

Case Study

# Public awareness of cork in construction: From a building material to ecosystem stewardship

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**Abstract:** The construction industry is one of the largest contributors to global greenhouse gas emissions. In response, sustainable construction practices using environmentally friendly, low-impact materials are gaining prominence, in line with recent EU regulations. Among bio-based materials, cork stands out for its sustainability and versatility. However, public awareness of its potential in construction remains poorly understood. This study presents the results of a public survey ( $n = 237$ ) conducted across four Portuguese cities located in different regions of the country. We assessed public awareness of cork as a sustainable building material and perceptions of the socioecological importance of cork oak land use systems, while examining how respondents' demographic factors influence awareness levels. While most respondents (70%) were familiar with common construction materials in Portugal, only 5% identified cork as a potential material for exterior façades. Most respondents (90%) perceived cork as a sustainable material, mainly for environmental reasons. Younger individuals (18–34 years old) consistently exhibited the lowest awareness, whereas older respondents ( $\geq 55$  years) showed the highest. Regional contrasts were also observed, with Setúbal exhibiting the lowest awareness and Coimbra and Aveiro showing the highest. Our findings highlight a gap in public awareness of cork's potential for exterior façades and the broader socioecological importance of cork oak land use systems, underscoring the need for targeted communication and education strategies. Although grounded in Portugal, the insights may inform broader initiatives to integrate locally sourced bio-based materials into sustainable construction strategies and public awareness efforts.

**Keywords:** bio-based building material; cork oak land use systems; construction industry; montado; cork; Portugal; survey

## 1. Introduction

The construction industry is one of the main global contributors to greenhouse gas emissions, accounting for nearly 21% of global CO<sub>2</sub> output [1]. It encompasses the production of building materials, the construction process, building operations, renovations, and eventual demolitions. The construction industry accounts for 30% of natural resource extraction and 25% of total waste generation [2,3]. Moreover, conventional building materials such as concrete, brick, and steel are highly energy-intensive and contribute significantly to environmental pollution [4–6]. Nevertheless, this industry is the largest industrial employer in Europe, contributing about 6% to the EU's GDP and employing around 13.5 million people as of 2021 [7].

In this context, sustainable construction practices have gained prominence over

the last decade, with greater attention to bio-based materials, for their environmental friendliness and low impact [8–11], thereby contributing to reducing life-cycle costs and minimizing a building's environmental footprint [12]. Guidelines for best practices in their implementation are also slowly being established [13,14].

This renewed interest in bio-based materials in the EU was also driven by market adjustments to the EU's Energy Performance of Buildings Directive (EPBD, EU/2024/1275, implemented in Portugal through Decree-Law No. 101-D/2020), which aimed to achieve nearly zero energy consumption in new buildings by 2020, and the new Carbon Removal Certification Framework (CRCF, Regulation (EU) 2024/812, 2024) which proposed EU-wide certification for long-life biogenic materials to support climate mitigation strategies (Regulation (EU) 2024/812, 2024). Cork is mentioned among these bio-based materials, being recognized for its sustainability, versatility, and strong potential in 21st-century architecture [15–17].

Cork offers a very good example of how traditional materials rooted in natural landscapes can meet more modern, sustainable construction ambitions [18]. Cork is the outer bark of the cork oak tree (*Quercus suber* L.), a species native to the western Mediterranean region, with its largest distribution in the Iberian Peninsula. Portugal alone accounts for 49% of global cork production, and Portuguese cork oak landscapes are considered socioecological systems (SES) that provide important ecosystem services, such as cork production, biodiversity conservation, soil and carbon regulation, and support for other ecological functions [19]. These landscapes can take the form of montados, i.e., traditional Portuguese cork oak agroforestry systems that integrate tree cover with extensive grazing or agriculture, or appear as cork oak woodlands with denser canopy and without understory use. Although their structure, management intensity, and socioeconomic relevance vary considerably across regions, both forms are recognized as multifunctional systems of high ecological and cultural value, shaped by long-term interactions between ecological processes, land management practices, and policy frameworks [20–24].

Cork in Portugal is harvested in nine-year cycles through a traditional, non-destructive process that does not harm the tree, making it a naturally renewable material [25]. After each extraction, the bark begins to regenerate immediately. Its cellular structure provides low density, elasticity, impermeability, and excellent thermal and acoustic insulation within construction applications. It is also flame-resistant and hypoallergenic [26–28]. It is biodegradable, recyclable, and reusable, aligning with the principles of the circular economy and sustainable design [26]. Its environmental benefits are also context-dependent, and recent design research emphasizes the added value of applying cork where it can replace less sustainable materials, to maximize ecological benefit [29].

Interest in cork as a construction material began in Europe in the Middle Ages with archaeological findings in the Mediterranean basin [30,31]. In the Modern times, the dissemination of cork-based practices in Portugal dates back to the 1940s, following visits by a Portuguese researcher to institutions in the United States [32]. Since then, cork has gained relevance in international patents and applications, from insulation panels to composite boards and cork-reinforced concrete [33], as well as in innovative and sustainable architecture, e.g., the Portuguese Pavilion at Expo 2000 in Hannover, Germany [34].

Although cork bottle stoppers still dominate exports, demand for agglomerated cork in the construction sector has been rising significantly. Between 1996 and 2008, exports of agglomerated cork products increased by 88% in Spain and 46% in Portugal. As a result, Iberian cork exports vastly exceed imports [35]. Later, in 2022, construction materials exports accounted for 25% of all cork exported worldwide [36].

Despite extensive research on cork's physical, chemical, and ecological properties [28,37], there is limited understanding of public awareness and perception of cork as a sustainable construction material, as well as the importance of cork oak land use systems. As public awareness drives the adoption of sustainable building materials, increased awareness will likely lead to greater demand, influencing market dynamics and shaping policy development [38,39]. Therefore, it is highly relevant to investigate this topic in the sense that it can serve as a baseline for others to develop effective marketing techniques and environmental education programs, fostering the adoption of cork in construction, encouraging more environmentally friendly consumption practices, and supporting the stewardship of cork oak land use systems. Moreover, public familiarity with these systems cannot be assumed, particularly outside rural or cork-producing areas, making them a relevant component of our study.

Previous studies addressing public engagement with sustainable materials have shown that the concepts of awareness, knowledge, and perception are closely related but analytically distinct [40]. Awareness generally refers to an individual's familiarity with a material, system, or concept. Knowledge refers to a deeper understanding that involves factual information. Perception, in turn, relates to judgments, sensory experiences, or beliefs [41,42]. These three dimensions are often treated as complementary steps in the adoption of sustainable practices, with awareness enabling knowledge acquisition and knowledge shaping perceptions [39]. In the present study, we tackled these three concepts through a survey that included different sets of questions, each exploring one or more of the concepts applied to either cork as a bio-based construction material or to cork land use systems. We applied the survey in four distinct locations in Portugal intending to analyse (i) public awareness, knowledge, and perception of building materials for exterior façades, in particular cork as a building bio-based material and its applications in construction, (ii) awareness of cork oak land use systems and perception of their socioecological importance, and (iii) the most relevant demographic factors influencing the adoption of cork in construction.

## **2. Materials and methods**

### **2.1. Survey design and implementation**

Aiming to understand public awareness (individual's familiarity with cork as a building material or of cork oak land use systems), knowledge (factual information about origin, properties, applications, or functions), and perception (evaluative judgments regarding sustainability, comfort, and socioecological importance) of cork as a building material, as well as the socioecological importance of cork oak land use systems, we developed and applied a survey comprising 12 main questions, including both closed-ended and open-ended questions. Closed-ended items used binary (yes/no), multiple-choice, and ordinal rating scales (e.g., five-point scales for thermal and acoustic comfort), while open-ended questions allowed respondents to freely

name materials, applications, locations, or reasons underlying their answers. The full wording of all survey questions and the corresponding response options is provided in the Supporting Information (Appendix A).

The survey questions were grouped into four sections. The first focused on general knowledge of construction materials and on perceptions of building quality and comfort in Portugal, including the characteristics of a comfortable, efficient building. The second section aimed to assess visual recognition of cork, perception of cork as a sustainable building material, and knowledge of cork applications in construction. The third section aimed to assess public awareness of cork oak land use systems and their socioecological importance, including their location and the ecosystem services they provide. Questions related to cork oak land use systems were included to assess baseline public awareness of these landscapes and the ecosystem services they provide, rather than to evaluate management practices or stakeholder engagement. The fourth section characterized the respondents (age, gender, and place of residence). While multiple individual factors may influence the adoption of sustainable building materials, including economic constraints, professional background, or personal values, the demographic factors chosen for this study are commonly used in perception and awareness studies for being robust, comparable across populations, and have been shown to influence environmental awareness and material adoption preferences significantly [39,43]. For this reason, we chose to use them as key proxies for social context, exposure, and experience.

The survey was implemented at four Portuguese cities (Aveiro, Cascais, Coimbra, and Setúbal), which were selected based on three criteria: (i) the presence of buildings with cork façades in public areas; (ii) public areas with a high volume of pedestrians, and (iii) geographic diversity, as they are located in different regions of Portugal, allowing to capture variations in awareness, knowledge and perception.

The survey was intentionally conducted in urban public spaces outside the main cork-producing regions. The objective was not to assess local ecological knowledge among populations directly involved in cork production, but rather to evaluate general public awareness and perception of cork as a building material and of cork oak land use systems among non-specialist urban populations. Conducting the survey in front of publicly accessible buildings with cork façades allowed us to assess awareness in a real-world context, where individuals encounter cork as an architectural material rather than as a rural land use system.

Data collection took place between March and April 2023. Responses were collected during weekdays from 10 am to 6 pm in three cities and on weekends in Coimbra, near four selected buildings with cork façades, located in parks or other public access areas. **Figure 1** shows the four selected buildings: **Figure 1A** Cacia Clinic in Aveiro, a private medical center covering 208 m<sup>2</sup> with expanded cork agglomerate; **Figure 1B** Siza Vieira's Portugal Pavilion in Coimbra, a prefabricated building originally constructed for the 2000 Exposition in Hannover and now located in Coimbra, covered with approximately 55 tons of expanded cork agglomerate; **Figure 1C** the Nature Tourism Information Office in Cascais, known as Eco-Cabana, a 70 m<sup>2</sup> cork-covered model aimed at promoting sustainable housing systems and ecological footprints; and **Figure 1D** the Tourist Information Office in Setúbal, a 36 m<sup>2</sup> public building entirely enveloped in cork, located near the catamaran pier.

A total of 237 pedestrians were randomly selected from the vicinity of these four locations for participation. To comply with the General Data Protection Regulation, a project team member explained the project's purpose to potential participants. Participants provided informed consent before completing the survey.



**Figure 1.** Map of Portugal showing the distribution of cork oak land use systems, and survey locations: **(A)** Cacia clinic in Aveiro; **(B)** Siza Vieira's Portugal Pavilion in Coimbra; **(C)** Nature Tourism Information Office in Cascais; and **(D)** Tourism Information Office in Setúbal.

Before full implementation, a survey pre-test was conducted involving ten cork experts, non-experts, and civil engineers, along with informal interviews, to refine the clarity and relevance of the questions. Based on feedback from the pre-test, the wording of the questions was adjusted. Responses from this group were excluded from the final survey results.

## 2.2. Statistical analysis

Collected responses were recorded in Microsoft Excel for subsequent statistical analysis. Open-ended questions were analyzed with content analysis, following Field's methodology [44]. Closed-ended questions were analyzed with descriptive statistics, tests of significance, and multiple correspondence analysis (MCA). We used

the Chi-square test with a significance level of 0.05 to assess differences in responses across groups defined by age, gender, and place of residence, using SPSS version 28.0.

We performed MCA on the 237 individual responses, using nine categorical variables derived from closed-ended questions, as shown in **Table 1**. In this study, MCA was used to explore relationships between variables and identify groups of respondents, in order to assess the individual characteristics linked to specific awareness and perception that may influence the adoption of cork in construction. MCA was performed using the R package FactoMineR [45].

**Table 1.** Variables compiled from surveys and used in multiple correspondence analysis (MCA). Survey questions are detailed in supporting information (Appendix A, Table A1).

Variable	Category
Gender (survey question A)	2 levels: male; female
Age (survey question B)	3 levels (years): 18–34; 35–54; $\geq 55$
Residence (survey question C)	2 levels: resident; non-resident (includes temporary residents, tourists, others, and no answers)
Location of survey	4 levels: Aveiro, Cascais, Coimbra, Setúbal
Visual recognition of a piece of cork (survey question 6)	2 levels: yes; no
Perception on the use of cork for civil construction (survey question 8)	2 levels: yes; no
Perception of cork as a sustainable material (survey question 9)	2 levels: yes; no
Awareness of cork oak land use systems (survey question 10)	2 levels: yes; no
Perception of the socioecological importance (ecosystem services - ES) of cork oak land use systems (survey question 11)	4 levels: None; 1 ES; 2-3 ES; $\geq 4$ ES

### 3. Results and discussion

#### 3.1. Characterization of respondents

We surveyed a balanced sample of 237 participants across the four locations: Aveiro (24%), Cascais (22%), Coimbra (31%), and Setúbal (23%), as shown in **Table 2**. Despite a slightly higher total number of male respondents, the survey achieved nearly equal participation from both genders. The youngest age group (18–34 years old) accounted for 42% of respondents, while the oldest group ( $\geq 55$  years old) accounted for 30%. The majority of respondents were permanent residents of the surveyed municipalities (78%), with only a small percentage of temporary residents (7%) and tourists (11%).

#### 3.2. Knowledge of building materials for exterior façades

Answers regarding commonly used construction materials for coating building façades revealed that 70% of respondents were familiar with them. Knowledge levels varied significantly across age groups ( $\chi^2(5) = 18.115$ ,  $p = 0.003$ ), with a higher

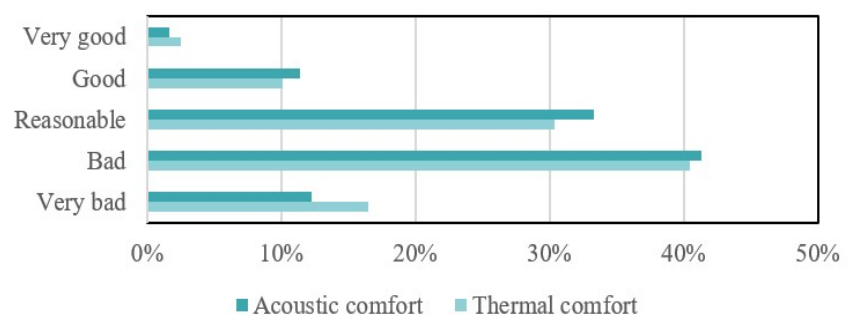
proportion of respondents over 35 years old indicating familiarity with several construction materials (above 78%) than younger respondents aged 18–34 (around 57%).

**Table 2.** Distribution of the 237 survey respondents by gender, age group, and place of residence across the four survey locations (Aveiro, Cascais, Coimbra, and Setúbal). Respondents were classified by gender (female, male), age group (18–34 years, 35–54 years,  $\geq 55$  years), and place of residence, categorized as permanent residents (PR), temporary residents (TR), tourists (T), and others or no answer (O).

Cities	Gender (%)		Age group (%)			Place of residence (%)			
	Female	Male	18–34 years	35–54 years	$\geq 55$ years	PR	TR	T	O
Aveiro	13.9	17.3	11.0	9.3	11.0	25.7	1.3	0.8	3.4
Cascais	12.7	11.8	8.4	5.5	10.6	16.5	3.4	1.3	3.4
Coimbra	8.4	11.0	10.1	5.1	4.2	15.2	1.7	1.3	1.3
Setúbal	10.6	14.4	11.8	8.9	4.2	17.3	0.8	3.0	3.8
Total	45.6	54.5	41.3	28.7	30.0	74.7	7.2	6.3	11.8

Concrete, stone, tiles, and styrofoam were frequently mentioned as coating materials. Regarding bio-based materials for façade coating, only 5% of respondents mentioned cork, and 11% mentioned wood, with all age groups represented.

Regarding the most important characteristics when coating a building's exterior façade, thermal insulation (87%), acoustic insulation (67%), and impermeability (66%) were the top choices among respondents. Ratings for the acoustic and thermal comfort characteristics of Portuguese buildings were generally between "poor" and "reasonable" as shown in **Figure 2**, based on a 5-point Likert scale ranging from 1 (very bad) to 5 (very good). Age-group analysis indicated that opinions on acoustic comfort varied by age, with respondents over 65 showing lower satisfaction, however, this difference was not statistically significant ( $p > 0.05$ ).



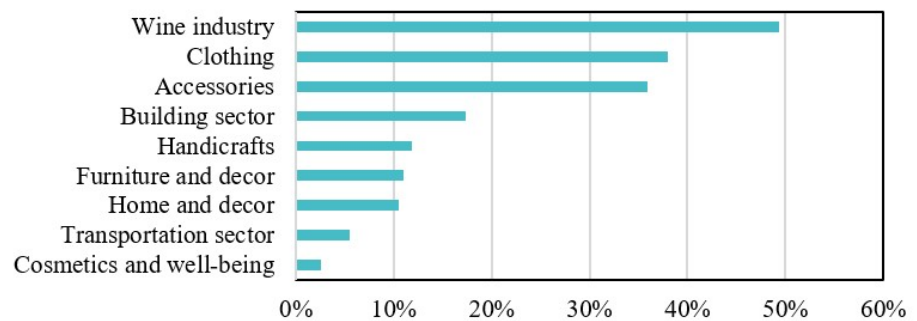
**Figure 2.** Ratings of acoustic and thermal comfort of Portuguese buildings by the 237 survey respondents.

If respondents had to buy materials to build or renovate their home, preferences for the origin of materials used in exterior façades favored Portuguese products (94%), influenced by both price (63%) and quality (59%). Only 25% indicated that local availability would impact their purchasing decisions.

### 3.3. Knowledge of cork applications and perception of cork as a sustainable building material

Most respondents (85%) visually recognized a piece of cork, but this varied significantly by age group ( $\chi^2(5) = 16.680, p = 0.005$ ), with younger respondents (18–34 years old) showing the lowest recognition rates. Most respondents (70%) also correctly identified cork oak as the tree from which cork is extracted. Once again, knowledge levels varied significantly across age groups ( $\chi^2(5) = 21.028, p < 0.001$ ), with younger respondents (18–34 years old) showing notably lower recognition compared to older participants.

The most frequently mentioned applications among respondents were the wine industry (49%), clothing (38%), and accessories (36%), including cork-based jewelry, notebooks, and wallets. As **Figure 3** shows, cork applications in the building sector ranked fourth (17%), while applications in the transportation and aerospace sectors were referred to by a much lower percentage of respondents (5%).



**Figure 3.** Distribution of cork applications identified by respondents (%).

Nevertheless, when asked whether cork could be more widely applied in construction, 85% of respondents agreed, indicating knowledge of a wide range of possible applications, including insulation, interior design, exteriors, flooring, wall coverings, and furniture. Additionally, 79% of respondents believed that the use of cork in exterior façade coatings enhances a building's value in terms of both comfort and aesthetics.

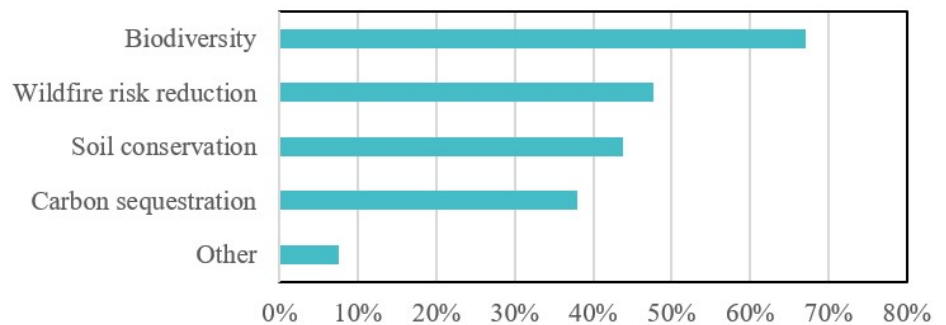
The majority of respondents (90%) perceived cork as a sustainable material, while 2% disagreed, and 8% had no opinion. Among those who considered cork sustainable, 89% cited environmental reasons, 40% economic reasons, and 15% social reasons.

### 3.4. Awareness of cork oak land use systems and perception of their socioecological importance

Only 62% of respondents were aware of the existence of cork oak land use systems. Awareness levels varied significantly across age groups ( $\chi^2(5) = 21.028, p < 0.001$ ), with younger respondents showing notably lower awareness than older participants. In contrast, no statistically significant differences were found based on gender ( $\chi^2(1) = 0.263, p = 0.608$ ), place of residence ( $\chi^2(1) = 0.420, p = 0.517$ ), or survey location ( $\chi^2(3) = 1.837, p = 0.607$ ).

Respondents identified Alentejo as the region with the largest area of cork oak

land use systems, followed by the Lisbon/Tagus Valley region (79% and 10%, respectively). **Figure 4** shows that the ecosystem services (ES) provided by cork oak land use systems in Portugal, as identified by respondents, were most frequently biodiversity conservation (67%), wildfire risk reduction (48%), and soil conservation (42%).



**Figure 4.** Socioecological importance (based on the identification of ecosystem services, ES) of cork oak land use systems in Portugal, as reported by the survey respondents.

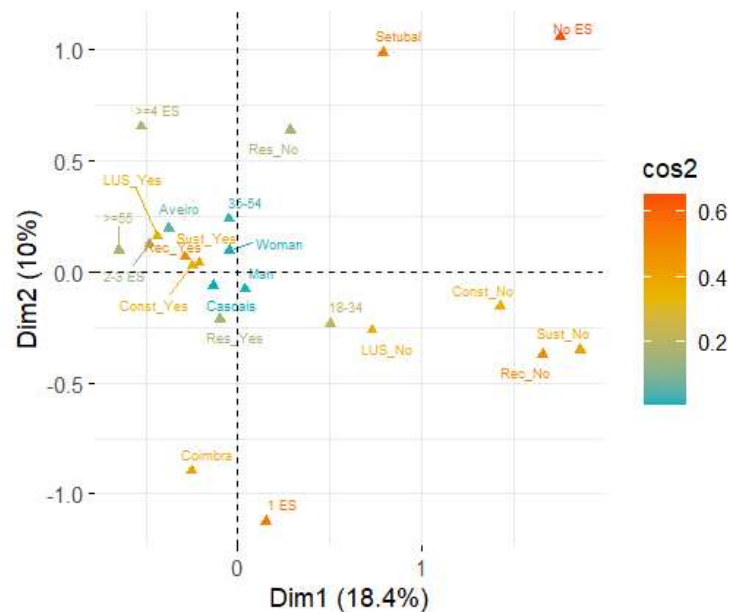
### 3.5. Importance of variables explaining responses and the association between variables

We used the first two dimensions of the MCA, which together explained 28.4% of the variance (18.36 and 10.04% for the first and second dimensions, respectively), exceeding the average expected variance per dimension (7.14%).

**Figure 5** illustrates the variable association and contribution for each dimension, based on the squared cosine ( $\cos^2$ ), which measures the degree to which each variable category is represented on the dimensions (closer to 1 indicates a better representation). The best represented variables (with the highest values of  $\cos^2$ ) were: perception of respondents regarding cork (cork visual recognition and cork as a sustainable material); awareness of cork oak land use systems and perception of their socioecological importance (no ES or only one ES); and survey locations of Setúbal and Coimbra. Residence and age groups, specifically those aged 18–34 years and 55 years and older, were also important variables explaining the results. The gender, survey locations in Cascais and Aveiro, and the age group of 35–54 years old contributed the least to explaining variance in the first two dimensions (lowest  $\cos^2$ ).

The variable categories significantly associated with each dimension ( $p < 0.05$ ) are shown in the Supporting Information (Appendix B, Tables B1–B4). **Figure 5**, right panel, illustrates the first dimension (horizontal axis), which mainly separated younger individuals (18–34 years old), especially non-residents surveyed in Setúbal, characterized by low awareness of cork oak land use systems, low perception of their socioecological importance (no ES), low recognition of a piece of cork, and low perception of cork's sustainability and construction applications, from **Figure 5**, left panel, which displays older participants ( $\geq 55$  years old) residing in Coimbra or Aveiro, who showed higher awareness of cork oak land use systems, perception of multiple ES ( $> 2$  ES), visual recognition of a piece of cork, and positive perceptions of cork as a sustainable building material.

**Figure 5**, top vs. bottom panels (and Supporting Information Appendix B, Tables B3–B4), illustrates the second dimension (vertical axis) which contrasted individuals aged 35–54 years non-residents surveyed in Setúbal, with awareness of land use systems, either very low or very high perception of their socioecological importance (no ES or >4 ES) and visual recognition of a piece of cork, from younger individuals (18–34 years old) residing in Coimbra, who displayed low visual recognition of cork, low awareness of cork oak land use systems, and identified only one ES.

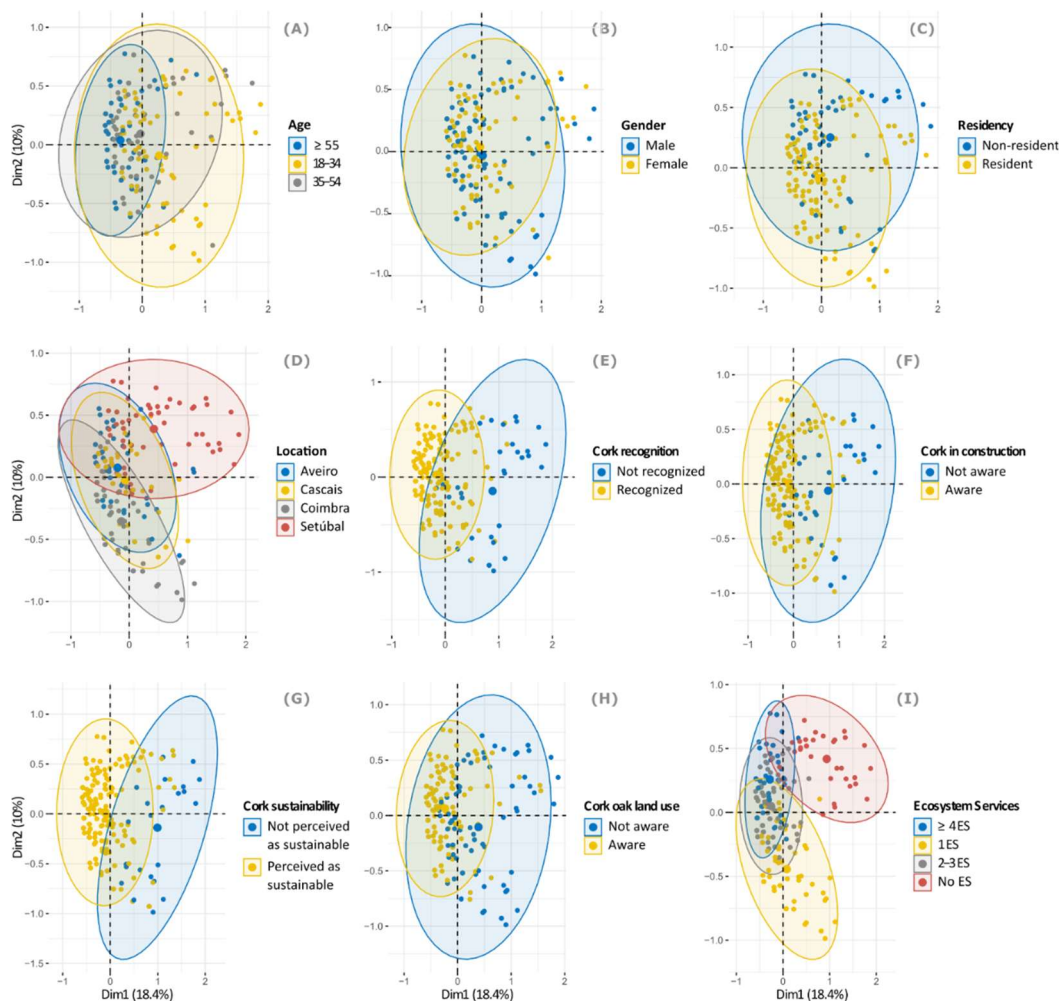


**Figure 5.** Results of the MCA showing the contribution and representation quality of variable categories across the first two dimensions (Dim1 and Dim2), which explain 18.4% and 10.0% of the variance, respectively. The color scale represents the squared cosine ( $\cos^2$ ), indicating how well each category is represented by the two dimensions (values closer to 1 reflect stronger contributions). Dimension 1 contrasts respondents with low awareness and perception of cork and cork oak land use systems (mostly younger individuals) with older, more informed participants. Dimension 2 separates individuals with extreme (low or high) perception of socioecological importance from those with more moderate views. Triangles represent the categories of the nine survey variables. Ecosystem Services (ES); Visual recognition of cork (Rec); Perception of cork as a sustainable material (Sust); Perception of cork use in construction (Const); Awareness of cork oak land use systems (LUS); Residence (Res). Age groups and survey locations are also shown.

### 3.6. Associations between individuals within categories of variables

**Figure 6** illustrates the associations among individuals within the nine categories of the variables used. In agreement with the above results, there are significant differences in responses (clear separation between ellipses) across age groups, particularly between the oldest and youngest groups. On the contrary, there are similar patterns in responses (heavy overlap of the ellipses) based on gender or residence. In terms of survey location, Setúbal showed the highest differences compared to the other locations.

In addition, respondents clustered into two main groups in terms of perception and awareness regarding cork and cork oak land use systems: (i) one group was characterized by lack of cork visual recognition, lack of perception of cork as a sustainable material and used for construction and lack of awareness of cork oak land use systems and perception of their socioecological importance (ecosystem services); (ii) the other group showed visual recognition of cork, perception and awareness of these issues. In particular, there was a clear separation between individuals who recognized a piece of cork and those who did not, as well as between those who did and those who did not perceive cork as a sustainable material. **Figure 6** illustrates a similar separation between individuals with no perception of the socioecological importance of cork oak land use systems (no ES) and those with low perception (only one ES).



**Figure 6.** MCA showing associations between individuals and categorical variables. Ellipses represent the distribution of individual responses across the two MCA dimensions (Dim1 and Dim2), grouped by: age group (A), gender (B), residency status (C), survey location (D), visual recognition of cork (E), perception of cork as a material used in construction (F), perception of cork as a sustainable material (G), awareness of cork oak land use systems (H), and perception of ecosystem services provided by these systems (socioecological importance) (I).

## **4. Discussion**

### **4.1. Public awareness of cork as a sustainable building bio-based material and of cork oak land use systems**

Throughout the analysis of the survey results, we found several pieces of evidence indicating important gaps in the general public's awareness of aspects of cork as a building material and of the cork land use systems that should be discussed. Firstly, only a small proportion of respondents recognized cork as a potential material for exterior façades, despite being familiar with other commonly used building materials in Portugal, such as concrete, stone, and tiles. It suggests that public awareness of the potential of cork and other bio-based materials as façade materials, particularly in terms of their versatility, sustainability, and carbon footprint [46], still has considerable room for improvement. In fact, such a low level of awareness likely reflects the limited use of cork as a façade material in the Portuguese construction sector. A more encouraging note is that most respondents supported the use of Portuguese materials in construction, including cork, provided they are not excessively costly and maintain high-quality standards.

Secondly, despite previous studies assessing the sustainability of cork products in Portugal clearly emphasize not only the environmental dimension, but also the social (e.g., local traditions, sense of belonging, and cultural heritage) and economic dimensions (e.g., contributions to the regional economy, employment, and population retention in interior regions), e.g., [47], most respondents to our survey still perceive cork as a sustainable material, primarily for environmental reasons, and the other two dimensions are quite dismissed.

Thirdly, the extent to which the cork oak land use systems, considered as SES, are currently associated with active local livelihoods, cultural practices, or stakeholder engagement varies considerably across regions and socioeconomic contexts, depending on management intensity, land use trajectories, and broader policy and market dynamics [48–50]. This heterogeneity has been widely documented in Mediterranean oak agroforestry systems such as montados and dehesas [51,52]. Within this framework, the concept of ecosystem stewardship can offer a useful lens for understanding the roles of individuals and communities in sustaining these systems. Stewardship emphasizes proactive management of ecosystems in the face of uncertainty and change, integrating local knowledge, values, and institutions to promote resilience and sustainability [53,54]. However, our results show that temporary residents, tourists, and younger individuals generally exhibited the lowest levels of awareness, particularly in Setúbal, a region characterized by cork oak land use systems. It suggests that, despite their relevance, these intertwined socioecological and stewardship aspects remain poorly understood by citizens who are not directly involved in the cork value chain or who do not reside in rural areas where cork oak land use systems are present or prevalent.

Overall, raising public awareness of the socioeconomic and ecological benefits of cork is essential to supporting its broader adoption in the construction sector, as there is a proven connection between consumer sustainability knowledge and the predisposition to adopt sustainable building materials. Plus, user acceptance and

satisfaction tend to increase when individuals are familiar with a material's biography, properties, life cycle, and attributes such as recyclability, biodegradability, and durability [55,56]. While increased awareness does not necessarily translate into ecosystem stewardship, it is widely recognized as a necessary precondition for building societal support for conservation-oriented policies and sustainable land use practices [57]. Nonetheless, fostering such awareness remains a challenge, as limited targeted dissemination of knowledge can result in reduced general interest [58].

Among the demographic factors analyzed, age emerged as the most significant predictor of awareness of cork's origin. While younger individuals consistently demonstrated the lowest levels of awareness, including visual recognition of a piece of cork, older respondents showed the highest levels of awareness of cork as a sustainable building material and of the socioecological importance of cork oak land use systems. These findings are in line with previous studies indicating that environmental awareness tends to increase with age [59,60], if not specifically targeted by awareness and education campaigns, as, e.g., in the cases of recycling and climate change activism [61,62]. It may also reflect a weaker connection between younger generations and rural areas and primary production systems [63]. Along these lines, we suggest that increasing awareness among younger people about the sustainability of cork as a building material and its role in the circular economy may foster innovation in product design and green entrepreneurship, areas in which Millennials and Generation Z have shown growing interest [64].

Another demographic factor that further contributed to variation in responses, with notable regional differences, was the survey location. The lowest levels of awareness were observed in Setúbal, particularly among younger individuals who were not residents, while the highest awareness levels were found in Coimbra and Aveiro among older, permanent residents. Gender was the one factor that did not significantly influence response patterns. Considerations derived from these demographic factors must be taken carefully, as the patterns observed may reflect differences in residency status, urban context, level of education, and exposure to cork-related landscapes or infrastructure. In particular, Setúbal's coastal urban profile and the likely presence of tourists among the non-resident respondents may help explain the lower levels of awareness observed. At the same time, older permanent residents in Coimbra and Aveiro may have stronger ties to local ecological knowledge and a longer history of using cork.

One limitation of our approach, encountered during analysis of the survey results, is that we did not explore economic factors in a way that enabled us to draw clear conclusions. Despite the survey's questions 5 and 5.1 indicating a positive acceptance of national materials, including cork, if not excessively costly, this is not enough to say that it reflects aspirational or value-based preferences that could be moderated in real decision-making contexts by financial constraints or limited market access. It is known that cost-related considerations tend to operate as implicit filters in public acceptance of sustainable construction materials, e.g., high initial costs, longer payback periods, perceived costs, and higher prices compared to commonly used materials, which are among the cited barriers to their adoption [65–67]. However, the distinction between symbolic acceptance (i.e., general support or positive attitude towards the materials) and practical adoption (i.e., actual use of these materials in

construction projects), which is well documented in previous research on sustainable construction materials and shows that, despite their positive environmental impacts, conventional materials are often preferred due to lower costs and well-established performance [68–70], cannot be applied to our case study due to lack of empirical data. Moreover, in a scenario of expansion of cork applications in construction, with an inherent mix of social, economic, and environmental benefits and challenges, one of the trade-offs to be considered is indeed the economic viability of the materials, as their higher cost may limit their adoption despite their environmental benefits [71]. The sustainability consequences of an increased demand, thus intensified production, and the environmental impacts of the production process are also to be considered [72,73].

In this context, further research would benefit from more explicitly integrating economic variables by combining perceptions with information on price ranges, life-cycle costs, or hypothetical purchasing scenarios, thereby allowing for a clearer understanding of how the economic viability of the materials interacts with environmental values to shape public acceptance of cork-based construction solutions.

#### **4.2. Strategies to increase public awareness of cork as a sustainable building material and the importance of cork oak land use systems**

Promoting cork as a construction material aligns closely with the EU's sustainable development goals and offers a concrete way to reduce the construction industry's carbon footprint [74,75]. The EU's "Fit for 55" package, enshrined in the European Climate Law and adopted between July and December 2021, committed to reducing greenhouse gas emissions by at least 55 % by 2030, compared with 1990 levels, emphasizing the urgency of adopting sustainable building solutions [76]. In Portugal, traditional buildings often lack modern energy-efficiency features, offering a strategic opportunity to incorporate environmentally friendly materials, such as cork, to improve energy efficiency and reduce emissions [77]. In light of our study's results, strategies to increase public awareness of cork as a sustainable building material could help meet these objectives. At the same time, increasing public awareness of the importance of cork oak land use systems would help facilitate public adoption of these materials.

Increasing public awareness of cork as a sustainable building material, strategies such as showcasing its versatility in construction [78–81], and applying creative methods of eco-ideation and design [82,83], have already been explored. Nevertheless, other strategies, such as campaigns to disseminate information on the economic relevance of cork production, its role in supporting rural livelihoods, and the ecological value of cork oak land use systems, would be very important to deliver to the general public [84]. The challenge is that although the cork industry produces high-quality information, its dissemination remains limited to niche audiences [85].

Several environmental education initiatives already introduce students to cork oak land use systems (e.g., the "Green Cork Program" by QUERCUS (<https://www.greencork.org/>), the "Forest Literacy Program" by LPN ([www.lpn.pt](http://www.lpn.pt)), and Arte3C by Charneca Landscape Observatory (<https://opc-paisagem.pt/art3c/>). These programs, implemented within the framework of the National Strategy for

Environmental Education 2020, have reached thousands of students across Portugal. Nevertheless, broader and more targeted efforts are still needed to strengthen public recognition of cork oak land use systems and their associated products. Here, previous awareness campaigns on other topics, such as waste separation and the environment in general, have demonstrated to be very successful [86,87], and could serve as the baseline for this case. It includes reinforcing school and higher education programs, training teachers, and engaging the media [40,88,89]. Partnerships with journalists and public campaigns that use social media citizen engagement techniques can further expand outreach and drive behaviors [90–92]. Considering our results, it seems essential to both diversify dissemination channels and tailor communication strategies to target groups that are frequently overlooked, such as urban populations and professionals outside the forestry and cork sectors.

Similar to other cases, such as in Corsica, where collective strategies were used to revive a local industry of cork-manufacturing [93], efforts should actively engage third-party players such as the construction professionals, not only by providing technical information, but also by involving them as key agents in promoting the use of bio-based materials. Finally, certification through ecolabels and environmental certifications, which confirm environmental benefits and compliance with sustainability criteria, would strengthen market confidence and might support broader adoption among builders and consumers. There are recent EU Standards and market placement rules for, e.g., cork flooring and coverings [94], but there are other very interesting initiatives in other places that can be adopted to our context and foster the use of cork, such as in the U.S., where the Green Building Council awards points for using rapidly renewable materials like cork [95], or other incentives programs directed to foster environmental responsible building practices [96].

## **5. Conclusion**

The construction sector in Europe requires a paradigm shift toward more sustainable building practices to address its considerable contribution to global CO<sub>2</sub> emissions and natural resource depletion. And, as this transition toward more sustainable practices continues, cork stands out as a renewable, low-impact material with strong integration potential. A renewed interest in cork, particularly among architects and designers incorporating it into contemporary architectural works, further signals its potential for wider adoption. However, public awareness remains low regarding both cork as a sustainable building material and the importance of cork oak land use systems. This is what our study, which assessed both mentioned public perceptions, has found. The survey, conducted in four Portuguese locations, revealed important gaps in public awareness, particularly among younger individuals and non-residents, as well as regional differences. These findings underscore the need for targeted awareness strategies, not only to support the adoption of cork in the construction sector in line with EU sustainability goals, but also to foster a broader culture of ecosystem stewardship along the cork value chain.

Future research needs to identify effective educational and communication strategies to raise public awareness and promote the use of cork-based materials among consumers, architects, and builders. Although the empirical analysis focuses

on the Portuguese context, several of the patterns identified in this study, namely limited public awareness of bio-based construction materials, the predominance of environmental over socioeconomic perceptions, and generational differences in knowledge, are likely to be relevant in other cork-producing regions, such as the several *montados* and *dehesas* across the Mediterranean. As such, the findings may inform interdisciplinary research and policy discussions on the adoption of locally sourced, bio-based materials in construction.

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## Appendix A. Survey structure and content

This appendix provides an overview of the survey's structure and content used in this study. It outlines the main sections of the questionnaire, which aimed to capture demographic information, awareness and perceptions of cork as a building material, and knowledge of cork oak land use systems and their socioecological importance.

**Table A1.** Detailed structure of the survey questionnaire, including thematic sections, question types, numbering, and available response options.

Thematic structure of the question	Type of question	Nr.	Question	Answers available
Section1. Perception and awareness of building materials in Portugal	Closed-ended	1.	Do you know which materials are most used to coat building façades in Portugal?	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> <li>• Rather not answer/ I have no opinion</li> </ul>
	Open-ended	1.1.	What type of building façade coatings do you know?	<ul style="list-style-type: none"> <li>• Lightness</li> <li>• Elasticity</li> <li>• Flexibility</li> </ul>
	Closed-ended	2.	In your opinion, which of the following characteristics are most important when coating a building façade?	<ul style="list-style-type: none"> <li>• Impermeability</li> <li>• Aesthetics, beauty</li> <li>• Transparency</li> <li>• Thermal insulation</li> <li>• Acoustic insulation</li> <li>• Anti-vibration insulation</li> <li>• Other</li> </ul>
	Closed ended	3.	How would you rate the thermal comfort of buildings in Portugal?	<ol style="list-style-type: none"> <li>1) Very bad</li> <li>2) Bad</li> <li>3) Reasonable</li> <li>4) Good</li> <li>5) Very good</li> </ol>
	Closed ended	4.	How would you rate the acoustic comfort of buildings in Portugal?	<ol style="list-style-type: none"> <li>1) Very bad</li> <li>2) Bad</li> <li>3) Reasonable</li> <li>4) Good</li> <li>5) Very good</li> </ol>
	Closed-ended	5.	If you had to buy materials to build your house, would you consider buying national materials?	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> <li>• Rather not answer/ I have no opinion</li> </ul>
	Closed-ended	5.1.	If you answered yes, choose why.	<ul style="list-style-type: none"> <li>• Cost</li> <li>• Local availability</li> <li>• Material quality</li> </ul>
	Closed-ended	5.2.	If you answered no, choose why.	<ul style="list-style-type: none"> <li>• Too expensive</li> <li>• It does not make any difference</li> </ul>
Section 2. Recognition and perception of cork in construction	Closed-ended	6.	Do you recognize this material? (Showing a piece of cork)	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> <li>• Rather not answer</li> </ul>
	Open-ended	6.1.	If you answered yes, name the tree that produces cork.	

**Table A1. (Continued).**

Thematic structure of the question	Type of question	Nr.	Question	Answers available
	Closed-ended	7.	Do you consider that cork-coated façades add value to buildings?	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> <li>• Rather not answer/ I have no opinion</li> </ul>
	Closed-ended	7.1.	If you answered yes, in what way?	<ul style="list-style-type: none"> <li>• Aesthetics</li> <li>• Comfort</li> <li>• Other</li> </ul>
	Open-ended	7.2.	If you answered no, why?	
	Closed-ended	8.	As Portugal is one of the world's largest producers of cork, do you consider that cork could be used in construction?	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> <li>• Rather not answer/ I have no opinion</li> </ul>
	Open-ended	8.1.	If you answered yes, how?	
	Open-ended	8.2.	If you answered no, why?	
	Closed-ended	9.	Do you consider cork a sustainable material?	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> <li>• Rather not answer/ I have no opinion</li> </ul>
	Closed-ended	9.1.	If you answered yes, what characteristics make it sustainable?	<ul style="list-style-type: none"> <li>• Environmental</li> <li>• Economic</li> <li>• Social</li> <li>• Other</li> </ul>
Section 3. Awareness of cork oak land use systems and ecosystem services	Closed-ended	10.	Do you know what cork oak land use systems (montados) are in Portugal?	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> <li>• Rather not answer/ I have no opinion</li> </ul>
	Open-ended	10.1	If you answered yes, where are they located?	
	Closed-ended	11.	In your opinion, what is the environmental importance of cork oak stands in Portugal?	<ul style="list-style-type: none"> <li>• Biodiversity and habitats</li> <li>• Soil conservation</li> <li>• Fire risk reduction</li> <li>• Carbon sequestration</li> <li>• Other</li> </ul>
	Closed-ended	12.	Are you aware of other applications for cork material?	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> <li>• Rather not answer/ I have no opinion</li> </ul>
	Open-ended	12.1	If you answered yes, which ones?	

**Table A1.** (Continued).

Thematic structure of the question	Type of question	Nr.	Question	Answers available
Section 4. Sociodemographic profile of respondents	Closed-ended	A.	Sex category: Select the category that best fits your profile.	<ul style="list-style-type: none"> <li>• Female</li> <li>• Male</li> <li>• Other</li> <li>• Rather not answer</li> </ul>
	Closed-ended	B.	Age group: Select the group that best fits your profile.	<ul style="list-style-type: none"> <li>• 18–34 years</li> <li>• 35–44 years</li> <li>• ≥55 years</li> <li>• Rather not answer</li> </ul>
	Closed-ended	C.	Place of residence: Select the category that best fits your profile.	<ul style="list-style-type: none"> <li>• Permanent resident</li> <li>• Temporary resident</li> <li>• Tourist</li> <li>• Other</li> <li>• Rather not answer</li> </ul>

## Appendix B. Multiple correspondence analysis (MCA)

This appendix provides the results of the Multiple Correspondence Analysis (MCA), detailing the variables and their respective categories that are significantly associated with the two main dimensions. These results complement the interpretation presented in the manuscript (see **Figure 5** and **Tables B1–B4**).

**Table B1.** Association between variables and Dimension 1 of the MCA (1-way ANOVA).

Variable	R <sup>2</sup>	<i>p</i> -value
Ecosystem services (ES)	0.5633	$1.12 \times 10^{-41}$
Cork visual recognition (Cork_Rec)	0.4748	$1.03 \times 10^{-34}$
Perception of cork as sustainable (Cork_Sust)	0.3896	$5.35 \times 10^{-27}$
Perception of cork in construction (Cork_Const)	0.3520	$6.28 \times 10^{-24}$
Awareness of land use systems (LUS)	0.3193	$2.15 \times 10^{-21}$
Age	0.2303	$5.04 \times 10^{-14}$
Survey location (Location)	0.2126	$4.61 \times 10^{-12}$
Residency status (Resident)	0.0274	$1.07 \times 10^{-2}$

**Table B2.** Variable categories significantly associated with Dimension 1.

Category	Estimate	<i>p</i> -value
ES = None	0.817	$3.38 \times 10^{-35}$
Cork_Rec = No	0.519	$1.03 \times 10^{-34}$
Cork_Sust = No	0.553	$5.35 \times 10^{-27}$
Cork_Const = No	0.447	$6.28 \times 10^{-24}$
LUS = No	0.312	$2.15 \times 10^{-21}$
Location = Setúbal	0.418	$1.80 \times 10^{-13}$
Age = 18–34	0.303	$1.21 \times 10^{-11}$
Resident = No	0.102	$1.07 \times 10^{-2}$

**Table B2.** (Continued).

Resident = Yes	-0.102	$1.07 \times 10^{-2}$
Location = Coimbra	-0.139	$8.60 \times 10^{-3}$
Location = Aveiro	-0.203	$9.88 \times 10^{-4}$
ES $\geq$ 4	-0.401	$6.00 \times 10^{-6}$
ES = 2–3	-0.377	$7.97 \times 10^{-8}$
Age $\geq$ 55	-0.311	$1.08 \times 10^{-11}$
LUS = Yes	-0.312	$2.15 \times 10^{-21}$
Cork_Const = Yes	-0.447	$6.28 \times 10^{-24}$
Cork_Sust = Yes	-0.553	$5.35 \times 10^{-27}$
Cork_Rec = Yes	-0.519	$1.03 \times 10^{-34}$

**Table B3.** Association between variables and Dimension 2 of the MCA (1-way ANOVA).

Variable	R <sup>2</sup>	p-value
Ecosystem services (ES)	0.6329	$1.91 \times 10^{-50}$
Survey location (Location)	0.5025	$4.09 \times 10^{-35}$
Residency status (Resident)	0.1374	$3.91 \times 10^{-9}$
Awareness of land use systems (LUS)	0.0420	$1.52 \times 10^{-3}$
Age	0.0414	$7.06 \times 10^{-3}$
Cork visual recognition (Cork_Rec)	0.0239	$1.71 \times 10^{-2}$

**Table B4.** Variable categories significantly associated with Dimension 2.

Category	Estimate	p-value
Location = Setúbal	0.368	$1.51 \times 10^{-21}$
ES = None	0.348	$1.93 \times 10^{-11}$
Resident = No	0.168	$3.91 \times 10^{-9}$
ES $\geq$ 4	0.188	$1.26 \times 10^{-8}$
LUS = Yes	0.084	$1.52 \times 10^{-3}$
Cork_Rec = Yes	0.086	$1.71 \times 10^{-2}$
Age = 35–54	0.080	$2.10 \times 10^{-2}$
Cork_Rec = No	-0.086	$1.71 \times 10^{-2}$
Age = 18–34	-0.106	$2.38 \times 10^{-3}$
LUS = No	-0.084	$1.52 \times 10^{-3}$
Resident = Yes	-0.168	$3.91 \times 10^{-9}$
Location = Coimbra	-0.376	$5.45 \times 10^{-25}$
ES = 1	-0.514	$2.21 \times 10^{-41}$