beehives, occasionally still used today, were recorded by Columella (60 BC)⁹ and were found extensively in Spain and Portugal, and also further afield in areas including North Africa and France. Cork is said to be well-suited to use in beehives due to its insulative character, which helps to moderate temperature fluctuations within the hive. Historic cork beehives are an elegantly simple use of cork, formed of a section of the stripped cork that is simply reformed into its original cylindrical shape, giving a hollow vessel for the bees to inhabit. Early cork beehives were

oriented horizontally, whereas later hives, dating back several centuries, were oriented vertically and capped, as beekeeping practice evolved. Vertical rectangular hives made of flattened pieces of cork have appeared in more recent times.¹⁰

Cork has long been used as a stopper for wine containers, with ceramic amphorae closed with cork plugs being included amongst archaeological finds from ancient Egyptian, Greek and Roman times.¹¹ The prevalent use of cork as a wine bottle stopper, which accounts for most of the revenue from cork farming today, is partly attributed to the activities of the Benedictine monk Dom Perignon in the French Champagne region in the seventeenth century.¹² He is credited with the method of tying the cork stopper to the bottleneck so it could successfully withstand the gas pressure of the sparkling wine, and this approach was subsequently adopted by neighbouring wine producers.

Cork has therefore been put to opportunistic good use for millennia, in a range of building and other applications that take implicit advantage of its light weight, elasticity, relative water impermeability, surprising resilience, and insulative capacity which makes it feel warm to the touch.

Cork roofs and walls

The literature reveals that although cork was widely used in construction during pre-industrial times in cork oak regions where the material was readily to hand, relatively little of this survives today, and it was only lightly documented in the literature of the time.^{5, 13, 14} The lack of literature from the period is in part because cork was typically used in everyday agricultural and other rural buildings that lacked prestige and so were not identified as being worthy of documentation. Also, there were no commercial reasons to document the use of corking in buildings in pre-industrial times as cork was not used in commercial building products in this period. Over the last couple of decades, due to growing research interest, a range of historical forms of cork construction have been documented.^{14, 15}

Following on from Pliny the Elder's observations regarding cork roofing, a range of further historical evidence exists on this application. As Ferreira has observed,¹⁵ Duarte de Armas documented the use of cork plank roofs at a number of the Portuguese fortified settlements along the border with Spain in his sixteenth century manuscript entitled the Book of Fortresses (Fig. 2). Silva has suggested that these cork plank roofs were supported on some form of timber rafters.¹⁴ This is a simple and appropriate use of the tree and its bark to provide a roof over inhabitants' heads, with cork insulating against heat and cold. The roof would also keep out most of the rain, although perhaps not all, unless there was more intricate forming or lapping of the cork than is made clear by the limited evidence available. Given the light weight of cork, it would have risked being blown off during storms.

Another early documented constructional use of cork is noted by Ferreira as dating back to 1668 when Cosimo III de Medici made a visit to Portugal and his entourage observed walls made of cork combined with earth, which the visitors found unusual. Ferreira and others have studied several forms of cork wall in historic buildings still in existence in Portugal.¹⁵ The cork is generally used as a form of masonry, in plank or block form, combined with either earth or lime to give a solid structural wall around half a metre thick (see Fig. 2). Compared to a more conventional solid masonry wall, this wall type would have had the advantages of being much lighter to build and more thermally insulative, and also more resistant to water transmission and water degradation than some forms of earth wall. The exact structural role played by flexible cork in these wall types, relative to the earth or lime, is not determined. The extent to which this type of wall may have been susceptible to degrade over time is also unclear, although the existence of a number of remaining historical examples indicates that some forms can be quite robust in some climates.

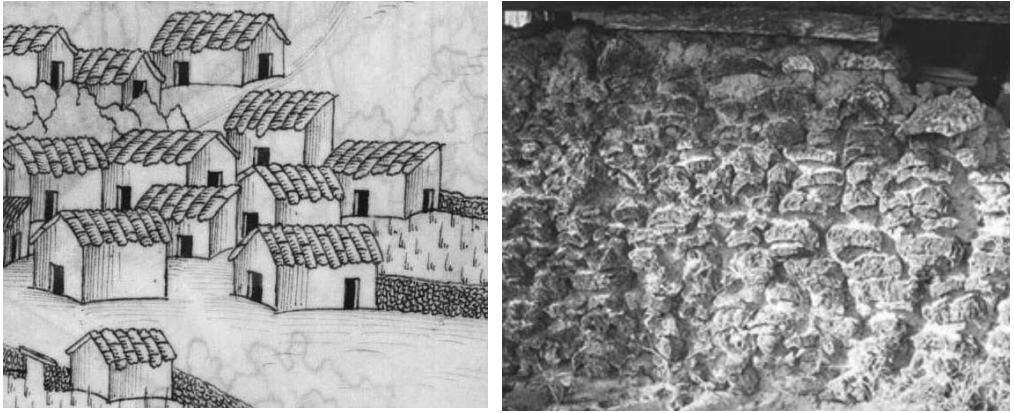


Figure 2. Left: Penha Garcia, Portugal, detail showing houses roofed in cork planks, from *Livros das Fortalezas*, 1495 to 1521. Author: Duarte de Armas. Source: Arquivo Nacional Torre do Tombo CC BY-SA 3.0. Right: Cork masonry wall, Gralheira, Corticadas de Lavre, Portugal. Photographer: Rui Fontes Ferreira.



Figure 3. The Convent of the Capuchos, Sintra, Portugal. Left: Cork clad door. Source: Board of Trustees, RBG Kew CC BY 3.0. Right: Interior with ornamental use of cork to ceiling. Source: Parques de Sintra. © PSML-EMIGUS

In contrast to the relatively crude nature of the early architectural applications (strips of cork, or cork chopped into chunks and glued together), the use of cork in the Convent of the Friars Minor Capuchin, Sintra, Portugal, is relatively refined. The convent is popularly known as the Convent of the Capuchos and it dates from the late sixteenth century (Fig. 3). Cork is incorporated into the rather austere masonry architecture in many ways. Cork planks are used as linings and facings in ways that would have made

the internal environment more comfortable for its inhabitants, typically making rooms warmer in winter and cooler in summer, generally quieter and perhaps also a little drier. This includes the use of cork for door and window linings and architraves, door and window shutter cladding, and internal wall and ceiling finishes. In addition to these practical applications, cork is applied in relatively carefully judged ways such that it contributes to the aesthetic and architectural language of the convent buildings, in ways that would have contributed to the religious life of the monks. Cork is cut into the forms of religious iconography, including the cross, and is also put to ornamental use on walls and ceilings perhaps with the aim of giving the convent a rustic quality, such as the example pictured in Fig. 3.¹⁶

Other examples of a more ornamental use of cork in pre-industrial traditions exist in the Sintra region of Portugal. The best known of these is the romantic cottage, loosely modelled on an alpine chalet, called the Chalet of the Countess of Edla. It was originally completed in 1869 and following a fire in 1999 was extensively repaired in 2007.¹⁷ Here, cork is applied in the romantic spirit of nineteenth century, including externally in the form of arboreal motifs to the facades and ornamentally to the eaves and balconies. Internally it put to a range of uses, including in an elaborate inlaid arrangement in the dining room.¹⁸

Cork industry, invention and Modern architecture

Cork Science

In 1665, in his book *Micrographia*, Robert Hooke observed "...our microscope will inform us that the substance of Cork is altogether fill'd with Air, and that Air is perfectly enclosed in little Boxes or Cells distinct from one another."¹⁹ (Fig. 4) Thus started the detailed scientific investigation of cork that informs our current understanding and exploitation of the material.

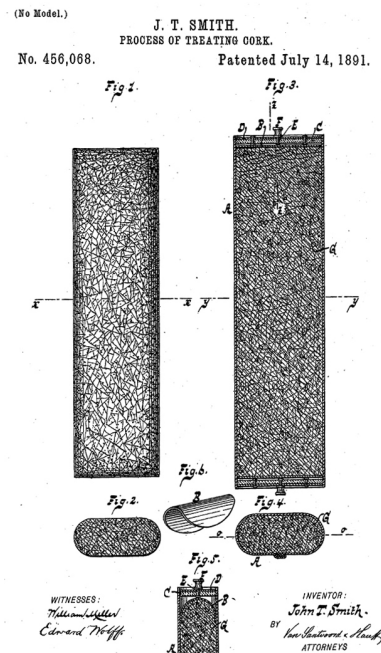
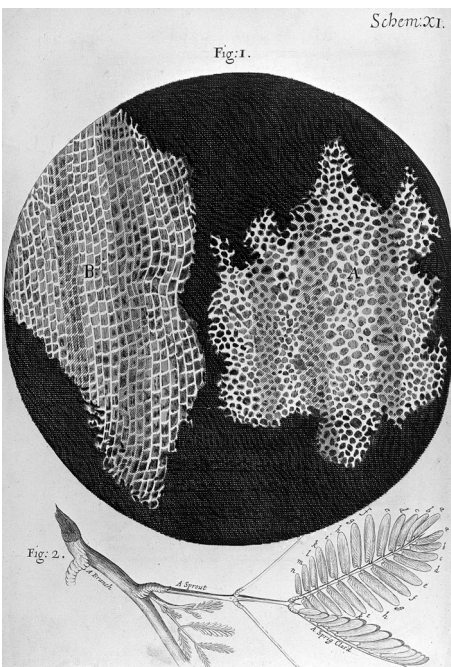


Figure 4. Left: The 'little cells' of cork, upper drawing, as observed by Robert Hooke with his microscope in *Micrographia*, 1665. Source: Wellcome Collection CC BY 4.0. Right: Drawings describing expanded cork from John Smith's patent of 1891 [20]. Author: John Smith.

The unique properties of cork as a construction material derive from its physical structure and chemical composition. Cork is a closed-cell foam with thin-walled cells in the shape of hexagonal prisms, average cell width around 30 µm, giving around one hundred million cells per cubic centimetre. It is under 20% solid by volume so is relatively light, with an average density of around 150 kg/m³. Cork is composed on average of 43% suberin, an impermeable waxy substance, 22% lignin, a complex organic polymer that contributes to rigidity, and other compounds including cellulose.²¹

Cork has very low heat transfer, due to its large air content and small cell size, and a high surface friction, resisting movement. It is hydrophobic and rather impermeable to water; relatively inert and surprisingly resilient and resistant to surface wear. It is also elastic and has reasonable compressive strength, with some capacity to take compressive loads.²¹

Cork industry and invention

Following the Industrial Revolution, cork started to be exploited more widely in construction, with different applications being developed to take advantage of specific aspects of its very particular character. This expansion utilised developments in industrial processes occurring during the period and was linked with growth in the international trade in cork, that may have begun as early as 1438²², but really only started to operate at scale in the nineteenth century.

Cork wine bottle stoppers were a core financial driver for the farming of cork, with the finest cork being reserved for this purpose. The stoppers were initially hand crafted and the process subsequently became more industrialised, with the development of tools specifically designed for the task. The use of cork in its natural form for stoppers and a small number of other artefacts left a great deal of waste cork available in the form of waste from the bottle stopper factories, virgin and second strip cork unsuitable for stoppers, and other cork from forestry such as that stripped from trimmed branches. This waste product amounted to around three quarters of total available cork, and it was this material that would come to be predominantly used in cork construction products.

The mid-nineteenth to early twentieth century was a period of major invention and innovation. During this time, considerable intellectual and entrepreneurial energy went into developing a range of new construction products utilising waste cork in granulated form combined with binders to give tiles, bricks, boards and other forms of product. Linoleum flooring was invented in 1855 by Fredrick Walton, consisting of a canvas backing sheet coated with a mix of cork flour, minerals and oxidised linseed oil.²³

Some of the key innovators during this period were companies that formed in the mid- to late-nineteenth century with an initial focus on cork stoppers but then diversifying into cork construction products. They became some of the major manufacturers of a range of cork construction products. Armstrong Cork Industries started in 1860 in the United States with Thomas Armstrong and John Glass carving bottle stoppers by hand and grew and diversified to become the largest cork supplier in the world by its incorporation in 1891. By the early twentieth century, it was a major cork construction products supplier, and the corporation still exists today under a different name although it has now diversified away from cork products.²⁴ Amorim in Portugal commenced operations in 1870 and became a major cork stopper manufacturer and cork exporter by the early twentieth century, developing a stronger construction products manufacturing capability in the second half of the twentieth century. Today it is the largest cork focussed corporation in Portugal.

Impregnated Corkboard

Around 1890 the German company Grunzweig and Hartmann acquired patent rights in Germany and the United States for a new form of insulation known as Impregnated Corkboard. This consisted of cork granules bound with a special type of clay. The product was well received and was mostly used for insulating cold storage rooms.²⁵ This approach to insulating cold stores by incorporating an explicit insulation layer came in due course to migrate across to the insulation of inhabited buildings, as Moe has identified.²⁶ This evolved to be an established architectural design approach and influences to this day the culture and legislation around how we insulate our buildings.

Consolidated Cork

One of the most fortuitous and significant developments in the exploitation of cork in construction occurred during the late nineteenth century when John Smith accidentally discovered expanded cork. Thomas²⁷ records that Smith owned a boat works in New York making a range of products including steamed oak frames for rowing boats, utilising fireboxes for heating water for steam, and lifejackets, made by stuffing a canvas jacket with granulated cork using a tin tube. One morning Smith was cleaning out a firebox when he discovered a tin tube containing cork granules that had by accident rolled into the dying embers of the fire box the previous afternoon. Rather than turning the cork to ash, the heat had turned the granules into a substantial dark brown cork cylinder, formed by the tube. Smith realised the significance of this and went on to develop Smith's Consolidated Cork, patented in 1891.²⁰ (Fig. 4) This pure cork agglomerate has no added binder, consisting of cork granules that expand when heated in an oven and are bound together by chemicals released under heat from the cork itself to give a lightweight, rigid corkboard ideal for insulation. This makes it, to this day, a remarkable engineered non-composite biomaterial, formed using cork waste and by-product.

Cork Boards

By the early twentieth century insulation corkboards had become widely used in a range of building types, principally in cold stores. (Fig. 5) The plentiful trade literature of that time extolled its unique combination of virtues. In 1917, the United Cork Companies manufactured three types of insulation corkboard: Crescent Corkboard made of pure baked cork granules, Star Corkboard (Waterproofed) which incorporated 6% undisclosed "odourless waterproof binder"²⁸, and Economy Corkboard which was made of re-granulated cork by-product bound by the Star binder. The benefits of insulation corkboard were summarised as so:

"First -... Maximum Amount of Insulation Efficiency... Second -... occupies a Minimum of Space... Third -... remains Permanently Efficient (*because it*) resists moisture... Fourth - ...No Expense for Repairs... Fifth - ... Free from Odor and Absolutely Sanitary... Sixth - ...finished with cement plaster (*it*) provides an Actual Fire Protection... Seventh -... Superior Structural Strength... Eighth -... The Most Economic Insulation... when efficiency and permanent service are considered."²⁸

A range of further developments in the manufacture of expanded corkboard occurred in relatively short succession, including that documented in US patent number 1,607,047 in 1926. Assigned to the Armstrong Cork Company, the patent describes a method of manufacturing expanded corkboard by passing super-heated steam through a mould containing cork granules which then expanded to take the form of the mould, the forerunner of methods used today.

By around 1930, cork, "The Tree Bark of a Hundred Uses",²⁹ was present in a vast array of products. It had become a part of the iconography of everyday life, adding comfort, convenience and fun. Cork insulation board helped to keep homes warm in winter and cool in summer, it also helped to keep food



Figure 5. Left: Drawing of the Central Cold Storage Company building, Chicago, 1917, the “Largest Modern Cold Storage Warehouse in the World” at that time.[28]. Right: Workmen installing cork insulation on the White House ceiling during renovation works, with President Truman looking on, Washington, 1951. Source: Abbie Rowe, National Park Service. Harry S. Truman Library & Museum.

fresh in cold stores, cold boxes and early refrigerators. Cork could be found in shoes and in linoleum and cork rubber floor tiles, adding a spring to the stride and providing calming acoustics. It was present in numerous other products ranging from pin boards to boat fenders, baseball bats, cars, shuttlecocks and sofas.

Armstrong Cork Company deployed extensive advertising of its cork construction products, aimed at the business or domestic consumer. This included the successful and long-lasting Armstrong rooms campaign³⁰, using illustrations or photographs of elegantly furnished rooms incorporating its flooring products plus a sales pitch under a suitably eye-catching slogan. Armstrong’s Linoleum Floors were advertised with slogans such as “Linoleum raised to new dignity” in 1919, “Spick-and-Spanning is so easy since my Armstrong Floors were laid” in 1928, and “You’re sure to be envied” in 1937. Cork floor and wall tiles were initially viewed as an industrial product best suited to the workplace, with applications ranging from offices to hospitals. Their use spread and became more common in the home as the century progressed. Armstrong’s Cork Tiles were advertised for the office market in 1951 with the slogan “Antidote for business tension”, accompanied by an illustration of a relaxed and colourful office complete with cork tile floor and wall panels. An advert, also from 1951, for the domestic market features an illustration of a bedroom with cork floor, enlivened by inlaid brass squares, and notes “Armstrong Cork Tile is just right for a bedroom floor”.

Cork added comfort to existing buildings as well as new ones. Cork tiles famously lined the Parisian bedroom at 102 Boulevard Haussmann where Proust spent much of the final, frail years of his life writing *A la Recherche du Temps Perdu*, ending in 1922.³¹ Cork insulation board was used to line the White House in Washington during a major 1951 refurbishment (Fig. 5), selected in order to give thermal and also acoustic benefits.

Cork and the rise of Modern Architecture

As Modern Architecture began to fully emerge in the early twentieth century, so cork appeared as a biological material that was functionally and aesthetically ideally suited to complement the geologically derived materials, steel, glass, concrete, masonry, that tended to comprise the Modern Architecture palette of that era. Cork, with its origins as a deeply traditional forestry product, had by this time been metamorphosed by recent developments in manufacturing to provide the basis for a multiplicity of highly Modern, industrialised, engineered construction products that were embraced by the Modern architects of the period. Standardisation, orthogonal modularity, and a range of invaluable performance characteristics, offered by few other construction products in this era, aided the easy integration of cork products into the architecture of the era.

Le Corbusier enthusiastically advocated the use of cork in some of his projects. In a profusely illustrated letter to Mme Meyer in 1925 regarding the ultimately unrealised Villa Meyer project in Neuilly-sur-Seine, he noted “This floor is a single room... Oh yes, the service drum! In the middle. Of course! For it to serve something. It is made with cork bricks that isolate it like a phone booth or a thermos. Funny idea!”³² Cork bricks were to be used in line with the architect’s general intentions to deploy partitions that played no structural role but could perhaps do other things. The Maison aux Mathes, France, 1935 was designed by Le Corbusier to be built to a low budget and accordingly had streamlined construction phasing. Phase one incorporated foundations and all masonry work, and on top of this phase two was built, of timber framed construction. This incorporated loose fill cork granule insulation to the roof, filling the voids between the timber roof joists.³³

Gropius’s Trockenmontagebau with cork

The Weissenhof development in Stuttgart was built for the Deutscher Werkbund exhibition of 1927 and coordinated by Mies van der Rohe. It was part of a wider movement at that time to use industrial methods to address the shortage of housing after World War 1 and as Europe moved to a more industrialised, town and city focussed model of living. The development included designs by various emerging Modernist luminaries ranging from Le Corbusier to Hans Scharoun to Walter Gropius. Walter Gropius’s House Number 17 (Fig. 6), rather unremarkable in its finished appearance, is of particular interest here due to its use of cork in an innovative early prefabricated form of construction. It was designed using off-site manufactured components in an elemental approach to give a construction kit that was dry-assembled on site. This was an early manifestation of an approach that Gropius advocated, an industrial approach to house building using prefabricated components assembled on site in the manner of a giant toy construction kit: *Der große Baukasten*, the Big Construction Kit.³⁴ He contended in 1927 that the “...ready-made house off the shelf will soon be the main product of the industry”.³⁴

House number 17 used what Gropius rather charmingly referred to as *Trockenmontagebau*, dry montage construction. It consisted of concrete foundations, cast *in situ*, on top of which a hierarchy of off-site manufactured components were dry assembled. The external walls consisted of a steel frame into which 80mm thick cork insulation boards sealed with bitumen were fitted, (Fig. 6). The walls were clad with asbestos cement panels and lined with cellulose fibre boards, each spaced off from the cork boards to give air voids.³⁵ This lightweight, well-insulated form of construction appears rather prescient when viewed today, as many homes are now built with a similar, if more refined, approach. It is not possible to directly evaluate how the system used in the house has survived the test of time, as the house was destroyed during World War II. The walls would have provided a u-value relatively close to current UK Building Regulations requirements for new homes, albeit with some thermal bridging from the steel frame. Airtightness would most likely have been below current standards. Some air leakage from the external cavity to the outside would have aided the wall’s moisture performance, with the build-up acting

as a proto-rainscreen cladding system, with the principles of the ventilated rain screen not being formalised until later on in the twentieth century.

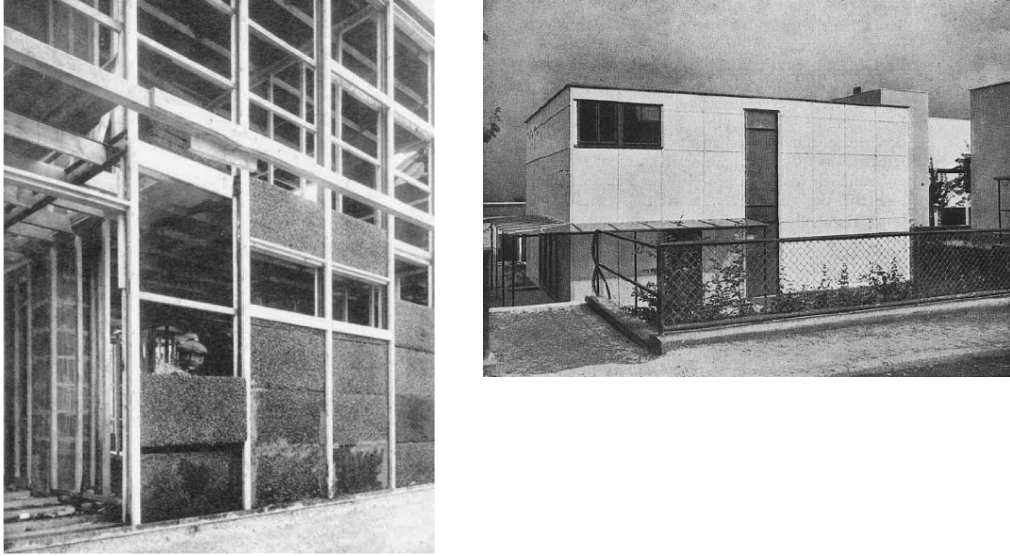


Figure 6. House Number 17, Weissenhof, Stuttgart, 1922, designed by Walter Gropius. Left: A builder fitting a corkboard into the steel frame. Top right: The unremarkable Modern façade. Source: *Bau und Wohnung*. [36]

Aalto's approach to building performance

In 1929 Alvar Aalto joined the Congrès Internationaux d'Architecture Moderne (CIAM), a group organised by Le Corbusier with other members including Gropius. The debate at CIAM influenced Aalto's ideas and design approach, and certain of his buildings from this period exhibited a functionalist character, relatively devoid of local architectural reference. This form of Modern Architecture, initiated in Western Europe, was evolved by Aalto in Finland with its colder climate and relatively low level of industrialisation.

Aalto developed a design methodology that broke up design into tasks in an elemental approach. The Standard Apartment Building, 1929, utilised an innovative form of structural concrete and Aalto described how cork had been used for sound insulation; "The dampening of the echo has been approached as a separate function, as is natural in the case of a concrete building."³⁷ Writing in *Rakennustaito*, The Finnish Construction Magazine, in 1928 he also explained how thermal performance was addressed, discrete from structural performance:

"...the question of heat insulation on the external wall is treated completely separately from the load-bearing question. It was treated merely as a matter of insulation. The insulation of the external wall was partly based on the air contained in the cored tiles and the expanded cork covering the whole of the inner surface of the external wall."³⁸

Aalto therefore understood the role that cork could play in evolving building performance whilst working within the Modern idiom of that time. He utilised a design methodology of allocating specific building performance roles to particular components and assemblies that has become the prevalent

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design methodology today. This has delivered benefits of improved building performance and also some complex challenges around unpredicted aggregate performance.

Paimio Sanatorium, 1933, (Fig. 7) is an archetype here with its Machine Age clean lines and its typology, orientation and building envelope tailored to deliver the architect's solar design strategy so those convalescing at the facility could benefit from plenty of health-giving sunlight. Bitumen bonded expanded cork insulation boards were used as wall linings, placed in the formwork of the in-situ concrete external walls, with bricks cast in as the external facing. This cast solid wall form gives a conceptual integrity relative to the monolithic appearance. 8595m² of cork flooring was used in the project³⁹, contributing to comfort and the relatively hygienic environment. Cork was also used to sound proof the patient room doors, and applied to exposed surfaces of concrete columns.⁴⁰ A mural of the wards' layout was painted on corkboard in the office of the chief physician by Eino Kauria.

Aalto's use of timber at Paimio is well known. His iconic Paimio armchair of 1932, designed for use at the sanatorium, is a beautifully simple and well-judged use of differing thicknesses of plywood to give a firm base and a springy seat. His use of cork could perhaps be seen as an extension of his work with timber during that period, a use of forestry products. However, timber had a distinct place in his psyche due to its role in Finland's cultural and architectural history, which cork, imported from the Mediterranean basin only in recent times, would not have had. Perhaps he intuitively understood the engineered cork products that he utilised as having some shared characteristics and lineage with timber.

"Wood...the redeemer of the architectural spirit...as a timeless material with ancient traditions, wood is always viable, not just in terms of construction but also for psychological and biological reasons."⁴¹



Figure 7. Left. Paimio Sanatorium patient wing with sun terraces in the 1930s. Photographer: Gustaf Welin. Source: Alvar Aalto Foundation. Right. Cork lined bathroom at Falling Water, Pennsylvania, 2016. Image courtesy of the Western Pennsylvania Conservancy.

Coates, Lubetkin and Lloyd Wright

Cork was used in a range of other renowned projects from the era. Upon leaving Germany in 1934, Gropius and a number of other Bauhaus émigrés came to reside at Lawn Road Flats, London, by Wells Coates. This was one of the first Modernist residences in London, and it incorporated cork in a number of roles. Cork insulation board is used as permanent shuttering, to form the inside faces of the external concrete walls whilst also providing thermal insulation. By the time of the Avanti Architects 2003 renovation of the building, the cork insulation had deteriorated.⁴² This may have been in part due to

interstitial condensation due to the wall build-up. Another iconic example of Modernism in the UK, Highpoint One, 1935, by Berthold Lubetkin and Tecton with structural design by Ove Arup, incorporated cork insulation to its walls and floors. And even penguins enjoyed a little of the comfort that cork can bring at the London Zoo Penguin Pool, 1934, by the same designers, which incorporated a pool surround of cork chips mixed with rubber and cement.⁴³

Across the Atlantic, Frank Lloyd Wright put cork insulation board to purposeful good use in the external walls of his famously windowless S.C Johnson Company Administration Building, 1936-1939. The solid wall build-up consisted of external red facing brick bonded to approximately 40mm of concrete, with approximately 75mm of bitumen-dipped cork insulation board at the core, followed by a similar configuration of concrete and red brick to the interior, giving a solid red brick appearance with an improved environmental performance, as identified by Siry⁴⁴. An article from that time notes:

“...not less than 3-in. of cork insulation in the outside walls and ceiling, plus the complete absence of doors or windows, with the exception of the protected main entrances, results in a building with a minimum of heat transfer, reducing the heating load in the winter and the cooling load in the summer. Absence of doors and windows, the heavy cork insulation, and the air spaces in the light sections also insure complete elimination of street noises”.⁴⁴

Another Lloyd Wright design that incorporated cork was Falling Water, 1939, where cork tiles were used in the house’s six bathrooms (Fig. 7). This was at the suggestion of Edgar Kaufmann Jr. who felt that Lloyd Wright’s specified stone floors might feel a little cold when leaving the shower. The floor tiles were hand waxed, to boost their natural water repellence, with the wall tiles being left with their natural finish.⁴⁵

The growing interest in cork from the Late Twentieth Century to the present day

Out with the old USPs and in with the new

As the twentieth century progressed, the cork construction products industry continued to evolve and expand, albeit with an interlude during World War II when the planting of American cork oak forests was considered to address cork shortages from Europe. After the war the international plastics industry, closely interrelated with the fossil fuels industry, rapidly evolved and expanded, fuelled by scientific and technological progress. This was initially aided by an aspirationally futuristic cultural profile that has since faded. Plastic-rich ‘House of the Future’s abounded, such as that designed by Peter and Alison Smithson for the Daily Mail Ideal Home Exhibition, London, 1956, and the Monsanto House of the Future at Disneyland, California, 1957, by architects Richard Hamilton and Marvin Goody with MIT.

A great succession of plastic construction products was invented and evolved, some progressing to command a significant share of their markets, from resilient flooring to thermal insulation board, partly at the expense of cork products. This altered the relative market positions of established cork products, from cork insulation board to linoleum, partially displacing them and laying to rest some of their old unique selling points. For example it was no longer possible to say of cork, the original rigid foam insulation board, that it offered the “...Maximum Amount of Insulation Efficiency...(and)... occupies a Minimum of Space...(whilst being)...The Most Economic Insulation...”²⁸ because other products such as polyisocyanurate (PIR) insulation were developed that outperformed it on these measures. At the same time new unique selling points for cork emerged, relating to matters including environmental sustainability performance and architects’ interests in material tactility.

A range of new cork products was developed, via the energetic activities of partnerships such as that between Amorim and University of Coimbra in Portugal. Many of these new products are highly-engineered cork/polyurethane composites designed to fulfil particular building performance roles relating to thermal, acoustic or anti-vibration performance. This has resulted in an expanded taxonomy of cork in construction, including cork planks used occasionally on special projects, granulated cork used as loose fill insulation and also added to lime renders, concrete, etc., cork/plastic composites used for floor and wall tiles, anti-vibration mounts and also furniture and other tactile applications, and pure expanded corkboard that is still used for thermal insulation.²¹

Sustainable development

A major factor in the growing interest in cork from the late twentieth Century was the emergence of the concept of sustainable development. Scholars had been addressing environmental degradation resulting from human activity for millennia. In his *Natural History*, Pliny the Elder discussed types of environmental degradation relating to activities including farming and mining. But it was not until the late twentieth century, in the face of environmental crisis, that ideas of progress and environmental conservation came together⁴⁶ in the birth of the current widely assimilated concept of sustainable development. This has brought to the fore certain environmental sustainability characteristics, that were always implicit in cork from sustainably managed sources.

Within the conceptual framework of sustainable development, building sustainability appraisal methodologies such as the Building Research Establishment Environmental Assessment Method (BREEAM) have from the 1990s been used to estimate the lifecycle environmental impacts of construction projects. The environmental profile of individual building components is accounted for within these methodologies. One reason for the increasing interest in cork products is that they can have very positive environmental profiles.

Expanded cork insulation board is noteworthy example here, being a 100% plant-based product. For example, Expanded Insulation Corkboard manufactured by Amorim utilises a method of ‘cooking’ the cork in autoclaves with 350°C superheated steam (Fig. 8). Over 90% of energy used comes from biomass waste. The Environmental Product Declaration (EPD) for the product (Declaration Number DAP 002:2016) states that the product is embodied carbon negative. This is because the atmospheric carbon dioxide absorbed when the cork grows is stored in the product for its lifetime and this exceeds emissions from manufacture. The use of cork products such as this has contributed to reducing embodied carbon in buildings at a time when this is increasingly becoming a priority, with nations including EU members committing to becoming carbon neutral by 2050.⁴⁷

It has recently become realised that composite cork products can also contribute to reduced environmental impacts. For example, in lime/cork mortars, cork displaces materials of higher embodied carbon, whilst also making the resultant render more thermally insulative. Concrete incorporating cork granules is also available, having been a subject of research interest for a number of decades.⁴⁸ On the matter of healthy indoor environments, located within the broader sustainable design agenda, cork makes a contribution to healthy indoor environments. Expanded cork has secured an A+, the top rating under French regulations on VOC emissions (Decree 2011-321).



Figure 8. Left: Pile of cork by-product ready for processing, Amorim, Portugal, 2016. Photographer: Oliver Wilton. Right: Two ‘freshly baked’ pure expanded cork blocks emerging from the autoclave, Amorim, Portugal, 2015. Photographer: Matthew Barnett Howland.

Another reason for the growing interest in using cork in construction is that it can help to sustain Mediterranean cork oak landscapes, appreciated in the region for their cultural value for centuries and now becoming internationally recognised. In 1996 UNESCO adopted a new Cultural Landscapes designation, and the Montado is the subject of a current application by Portugal.⁴⁹ Whilst the rich biodiversity of cork oak landscapes has long been known, the extent of the contribution that human use makes to the maintenance of this biodiversity is now becoming more fully understood. These landscapes provide significant ecosystem services, including contributing to hydrology to avoid desertification.⁴ Protecting biodiversity is becoming recognised as equal in urgency and challenge to climate change, with the United Nations forming the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) in 2012, the biodiversity equivalent of the Intergovernmental Panel on Climate Change (IPCC). So, the breadth and depth of the potential contribution of cork to sustainable architecture has been outlined, and its current construction industry status accounts only in part for this.

Cork evokes

In the late twentieth and early twenty first century the range of applications of cork in construction expanded and evolved beyond those in the mid-twentieth century. This was partly driven by architects’ growing interest in its evocative, tactile character related to its provenance as a renewable plant-based material – a material that slowly grows itself. Some architects incorporated cork into their designs because it improved building performance in ways that also contributed to the phenomenology of the building and the narratives that they developed to describe their designs.

The Portugal Pavilion, Expo 2000, Hannover, by architects Alvaro Siza and Eduardo Souto de Moura wore an insulative cork overcoat. The prefabricated metal-framed and -clad building was partially over-clad in expanded cork, used for the first time as an external weathering finish. The building was designed for disassembly and reuse, and after the expo it was moved to Coimbra in Portugal where it now serves as a municipal building. (Fig. 9) So here cork, with its humble origins, was selected for use as an emblematic material for an expo building, with the notion of a ‘cork pavilion’ presented on this international platform being a matter of national pride and prestige. Siza chose to use expanded cork to dress several other buildings. At Quinta do Portal, Portugal, 2010, cork was applied above a slate plinth that integrates the building into the broader vineyard landscape.

Another recently established use of expanded cork was for retrofitting as over-cladding to existing buildings, in order to improve the thermal insulation of historic solid walls so as to reduce building

energy use. The cork is either used bare (Fig. 9) or finished with lime render. Many types of historic solid wall construction have no damp-proof course and the wall can wick water up, which must then be dispersed. This means that any over-cladding must be vapour permeable, which expanded cork is. The external cork also acts as a rain screen, protecting the wall from rainfall and in doing so reducing the amount of water available to migrate across to the interior and reducing interstitial condensation risk.

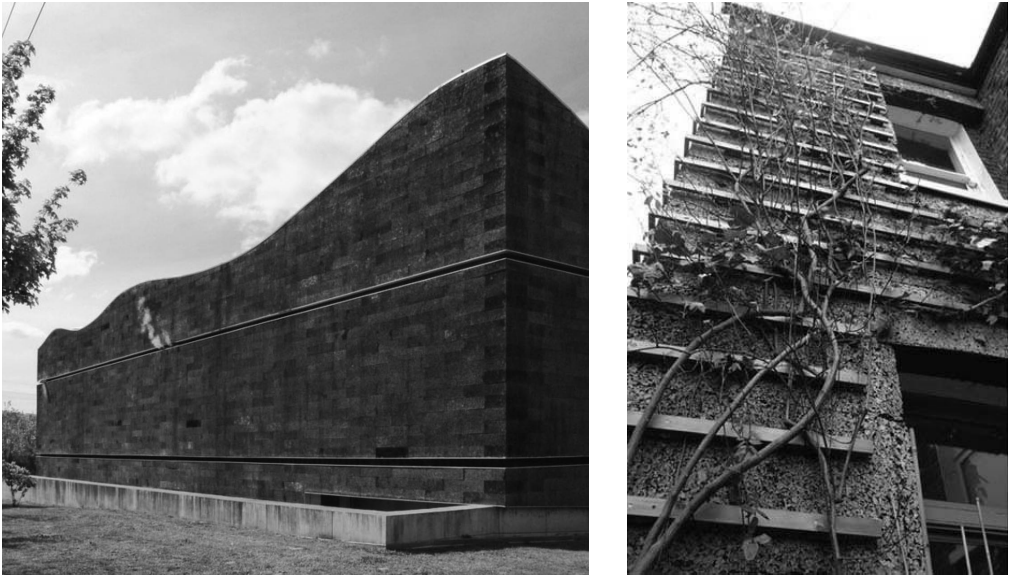


Figure 9. Left: The Portugal Pavilion for Expo 2000 Hannover, located in its permanent home, Coimbra, Portugal, 2015. Design: Alvaro Siza and Eduardo Souto de Moura. Photographer: Matthew Barnett Howland. Right: Victorian house retrofitted with expanded cork insulation over-cladding, Cornford Grove, London. Design and photograph: Venner Lucas Architects.

The Serpentine Pavilion, London, 2012, (Fig. 10) by architects Herzog and de Meuron and artist Ai Weiwei, utilised cork as a form of ‘made ground’, an inhabitable landscape intended to represent a fictional archaeology of the eleven previous Serpentine Pavilions. Semi-submerged and partially sheltered by a disc-shaped rainwater collecting pool overhead, it was populated by cork stools resembling giant mushrooms or champagne corks. Expanded cork with a polyurethane binder was used, suitable for robust tactile exposure to people and weather in this temporary application. The designers selected cork due to its haptic and olfactory qualities and it also contributed to their design methodology. In conversation with Vigo in 2016, Herzog noted “...we know that cork can be applied in spaces but to make a landscape...We were ... thinking of wood but cork is of course even more olfactory and it has this tactile sensation...”⁵⁰ and de Meuron had this to say “...cork is a natural material, it grows again (although it grows slowly), it is light and warm ...”⁵⁰ De Meuron explained how the use of cork contributed to their design methodology; “The cork had to be milled and we were interested in having a direct translation of our models which were also milled digitally on milling machines with the same information.”⁵⁰ Using cork gave the designers a more direct relationship to the constructed building, with a design methodology that utilised design data to CNC mill scaled models during the developmental stage, before then using the same data as the basis for milling the actual cork building components for the final design.



Figure 10. Serpentine Gallery Pavilion 2012. Designed by Herzog and de Meuron and Ai Weiwei. Photograph © Iwan Baan.

Steven Holl is another contemporary architect who has selected to use cork due to its particular experiential character. Careful consideration of the phenomenology of his buildings is a central element in his design methodology. Those who have entered the remodelled NYU Department of Philosophy, United States, 2007, have walked on a cork tiled floor into a cave-like lecture theatre that is entirely lined with cork tiles. This protective and acoustically damped environment is perhaps a little reminiscent of Proust's bedroom at 102 Boulevard Haussmann.⁵¹ Visitors to the Loisium Winery, Austria, 2006, may well find themselves experiencing an 'ooh' as they approach the sharp, slashed metal clad box, an alien form in this traditional farmed landscape, followed by an 'aah' as they enter its soothing cork-lined interior. These projects along with the others discussed in this section, and the way that they have foregrounded the use of cork, have contributed to the recent growing interest in using the material in construction.

At this point in the paper the authors must declare a broader interest in cork, extending from its construction history into its construction future. From 2014 to 2018 we worked to develop a solid expanded cork construction system, the Cork Construction Kit,⁵² driven in part by an interest in the tactile and technical material character of expanded cork, and its provenance and strong environmental profile. We created a very small prototype building, the Cork Casket, in early 2015 to test some initial ideas and hypotheses, with the involvement of Arup and Amorim. The team expanded under Innovate UK and EPSRC funding to include partners University of Bath, Amorim UK and Ty Mawr, with subcontractors including Arup and Wup Doodle. This enabled us to develop the cork construction system in earnest from 2015 to 2018, addressing matters including fabrication, assembly and disassembly, and technical performance. The work included the creation of the Cork Cabin, a prototype one-room building for testing and monitoring. When the cork system was sufficiently researched and developed, we utilised an evolved version for Cork House (Fig.11), designed by the authors with Dido Milne and completed in 2019. This is the first permanent building of its type, with a solid, structural cork building envelope.



Figure 11. Cork House, photographed from its garden, 2019. Design: The authors and Dido Milne. Photographer: Ricky Jones.

Conclusions

To recap, cork has been continuously available as a construction resource for millennia, harvested from cork oak landscapes in the Mediterranean Basin using traditional methods. The particular and unusual combination of physical and chemical properties of cork has led to its exploitation to produce a broad range of construction materials and components. These have been created and evolved over time in relation to developments in construction technology, building performance aims and requirements, and the broader environmental characterisation of buildings and their components. Broader shifts in architects' design ambitions, methods, and choices on what they foreground have also contributed.

The humble origins of cork in construction saw it generally utilised in the immediate localities of cork oak landscapes, growing on trees all around and readily stripped without killing the tree, as an integral part of local gathering and farming practices. Cork was crafted into basic planks and blocks and put to expedient good use, fulfilling a wide range of roles in building roofs, walls and floors. Most early uses relate to simple vernacular architecture, with the cork playing a pertinent and charming *de facto* role in relation to building inhabitation, rather than being a carefully considered contributor to a formal architectural language.

Following the Industrial Revolution developments in industrial processes, entrepreneurial endeavours and the international trade in cork created the environment in Europe and the United States for a leap forward, with the development of a great number of new standardised, factory-made cork construction products. These typically utilised by-product from the cork stopper industry and cork forestry formed into sheets or blocks with the addition of a binder or, in the case of pure expanded cork board, bound by its own resins released under heat. By the early twentieth century, manufactured cork construction

products were being widely used in various roles in a range of building types. Cork played a supporting role in the emergence of Modern Architecture, with some key architects of that period incorporating industrial cork products into their new forms of construction in order to augment building performance, including to increase thermal insulation and acoustic control.

During the Great Acceleration in anthropogenic resource usage,⁵³ from the mid-twentieth century, the development of low cost petrochemical plastic construction products repositioned established cork construction products in the market. At the same time a range of engineered cork composites have been researched and developed, precisely tailored to different aspects of building performance in an era when the depth and breadth of technical compliance requirements has expanded greatly.

In recent years the architectural debate around cork, timber and other renewable plant-based materials has evolved and they are now seen as progressive and, in some cases, prestigious in ways that were rare in the twentieth century. Contributing to this, concepts and concerns regarding sustainable development have become mainstream, leading to a broadening of the basis for judging construction products. This has foregrounded certain aspects of cork, always implicit in its back-story but now becoming viewed as a more concrete aspect of its construction status. This includes atmospheric carbon sequestration in cork as a renewable plant-based material, and the contribution that well-managed cork oak landscapes can make to sustaining regional biodiversity. These considerations give reasons to build with cork today, but with limited leverage as they sit outside of regulatory frameworks for construction, which tend to focus on emissions from buildings in use rather than addressing lifecycle carbon or biodiversity related to building component sourcing.

This research has revealed certain eras of building with cork to be relatively well-documented, with others being less so. The use of cork in construction from the early Twentieth century is relatively well-documented in the literature of the period, including trade and other periodicals and trade literature produced by cork construction products manufacturers, but has been lightly addressed from a construction history perspective. There are many times and places where the use of cork is less well-documented in the literature of the time, and which would benefit from further research by construction historians, including:

- Early uses of cork: Reference to archaeological literature and the literature of the time indicates that there was significant use of cork in construction during Roman times and before, in areas with cork oak forests. The construction history of cork during this period has generally not been written. It is very dispersed in the literature, in a number of languages, and has yet to be pieced together in any detail.
- Pre-industrial applications in the eighteenth and nineteenth centuries: The indication from the limited literature addressing this is that there was a broad range of simple, pre-industrial applications of cork in cork forest regions. For example, Ferreira identifies a range of simple applications in Portugal, with reference to historical accounts and simple field studies of some remaining structures. What were the pre-industrial construction uses of cork in other cork oak forest areas including southern Spain and parts of Italy and North Africa? Also, to what extent did these simple construction uses continue into the early twentieth century?
- The emergence of industrial applications in the nineteenth century: The nineteenth century was a period of great innovation in the use of cork in construction. The literature, including historical journals and patents, indicates that there were rapid developments in the application of industrial methods of production to create a range of tailored construction products made with cork forestry waste and cork stopper industry by-product. Some of these invented products went on to be mass-produced, the forerunners to modern cork construction products. What were these products, who made them and how, and what were their uses in particular construction projects during this century?

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