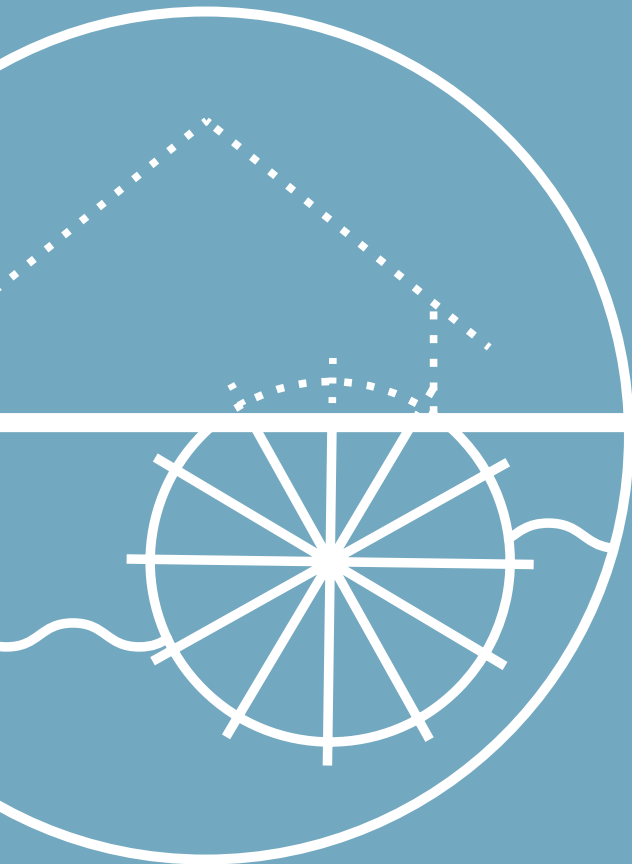


INHAVIT

Sustainability-led approaches for the rehabilitation
and revitalization of the cultural built heritage of
Montesinho Natural Park



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Javier Ortega | Graça Vasconcelos | Tiago Ferreira | Hugo Rodrigues | Eduarda Luso (eds.)

Photographs in between chapters by **Juan Camilo Arias Tapiero**

ISBN: 978-989-35653-6-0

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The INHAVIT Project 1

Sustainability-led approaches for the rehabilitation and revitalization of the cultural built heritage of Montesinho Natural Park

Javier Ortega¹, Graça Vasconcelos²



The main research hypothesis of the FCT funded INHAVIT research project is that the rehabilitation of vernacular buildings and the creation of better living conditions, can attract and retain strong local communities, becoming an effective measure to prevent the depopulation of rural areas. Many regions in Southern Europe are suffering a significant demographic decline that, together with population ageing, triggers a depopulation cycle with a profound multi-dimensional impact (economic, social, cultural and environmental). The cycle is thus perpetuated, creating a feedback loop (Figure 1).

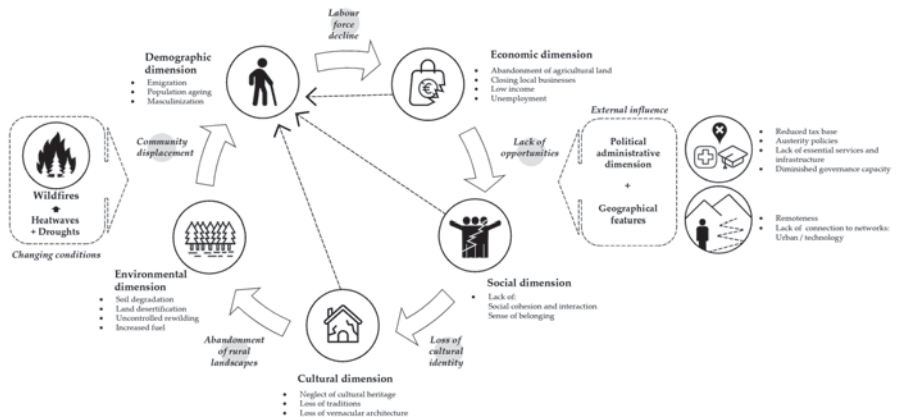


Figure 1. The depopulation cycle in rural areas with the multi-dimensional challenges involved (Graus et al. 2024a)

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Breaking this vicious cycle is a complex task involving multiple agents and out of the scope of the INHAVIT research project. Nevertheless, the overall narrative of INHAVIT has been to reflect on the role that the conservation of the vernacular heritage can have on this mission, acknowledging that cultural heritage is one of the main drivers for social cohesion and cultural identity, but also has an impact on the economic and environmental dimension of the regions and their communities.

Solely focusing on the vernacular heritage, depopulation leads to a loss of traditional construction knowledge and practices, and eventually to abandonment, leaving the buildings in a state of deterioration and ultimately ruin. The loss of the vernacular heritage erodes local identity and reduces the sense of belonging to a community, thus also contributing to the feedback loop of the depopulation cycle. Furthermore, there is a universal loss of this valuable cultural heritage and associated tangible and intangible aspects. For example, the transmission of essential vernacular knowledge on how to build with traditional techniques or how to cope with extreme weather conditions or hazards (e.g., wildfires) may be interrupted, misunderstood and, eventually, forgotten.

Within this context, the main objective of INHAVIT has been the study and identification of the physical, social and environmental vulnerabilities that may be contributing to the current state of progressive abandonment of several rural villages in the Montesinho Natural Park (MNP), in the northeastern Portugal, which is the case study of the research project and has approximately 8,000 inhabitants and 88 villages (Figure 2). Once the vulnerabilities are well defined and better understood, the results aim to contribute to safeguarding the vernacular heritage by creating awareness and promoting its continuous occupation by improving its living conditions and its resilience to multiple hazards.

The results and lessons gained during the completion of the research objective are discussed during this booklet, which is not meant to be an exhaustive scientific publication, but a general overview of the activities carried out. Moreover, to complement the discussion, the booklet includes perspectives on the conservation of the vernacular heritage from recognized researchers in different geographies. The

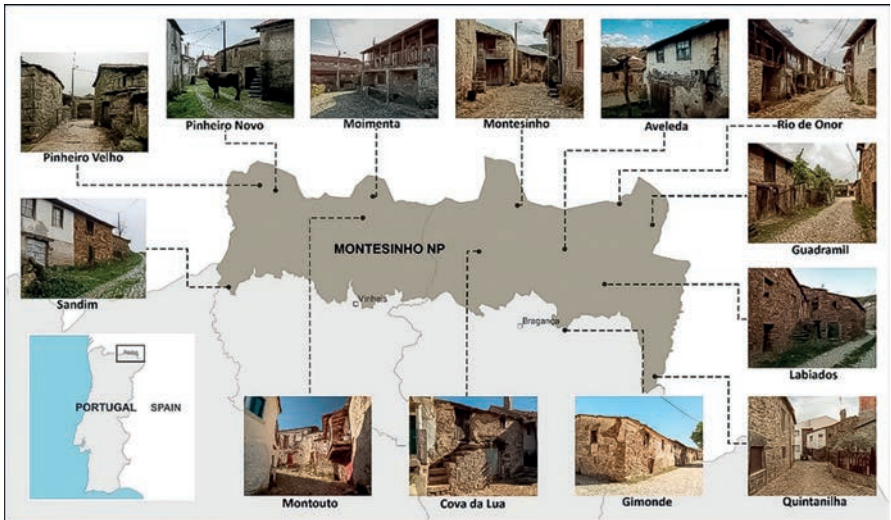


Figure 2. The INHAVIT research project case study: the Montesinho Natural Park location within Portugal highlighting the villages surveyed during the project with some examples of representative vernacular architecture (Arias-Tapiero et al. 2024)

outcomes of the project are expected to help stakeholders and local communities to make decisions on how to intervene in the vernacular built-up environment to transform it into sustainable, resource-efficient settlements.

The project team was mainly composed from architects and civil engineers from three different Portuguese academic institutions: University of Minho (UM), the project coordinator, the University of Aveiro (UA) and the Polytechnic Institute of Bragança (IPB), but also included academic and non-academic consultants from different countries: the Italian National Research Council (CNR), from Italy; the University of Burgos (UBU), from Spain; and the company Gratia-Hydro, from the Netherlands, specialized in the design and consultancy for building small hydroelectric power stations in historical water mills.

The complex problem and research objective has been tackled from different perspectives and research areas, involving theory of heritage conservation practice, conservation management, surveying and documentation, construction technology, digital models and

virtual reality, thermal comfort, building energy consumption, non-destructive testing, long-term monitoring, social vulnerability, multi-hazard vulnerability, climate-related hazards, etc. This integrated multidisciplinary approach is considered a step forward in the topic of rural heritage conservation. A summary of the activities carried out and how they contributed to accomplish the project research objectives is presented in Figure 3. Then, a brief overview of the different topics addressed in the research project is provided herein, before they are more extensively developed through the rest of the book chapters.

One of the main challenges faced during the project was the need to collect a vast amount of data about representative rural settlements and buildings in the Montesinho Natural Park, which required extensive on-site studies and missions. The characterization of vernacular buildings is crucial for understanding the historical, social, and cultural significance of a community. These buildings reflect a collective memory and result from a long adaptation process to the local environment. Thus, the first part of the project was mainly dedicated to the definition of a detailed methodology for documenting and inventorying the vernacular built heritage, and its implementation in our case study (Arias-Tapiero et

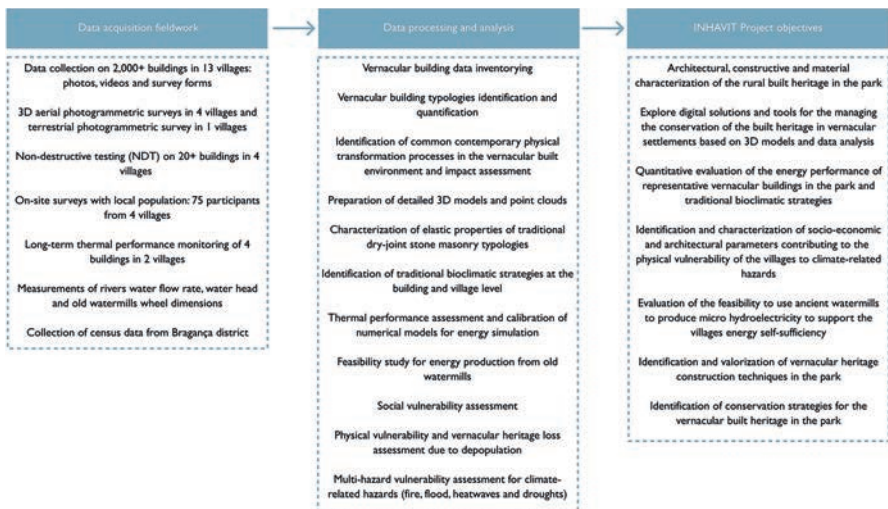
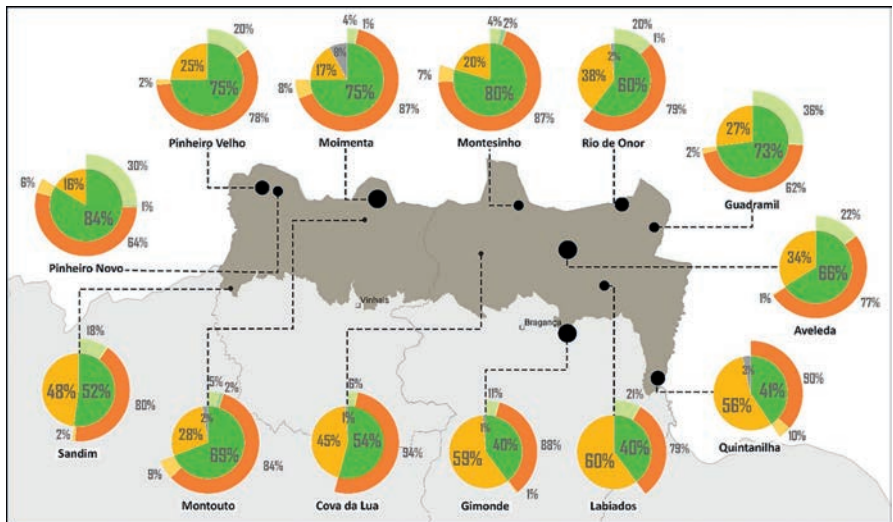


Figure 3. INHAVIT research activities and objectives

al. 2024a). More than 2,000 buildings and 13 villages of the park were surveyed, identifying the remaining vernacular buildings, and collecting data on aspects such as conservation state, materials, construction systems, past interventions, present use, and occupancy (Figure 4). A comprehensive understanding of the distinct built environment in the park was gained. Data was later used and analyzed for the subsequent tasks of the project, but the methodology proposed can be helpful for other contexts to aid in the development of management strategies and policies for the regeneration of rural settlement prone to depopulation.

Additionally, the physical vulnerability of vernacular dwellings in the park and the whole Bragança district where it is located, was evaluated using quantitative data from the National Institute of Statistics (INE) censuses from 1864 to 2021. Based on the methodology proposed by



Legend

Territory	Architectural condition	Current state of Vernacular Buildings
Montesinho Natural Park	Buildings with Vernacular elements	Unaltered Vernacular Buildings
Portugal	Non-Vernacular Buildings	Vernacular Buildings restored without dissonances
Spain	Non-inventoried buildings	Vernacular Buildings restored with dissonances
Municipalities		Buildings with foreign influences

Buildings per village: ● <100 buildings ● 100-150 buildings ● 150-200 buildings ● >200 buildings

Figure 4. Building characterization in the villages of MNP surveyed during the project (Arias-Tapiero et al. 2024a)

Tortajada et al. (2024), a study on how population decline influences the risk of deterioration and loss of vernacular architecture was carried out. Based on data on construction period, occupation and conservation state, a significant loss of more than 20% of vernacular buildings in the last two decades was identified. Moreover, 23% of the remaining vernacular dwellings were vacant, while 14.2% were categorized as being in poor condition (including ruin state). The numbers confirm the need for conservation management plans for safeguarding the vernacular heritage in the region.

The risk for the vernacular heritage to disappear is further aggravated by the impact of common contemporary transformation processes that it suffers. The project has deeply reflected on the meaning of authenticity in vernacular architecture. Authenticity in vernacular settlements is recognized to rely on its dynamic nature, accepting alterations and shaped by changing social, political, economic and environmental forces. Nevertheless, rural areas and vernacular settlements face the risk of cultural and architectural homogenization when incorporating external socio-cultural practices, materials, and construction techniques typically associated with urban environments, because of the subsequent loss of traditional knowledge that includes unique cultural and construction practices. Such practices hold important historical, social, spiritual and aesthetic values. Furthermore, the replacement of vernacular buildings with new ones that disregard the site's natural determinants can also affect the sustainable development of these communities. In this context, the INHAVIT project has developed and proposed a methodology for assessing the impact of common physical transformations on vernacular built environments (Figure 5), focusing on the loss of traditional constructions and subsequent impact on authenticity due to mischaracterization (Arias-Tapiero et al. 2025). Effective management strategies and proposed interventions must respect the cultural value of the vernacular heritage. The Multi-Criteria Decision Making tool can be adapted to the perspective of the communities and stakeholders from each specific site and is meant to inform intervention strategies while mitigating the current mischaracterization of vernacular built heritage.



Figure 5. Common physical transformations observed in the vernacular built environment of MNP (Arias-Tapiero et al. 2025)



Figure 6. Aerial view of the 3D model of Pinheiro Novo (Arias Tapiero et al. 2024b)

photogrammetry was carried out to obtain an even more detailed 3D model (Figure 6).

Besides serving as rigorous documentation of the heritage sites, the project has also investigated how to create digital solutions tailored for managing built heritage in vernacular settlements (Arias Tapiero et al. 2024b). The approach proposed utilizing a database containing information on each building within a settlement, and integrating it with a 3D model generated through photogrammetry in a Game Engine. This tool allows for interactive data analysis, exploration, management, as well as dissemination and educational purposes, aiming for community engagement.

Another major goal of the project was to evaluate the energy performance of representative vernacular houses in the park. Adapting vernacular architecture to appropriate current thermal comfort demands is considered a necessary approach for local regeneration and sustainability. Investing in strategies aiming at the preservation, adapting and reuse of the vernacular heritage is an important goal with a direct impact on society. With that purpose, several buildings were subjected

Because of this progressive loss of traditional construction practices, including artisans and masons, an important goal of the project has been to obtain a proper understanding of the construction technology in the region. Detailed constructive characterization of the building typologies, materials and construction techniques was carried out (Khei et al. 2024). A main focus was placed on analyzing the construction details that influence the energy performance of vernacular buildings, identifying passive bioclimatic strategies at the building and village level. Nevertheless, the team also put a focus on valorizing the most representative building techniques, such as slate roofs, preparing a technical construction manual with the help of reduced number of artisans in the region, and aiming to transfer this ancestral knowledge (Vaz et al., 2025).

Moreover, on-site inspection works included non-destructive testing of some selected buildings throughout the park for material characterization. The thorough experimental campaign including visual inspection for computation of masonry quality index, as well as sonic and ultrasonic testing, which will allow obtaining information about the elastic properties of different stone masonries in the park, including schist and granite masonry types. The main wall typology observed in the park consists of dry joint stone masonry. This masonry typology has received little attention in literature. Therefore, the database of experimental data collected during the project is also considered as an important contribution of the project.

Another main objective of the INHAVIT research project has been to explore the role of digital documentation for the understanding, promotion, management and conservation of vernacular heritage. Digital surveying, such as photogrammetry, has proven to be an essential tool in collecting and organizing information related to cultural properties, whether for site maintenance, or to ensure a posterity record in case of alteration or even disappearance. Within the project, four villages (Pinheiro Novo, Moimenta, Montesinho and Guadramil) were surveyed using aerial photogrammetry, obtaining detailed 3D models of the sites. In the case of Pinheiro Novo, combined aerial and terrestrial

to long-term thermal performance monitoring (indoor air temperature relative humidity). Also, exterior climate parameters were registered. The buildings were monitored during the whole year to understand their thermal performance in different seasons. The research addresses critical gaps in understanding vernacular building performance under extreme cold and hot conditions, observing that passive traditional strategies often fall short of modern comfort expectations (Khei et al. 2025). While bioclimatic features such as thermal mass and compact layouts offer some benefits, they are insufficient, particularly against prolonged cold. Results were fundamental to support and calibrate energy simulations of the buildings, including sensitivity analyses to obtain more realistic models that will investigate the energy performance of vernacular buildings in MNP. Results are considered to be essential to inform decision-making and intervention strategies that include targeted energy retrofits that enhance comfort without compromising heritage integrity.

The project also performed a feasibility study of using the traditional ancient watermills for renewable hydro-electricity production and turning the mills into local micro hydro-stations for the villages, aiming at energy self-sufficiency. Measurements were taken in different watermills, obtaining quantitative data on wheel dimensions, water flow rate and water head in different villages. The amount of water was proven to be insufficient for economically viable power generation. The area is overall dry and would require a back-up system consisting of solar panels and batteries. Since the water wheel will not have a large capacity because of the limited water flow, solar energy would then become the main source. Thus, the optimal solution for MNP would be to reduce the energy need for the house by passive solutions and isolation, together with solar panels and a battery for domestic energy supply.

Finally, another key objective of the project has been the identification and characterization of the hazards contributing to the vulnerability of the built heritage in MNP (and generally in rural areas prone to depopulation), mainly focusing on climate change related hazards, such

as heatwaves, droughts, floods and wildfires. The objective was to develop an integrated index-based vulnerability assessment methodology. The methodology, focused on physical vulnerability, has been applied in several villages, and provides a vulnerability index according to those construction and environmental conditions that most compromise the resilience of these structures to different hazards (Graus et al. 2025). Results are obtained per building, which allows mapping the results (Figure 7). Moreover, the incorporation of a multi-hazard approach allows evaluating how the interaction between threats can amplify physical vulnerability, which is an underexplored research area. Results obtained can be applied to other geographies with similar problematics, eventually informing efficient conservation and adaptation strategies for vernacular heritage at a village and regional level, contributing not only to heritage protection but also to territorial resilience in the face of climate change.

A particular focus was also placed on wildland-urban interface fire exposure in MNP. The severity of wildfires has increased in the last years in rural areas due to the combined effects of climate change and interventions on the environment. A Wildland-Urban Interface Index (WUIX) methodology was applied to assess the exposure of the

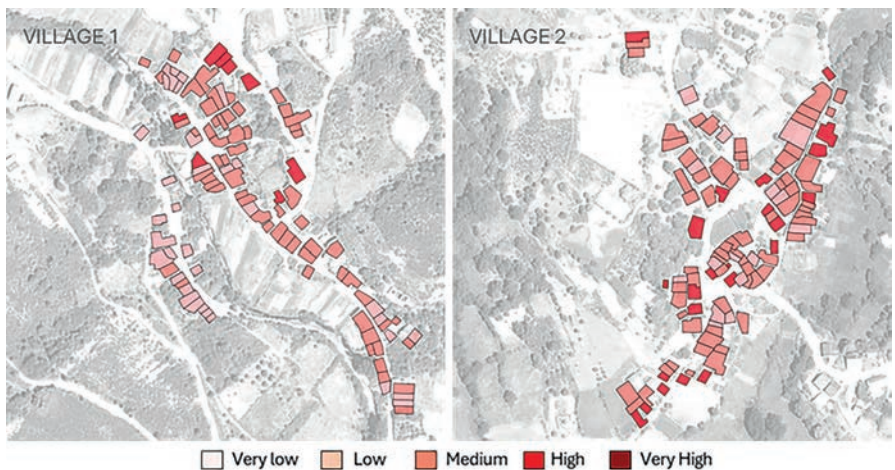


Figure 7. Physical vulnerability of buildings in two villages of MNP

wildland-urban interface (WUI) to wildfires in three villages of the park: Aveleda, Montesinho, and Rio de Onor (Silva et al. 2024). Results helped to map areas with greater exposure in small villages, pointing precisely to their places of occurrence, which is informative for inhabitants and authorities on how to act and mitigate the exposure of such buildings to fire.

Additionally, the project has included studies on social vulnerability in MNP. The project has evaluated the combined physical and social vulnerability of vernacular buildings exposed to climate-related hazards, focusing on how architectural and sociodemographic factors influence the resilience of these structures and their inhabitants. Data on social vulnerability were collected through on-site surveys conducted among the local population, identifying vulnerable groups, socioeconomic indicators and information related to the capacity of the community to cope with risk (Graus et al. 2024b). The results highlighted the varying levels of social vulnerability among the villages. Integrated physical and social vulnerability assessment allows defining differentiated mitigation strategies. Improvements in infrastructure, support programs for vulnerable groups, and rural revitalization policies could further strengthen the resilience of these communities in the face of future environmental and sociodemographic challenges.

In summary, the INHAVIT research project has been a great opportunity to explore how to analyze complex data to obtain a better understanding of vernacular heritage in rural areas prone to depopulation. Even though the outcomes did not aim to provide a direct way to interrupt the depopulation phenomenon through heritage conservation, it has opened new research paths and hopefully can offer tools and approaches for decision-makers on how to tackle this issue in practice. This pilot experience can also be replicated and extended in the future to other sites with similar problematics.

The research team would like to specifically acknowledge the city hall of Bragança and the parishes (*juntas de freguesia*) of França and Rio-de-Onor/Aveleda, for their active interest and collaboration in the project. The project was possible because of the funding received from

the Foundation for Science and Technology (FCT), under the call for Scientific Research and Technological Development (IC&DT) projects to promote interdisciplinary and multidisciplinary R&D activities to be carried out in the Montesinho Natural Park region, with reference MTS/BRB/0086/2020.

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The Montesinho Natural Park

A territory with history, natural and cultural values and a stunning landscape

2



Márcia Moreno¹, Maria Correia², Paulo Mafra³, Rafael Sobrinho Correia⁴

"I'm going to tell you about a Wonderful Kingdom. Although many people say no, there have always been and will always be wonderful kingdoms in this world. What is needed to see them is for the eyes not to lose their original virginity in the face of reality, and for the heart not to hesitate. Now, what I intend to show, mine and that of all those who want to deserve it, not only exists, but is one of the most beautiful imaginable."

Trás-os-Montes – Um Reino Maravilhoso, Miguel Torga (1950)



Figure 1. Montesinho Natural Park (photograph by the authors)

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- ³ Civil Works Department of the Municipality of Bragança, Portugal

A brief history of the Montesinho Natural Park

The whole of the Montesinho Natural Park is part of the Meseta Ibérica Transfrontier Biosphere Reserve, a declaration made in 2015 by UNESCO. This classification and international prominence result from the recognition of the natural values present, which function as living laboratories and represent an equitable balance between nature conservation and human activities. But the Park's history began 45 years ago. The Montesinho Natural Park (MNP) was created on August 30, 1979.

Decree-Law no. 355/79, of August 30, classifies the northern part of the Bragança and Vinhais municipalities as a Natural Park, a recognition given to the natural, landscape and human values present, as well as the receptiveness of local authorities to safeguarding their heritage and the potential for recreation and outdoor sports in the area.

In 1997, Regulatory Decree no. 5-A/97, of April 4, reclassified the MNP, given the “existence of animal populations and communities representative of Iberian and European fauna still in relative abundance and stability, including many of the threatened species of Portuguese fauna, as well as natural vegetation of great importance at national and world level, which, together with the reduced human pressure found in almost all of its territory, allows a large part of the ecological processes to evolve in patterns very close to natural ones”.

Later, in November 2008, the Montesinho Natural Park Management Plan was published by Resolution of the Council of Ministers no. 179/2008, of November 24, justified by the urgent need to apply appropriate protection measures, in terms of nature conservation, to an area that constitutes natural and European heritage.

Recently, in 2019, Decree-Law no. 116/2019 of August 21 was published, creating the Model of Co-management of protected areas, through a participatory and collaborative process, which aims to create a dynamic of proximity management in the political, territorial, cultural, social and economic dimensions. This shared dynamic of enhancing the protected area focuses specifically on the areas of promotion, awareness



Figure 2. Montesinho Natural Park (photograph by the authors)

and communication and is headed by a Stewardship Committee, an administrative and management body with specific responsibilities, operating rules and powers of its own, made up of local and regional entities, thus allowing for a closer relationship with citizens and key players and entities in the territory.

Thus, the Montesinho Natural Park Co-Management Committee was created on January 13, 2022, by Order No. 495/2022, and has since put into practice all its powers and duties, in an articulated and consensual manner, in order to achieve the objectives it set itself.

A territory with history, natural and cultural values and a stunning landscape

The Montesinho Natural Park (MNP) is in the north-east of mainland Portugal, to the north of the municipalities of Bragança and Vinhais, in the so-called *Terra Fria Transmontana*. With an area of 74,229 hectares, it is bounded to the north, east and west by the border with Spain, representing more than half of the total delimitation of this protected area.

According to the nomenclature of territorial units in Portugal, the MNP is part of the Norte region (NUT II) and the *Alto Trás-os-Montes* sub-region (NUT III).

Several factors have contributed to the Montesinho Natural Park's unique biodiversity, making it stand out on the national, Iberian and European scene. Its location in a transition zone – an ecotone – between the Mediterranean biome of the south and the Euro-Siberian influences coming from the extension of the Atlantic Mountain ranges of the Iberian Peninsula, gives it unique ecological characteristics. In addition, its peripheral position in relation to the major urban centers of Portugal and Spain has allowed for the preservation of sustainable communities and habitats that are rarely found in other regions and at comparable times.

In fact, the geographical location of the Montesinho/Coroa massif, together with the variation in altitudes (between 438 and 1486 meters), the geological and relief diversity, as well as the influence of human activity over the centuries, have contributed, and continue to contribute, to the formation of a remarkable wealth of communities and species.

We are therefore faced with one of the largest protected natural areas in Portugal. With its gentle elevations, deep valleys carved by the Sabor, Mações and Baceiro rivers, green meadows, holm oak forests and impressive rock formations, the park invites us to contemplate vast landscapes from its highest points.

The duly marked hiking trails provide an excellent opportunity to explore this exemplary biological diversity and capture truly memorable moments in photographs. In fact, the MNP is home to around 80% of the mammal species found in Portugal, making it a true biodiversity sanctuary. With an impressive fauna, it brings together more than 240 species of vertebrates, including around 150 birds, and it is easy to spot otters, wolves, deer and roe deer. Many of these species are endangered, are Iberian endemics, are rare or have a very limited distribution in Portugal.

The Park's flora also stands out for its diversity, revealing unique and constantly changing landscapes throughout the four seasons. It



Figure 3
Montesinho Natural Park
(photograph by the authors)

stands out at national level for its impressive diversity and the presence of numerous rare species, including several Iberian and Lusitanian endemics. This richness is the result of a complex combination of geological, climatic and orographic factors, combined with centuries of human intervention, which have given rise to a wide variety of plant communities. These habitats are home to plants of remarkable beauty, originality and high value for nature conservation.

Among the most notable elements is the flora that grows on ultrabasic rocks – an extremely rare type of geological formation in Portugal, responsible for highly selective and toxic soils for most plant species. The plants that grow in these adverse conditions are



Figure 4. Montesinho Natural Park (photograph by the authors)

particularly unique, and some of them only exist in the ultrabasic soils of *Trás-os-Montes*, occurring nowhere else in the world.

Autochthonous woodlands, such as oak groves, *sardoais* and riparian woodlands, also play a fundamental role in the high botanical diversity of this protected area.

Over the millennia, the people who have lived in this territory have given rise to a valuable cultural heritage, deeply rooted and shared by all. Despite the growing influence of external stimuli, these communities continue to assert their identity and proudly preserve the traditions they have inherited.

The relationship between human communities and the territory that today makes up Montesinho Natural Park is deep and ancient, shaped over time. This intimate connection has given rise to a living cultural heritage, which remains visible in the practices, traditions and material traces left by successive generations. The human occupation of this region is closely linked to the material expression of the culture of the communities that settled here, translating into a humanized landscape that reflects ways of life adapted to nature and geographical isolation.

Elements such as pastoral music, a traditional dance, an *escrinho*, a monument, a rural architectural complex or an archaeological site are expressions that help define the cultural identity of the people of this region. Each of these elements carries meanings that transcend time, bearing witness to forms of social organization, beliefs, rituals and livelihoods that have remained resilient even in the face of changes in the contemporary world.

Despite progressive demographic desertification, as described below, and the pressure of urban development models, it is precisely the people who remain in this territory who ensure the continuity of these traditions. With their ancestral knowledge and strong ties to the place, these communities have become essential agents in preserving



Figure 5
Montesinho Natural Park
(photograph by the authors)

not only the cultural heritage, but also the ecological integrity of the protected area.

As far as demographics are concerned, the PNM is spread over two municipalities, with Bragança occupying 43,637 hectares of the Park, corresponding to 37% of the municipality's total land area, and Vinhais covering 30,592 hectares of the MNP, corresponding to 44% of the municipality's total land area. More than half of Bragança's population (65%) lives in the geographical area of the union of parishes that make up the urban perimeter of Bragança (Sé and Santa Maria). In other words, less than half of Bragança's population (35%) lives in 38 parishes, 15 of which are in the PNM area, giving a total resident population of 3,866 inhabitants, which corresponds to 11.2% of the municipality's resident population. The reality of Vinhais is different from that of Bragança. Only 28% of its population lives in the urban perimeter of Vinhais (the parish of Vinhais) and the remaining population spreads across the remaining 25 parishes.

It should be noted that 13 are in the Park's protected area, totaling 2,437 residents, which corresponds to 31.4% of the municipality's total population. The resident population in Bragança and Vinhais is made up of more women than men and most of them are aged between 15 and 64. However, it should be noted that there are more people aged 65 or over (28.2% in Bragança and 44.4% in Vinhais) than young people under the age of 15 (10.8% in Bragança and 6.4% in Vinhais), which reflects the existence of a resident population that tends to be older, with foreseeable present and future consequences of depopulation.

In the Montesinho Natural Park, it is the people, albeit in increasingly small numbers, who keep the soul of the territory alive. They are the ones who preserve the traditions, ancient knowledge and sustainable practices that have shaped the landscape over the centuries. Their intimate connection to the land makes them guardians of the local identity and fundamental allies in the conservation of this valuable natural heritage. Without the presence and involvement of these communities, the cultural and environmental richness of the Park could hardly be preserved with the same authenticity.



Figure 6
Montesinho Natural Park
(photograph by the authors)

In this sense, conserving the Montesinho Natural Park is not just about protecting biodiversity and natural landscapes. It also involves valuing the human and cultural dimension that gives it its identity. The collective memory inscribed in the villages, in agricultural practices and in the daily gestures of their inhabitants is undoubtedly one of the region's greatest assets.

“Knock on a door, rich or poor, and the same trusted voice always answers: – Come in! Without anyone asking any more, without anyone coming to the window to peek, the intimacy of an entire family is opened up. What is needed now is to deserve the magnificence of the gift.”

Trás-os-Montes – Um Reino Maravilhoso, Miguel Torga (1950)

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Vernacular Architecture of Montesinho Natural Park

3



Euarda Luso¹, Débora Ferreira¹, Jorge Vaz¹, Sílvia Fernandes¹

Introduction

Montesinho Natural Park (MNP), located in the northeast of Portugal, is a territory rich in both natural and cultural heritage, where vernacular architecture plays a key role in defining its villages' identity. The region's geographical isolation and harsh climate led to the development of architectural solutions harmoniously integrated with the surrounding landscape. The vernacular architecture of MNP reflects centuries of adaptation to environmental conditions, resource availability and local traditions. These structures' construction materials and solutions showcase a deep understanding of sustainable building techniques, using natural and locally sourced elements that ensure thermal comfort, durability and harmony with the surrounding landscape (Figure 1). The traditional architecture of MNP is based on the use of local materials and construction techniques that have been passed down through generations. The buildings incorporate solutions that address the need for shelter from cold winters and hot summers while optimizing the available natural resources.

Despite the cultural and historical significance of Montesinho's vernacular architecture, several challenges have emerged over recent decades, leading to notable transformations within the region. One of the most critical issues has been the widespread abandonment of villages, driven by migration to urban centers. This demographic shift

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Figure 1. Landscape of MNP

has resulted in the deterioration of many traditional houses and the gradual loss of knowledge regarding ancient construction techniques, threatening the continuity of a unique architectural heritage.

In addition to abandonment, introducing new materials and architectural styles has profoundly impacted the traditional landscape. The replacement of locally sourced, natural materials with industrialized solutions such as cement, aluminium, and PVC has disrupted the villages' original aesthetic and environmental harmony. These modern interventions often contrast starkly with the vernacular character, undermining the visual and cultural coherence of the settlements.

Nevertheless, various preservation and enhancement initiatives have been undertaken to counter these trends and safeguard the region's architectural legacy. Restoration projects that use traditional materials have rehabilitated houses, many of which have been adapted for rural tourism. Furthermore, government bodies and local associations have developed programs to encourage the rehabilitation of vernacular buildings, providing technical and financial support for conservation

efforts. Importantly, a growing emphasis has been on promoting sustainable construction practices that combine traditional techniques with modern ecological innovations, such as integrating solar panels and using natural insulation materials.

The vernacular architecture of the MNP reflects a deep connection between humans and their environment. The buildings demonstrate structural efficiency and, although they do not fully meet current thermal efficiency standards, they show a conscious effort to achieve it, using the resources and knowledge available at the time. To preserve these traditions and ancient knowledge, it is essential to promote careful restoration efforts and bioclimatic passive architectural solutions, safeguarding that these building practices continue to be valued in the future, respecting original materials and techniques while integrating sustainable innovations that enhance liveability and energy efficiency. Recognising and reinterpreting vernacular solutions in contemporary architectural practice is crucial for preserving territorial identity and promoting truly adaptive bioclimatic design strategies.

Village Layout and Construction Details

The villages in MNP are typically compact and densely built, with clustered housing blocks that protect constructions from strong winds and extreme temperatures. The street layout often follows the natural terrain, and the arrangement of houses promotes thick shared walls, reducing heat loss and improving energy efficiency (Figure 2).

The rugged terrain and constant exposure to natural forces in the region led to developing specific construction techniques to ensure structural stability and longevity. The floor structures were built with wooden frames, chosen for their flexibility, which allowed the buildings to absorb movements without cracking or compromising the overall integrity.

Passive construction systems consist of constructive solutions integrated into buildings to contribute to their heating or cooling through natural means (Vaz et al. 2013). Given the climate of the cross-border



Figure 2. Montesinho Village

region, the winter situation requires special attention. In this regard, design strategies focus on reducing thermal losses and promoting solar gains during winter. Solar gains are promoted in winter by using well-sized and properly oriented glazed openings, preferably facing south

Challenges and Preservation Efforts

Many traditional buildings within the Montesinho Natural Park face significant deterioration due to various factors. Depopulation has played a central role, with younger generations migrating to urban centres, leaving numerous constructions abandoned and without proper maintenance. Over time, this neglect has allowed natural forces such as erosion and weathering to degrade the stone walls, ceramic roofing and wooden elements that define the region's vernacular architecture.

The introduction of modern construction materials that often replace traditional techniques is deepening these challenges. Concrete

and cement mortars are commonly used, disrupting the natural breathability of the original stone walls and causing persistent moisture problems. Likewise, the installation of PVC windows and metal roofing materials has compromised the visual identity and authenticity of the built heritage, creating a dissonance within the historic landscape.

Several sustainable restoration and conservation initiatives have been developed to preserve and adapt the vernacular architecture in response to these threats. Restoration efforts increasingly emphasize using traditional materials such as lime mortar, chestnut wood, and local stone, rejecting industrial substitutes incompatible with the original construction systems.

Eco-friendly adaptations have also been promoted, integrating elements like solar panels, green roofs, and advanced insulation solutions while preserving the traditional aesthetic. Additionally, many restored houses have been converted into guest accommodations as part of rural tourism initiatives, helping to revitalize local communities, promote cultural tourism, and sustain traditional craftsmanship practices.

Planning and Conservation Policies in MNP

The Montesinho Natural Park Management Plan and the Co-management Plan emphasize preserving traditional techniques, encouraging the sustainable rehabilitation of vernacular buildings.

The Montesinho Natural Park management plan was established by Decree-Law No. 355/79 of August 30th (Decreto Lei nº 355/79, 1979), with the primary objective of safeguarding the unique values found within its territory. These values result from the alternation between relatively humanised areas and spaces of high naturalness and ecological complexity, as well as from the patterns of land use which, combined with geomorphological variations, climatic differences, and its geographical position, have created conditions for the park to possess one of the highest levels of biological diversity in the country. The park also hosts natural vegetation of great national

and even global importance. Across much of its territory, it is possible to observe ecological processes operating in patterns very close to their natural state. All these values, exemplary in nature conservation, justify implementing appropriate protection measures for a territory that constitutes national and European heritage.

The policies outlined in the Montesinho Natural Park management plan reflect a profound commitment to preserving the region's natural values and rich cultural and architectural heritage. From a bioclimatic architecture and engineering perspective, these regulations guide sustainable and context-sensitive construction practices, ensuring that new interventions respect and enhance the unique character of the territory.

Article 2 of the plan establishes the objective of safeguarding and promoting cultural assets, including vernacular and erudite architectural heritage, which creates an essential foundation for bioclimatic intervention. Recognising the value of vernacular architecture not merely as an aesthetic artefact, but as an integrated response to the region's environmental, social, and material conditions, aligns with the principles of contemporary sustainable design. The conservation and valorisation of these structures safeguard bioclimatic strategies that have evolved organically over centuries, such as optimal orientation, thermal mass utilisation, and material synergies with the local microclimate.

Article 7 further reinforces this commitment by promoting actions to rehabilitate architectural heritage and improve the quality of new construction projects and infrastructure. From a bioclimatic standpoint, this mandate supports an architectural approach that seeks to preserve the past and reinterpret it intelligently, integrating modern ecological technologies in a way sympathetic to the traditional built environment. It also emphasises the importance of coherent urban planning within village clusters, reinforcing microclimatic advantages such as shelter from prevailing winds and the formation of favourable thermal environments.

Most critically, Article 32 establishes specific criteria for licensing buildings and infrastructures, ensuring that all interventions, particularly

outside urban perimeters, are subjected to rigorous evaluation by the Institute for Nature Conservation and Forests (ICNF). The requirement for architectural designs to harmoniously integrate with local vernacular patterns supports a low-impact, site-sensitive design methodology, a cornerstone of bioclimatic practice. Furthermore, the explicit protection of immovable cultural assets, particularly those of ethnological and vernacular character, underscores the necessity of conservation works that enhance usability without altering the fundamental character of structures. This principle ensures that traditional passive environmental strategies embedded within these buildings, such as thermal regulation through massive stone walls and natural ventilation through carefully placed openings, are maintained.

Additionally, the technical requirements imposed for project documentation—including detailed site plans, photographic surveys, and visual simulations of proposed changes—represent a robust mechanism to control and guide development, minimising environmental disruptions and ensuring that alterations are made with full awareness of their impact on the landscape and built heritage.

Finally, the specific provisions concerning boundary walls, particularly the emphasis on preserving or reconstructing dry-stone walls, reveal an appreciation for traditional landscape architecture elements that contribute to cultural identity and ecological stability, such as habitat continuity and erosion control.

According to MNP's co-management plan (Moreno et al. 2023), “the remarkable examples of vernacular architecture, using the characteristic materials of each region, are the result of thousands of years of refinement and adaptation to the environment. There are also purely functional aspects of vernacular architecture worth highlighting, such as dovecotes, mills, and the people's forges”.

Building Typologies

Vernacular constructions in the park can be divided mainly into residential, agricultural, and communal buildings.

Housing Buildings

The traditional residential buildings of the Trás-os-Montes region within the MNP exhibit a profound bioclimatic intelligence, rooted in the adaptation to the local climatic and material conditions. These buildings are typically organized into two or three floors, each assigned a specific function: the ground floor is reserved for animal shelters, cellars, and storage rooms, while the upper floors are dedicated to living spaces and, occasionally, additional storage. Internal vertical circulation is absent, with access to the main living quarters provided by an external staircase, reinforcing the separation of functions and enhancing thermal efficiency. A distinct feature is the external circulation and distribution at the level of the first floor, via a covered balcony or corridor, which also serves as a social space.

Heat production sources were traditionally limited to fireplaces and the natural warmth emitted by the animals housed on the ground floor. However, fireplaces often became points of significant heat loss due to inadequate control of roofing ventilation.

The façades are characterized by reduced fenestration, resulting in low levels of natural lighting indoors. This intentional design strategy minimizes heat loss during harsh winters and prevents overheating during the summer. Openings are preferably oriented between the south and west to maximize solar gains during the colder months. The structural walls, typically between 50 cm and 1 meter thick, are built using local stone masonry, mainly granite and schist, ensuring high thermal inertia and durability. Granite is also favoured for critical structural elements such as columns, stairs, and door thresholds. Wood, especially oak and chestnut, is used for flooring, roofing structures, doors, windows, and gates, combining strength with aesthetic warmth.

The roofs are built with wooden structures covered by ceramic tiles or slate, which, despite their charm, represent a thermally fragile component of the building envelope. Roofs usually extend beyond the building line to protect south-west facing balconies, optimizing solar exposure in winter while shielding from rain and snow.

The living areas, particularly bedrooms, are typically finished with wooden floors and partition walls, while kitchens often remain unlined, exposing the masonry and facilitating heat dissipation from cooking activities. The absence of thermal insulation in lightweight construction elements, such as partition walls and roofing, leads to significant thermal losses. However, the thick stone walls compensate with their substantial thermal mass, storing and slowly releasing heat.

Sanitary installations were originally non-existent, and were often incorporated later through adaptations. The interior ceiling height remains low, which is a deliberate strategy to reduce the air volume that needs heating. Bedrooms are compact, often internal, with small or no windows, further reducing thermal losses. They are usually clustered around the kitchen, the primary source of heat. The air renewal is naturally regulated through the permeability of materials and construction joints, contributing to lower indoor humidity levels. In his 1994 monograph, Carlos Guerra suggests the configuration of two facades for the traditional house in the Montesinho Natural Park (Figure 3).

These vernacular structures embody thermal mass, solar orientation, and functional zoning principles, offering valuable lessons in sustainable architecture adapted to climatic realities.

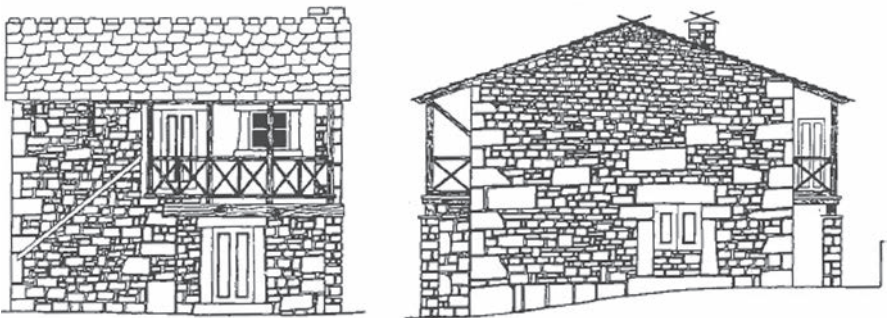


Figure 3. Facades (East and North) of typical houses in the Montesinho Natural Park (Guerra 1994)



Figure 4. Particular Oven



Figure 5. Particular Oven in Meixedo Village

Communal and Agricultural Buildings

In addition to houses, MNP's villages retain a variety of buildings essential to the local economy and community life:

- Blacksmiths and vegetable oil presses are small metalwork, olive oil, and wine production structures.
- Communal or particular ovens: used collectively for bread baking, reinforcing the communal spirit of the villages (Figure 4, Figure 5).
- Mills and dovecotes: mills powered by water (Figure 6) were crucial for grinding grain. Dovecotes, built from stone, played an essential role in food supply and soil fertilization.



Figure 6. Mill (França Village)

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Traditional construction materials and vernacular solutions in Montesinho Natural Park: A sustainable heritage

4



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Introduction

Vernacular architecture embodies a variety of characteristics specific to places where it originates from, with the use of local materials and techniques being one of its main features. Compared with industrially produced materials, traditional construction materials tend to have lower environmental impacts, making them a viable alternative for sustainable construction (Kirbaş et al. 2016; Fernandes et al. 2014).

Understanding each region's local materials and traditional construction techniques is essential for preserving the built vernacular heritage. In Montesinho Natural Park (MNP), traditional stone houses made from materials such as schist and granite illustrate how past generations adapted to the region's harsh climate. The phrase "nine months of winter and three of hell" is popular among the inhabitants of the Montesinho Natural Park, vividly captures the local climatic conditions.

Traditional Construction Materials

Local Stone Materials

The traditional architecture of the villages within the Montesinho Natural Park reveals a remarkable empirical understanding of local geological resources, reflected in the careful selection of construction

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materials over the centuries. Among the most widely used materials are schist and granite, whose abundance, physical-mechanical properties, and surface availability have significantly shaped the architectural solutions employed by rural communities in the region.

Schist, a foliated metamorphic rock, is primarily composed of micaceous minerals such as muscovite, biotite, and chlorite. It forms in contexts of regional metamorphism under high-pressure and high-temperature conditions. The typological diversity of schist arises from the variation in the original rock type and the degree of metamorphism it has undergone. The main types of schist and their characteristics include:

- Micaceous Schist – Rich in muscovite and biotite, exhibits a metallic sheen and marked foliation, allowing it to be split into thin layers.
- Chloritic Schist – Greenish tone, characterized by a high chlorite concentration, typically forming under low-grade metamorphic conditions.
- Graphitic Schist – Dark-colored with an oily texture, containing significant amounts of graphite, potentially suitable for industrial use.
- Garnet Schist – Contains garnet as an index mineral with a coarser texture and greater strength, typical of high-grade metamorphic environments.
- Talc Schist – Rich in talc, it is distinguishable by its soft, greasy texture, generally greyish or greenish.
- Hornblende Schist – Contains hornblende, characterized by dark tones and formation under medium- to high-grade metamorphic conditions.

The MNP is part of the Iberian Massif, featuring highly deformed and metamorphosed lithologies. Among these, the Schist-Greywacke Complex stands out, composed mainly of micaceous and chloritic schists, often associated with quartz and feldspar, and in zones of

higher metamorphism, garnet or graphite (Meireles et al. 2005). These schists are responsible for the rugged terrain and poor, acidic soils that define much of the Trás-os-Montes region landscape.

In areas where schist is dominant, the walls of traditional buildings were constructed using schist stone masonry and earth mortar with clay or lime. The colour and texture of the chloritic or micaceous schist strongly influence the aesthetic of façades, supporting the harmonious integration of buildings into the landscape of the MNP (Figure 1).



Figure 1. Influence of colour and texture of the chloritic or micaceous schist strongly in the aesthetic of façades

Granite, an intrusive igneous rock, is primarily composed of quartz, feldspar (orthoclase and plagioclase), and mica (biotite and muscovite) and may include accessory minerals such as hornblende and zircon. In the MNP territory, three granite massifs stand out, marking the edges of batholiths that extend significantly into the northwest Iberian Peninsula.

The most representative is located in the Serra da Gamoneda (in Spanish), where the village of Montesinho is located. This is a medium- to coarse-grained granite, rich in biotite and muscovite. Granitic

variants with a higher muscovite content have been identified near this village, giving the buildings lighter tones. The granites of the villages of Moimenta and Pinheiro Velho, although apparently distinct, belong to the same massif that extends into Spain (Meireles et al. 2005; POPNM 2008).

Compared to schist, granite is more geographically restricted within the MNP. The villages of Pinheiro Novo, Pinheiro Velho, Moimenta, Montesinho, and Soutelo are the main areas where granite has been widely used in traditional construction. Granite is valued for its compactness, durability, and mechanical strength. Its use is especially notable in: i) Exterior walls, built with large, irregularly placed blocks bonded with lime or earth mortar (Figure 2); ii) Retaining walls, often constructed in dry stone; iii) Structural elements such as door and window frames, staircases, and lintels, precisely carved from solid stone (Figure 2); iv) Interior features like fireplaces and chimneys, where granite's thermal resistance is particularly appreciated.

More than just a technical choice, the use of local stone represents a cultural expression. Schist, with its visual lightness and laminated



Figure 2. Exterior walls, window frames, staircases, lintels

texture, and granite, associated with strength and resilience, give buildings a distinctive rustic character. Both materials also contribute to the thermal efficiency of dwellings due to their high thermal inertia, playing a crucial role in the passive sustainability of traditional construction (Vaz et al. 2025; Vaz et al. 2013).

Stone Masonry Walls

Stone has long been the main material used in traditional construction in the Montesinho region, especially for walls, and it is valued for its abundance, durability, and natural integration into the landscape. Granite and schist are used in thick exterior walls, providing structural support and significantly contributing to thermal inertia (the thermal inertia of stone helps regulate indoor temperatures, keeping interiors cool in summer and retaining heat in winter). The result is that walls generally have one or two-leaf stone in their cross-section (Figure 3). When granite is used, the walls are made of irregular stones laid in mortar, and the hardest-looking stones are chosen to form the facings, which are dressed on one side, known as dressed stone masonry/rustic dressed stone (Casella 2003). Shale is easier to extract and work, resulting in irregular units of stone that overlap and are successively laid with mortar. Depending on the geological type of the shale rock

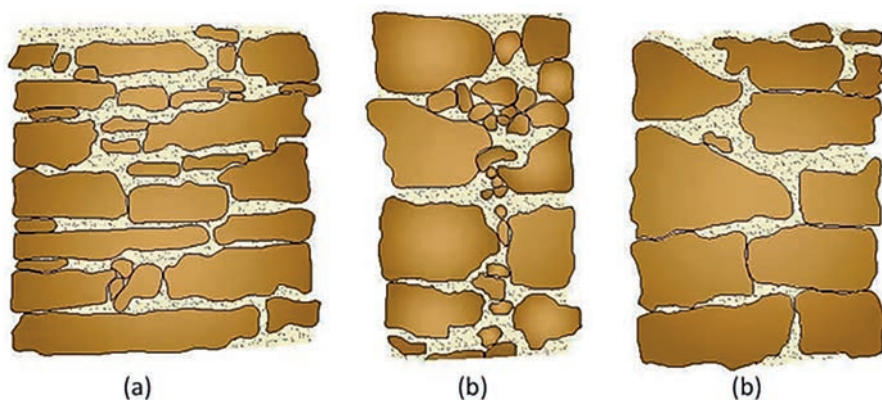


Figure 3. Cross-section typology of: (a) single-leaf walls; (b) two-leaf walls [8]



Figure 4. Schist and granite masonry walls details, in França and Montesinho villages

(already referred to in 2.1), the appearance of ordinary masonry can vary considerably (Figure 4).

Dry-stone masonry, a traditional building technique employed throughout the region, further exemplifies the craftsmanship associated with stone construction (Luso 2020). This method, which requires no mortar, relies on the precise fitting and balance of individual stones to achieve structural stability (Figure 5).



Figure 5. Fencing walls, mills and presses where the dry masonry technique is employed

Once again, in his 1994 monograph, Carlos Guerra (Guerra 1994) shows the zones of MNP where granite or schist masonry walls are used for the traditional house in the Montesinho Natural Park (Figure 6).

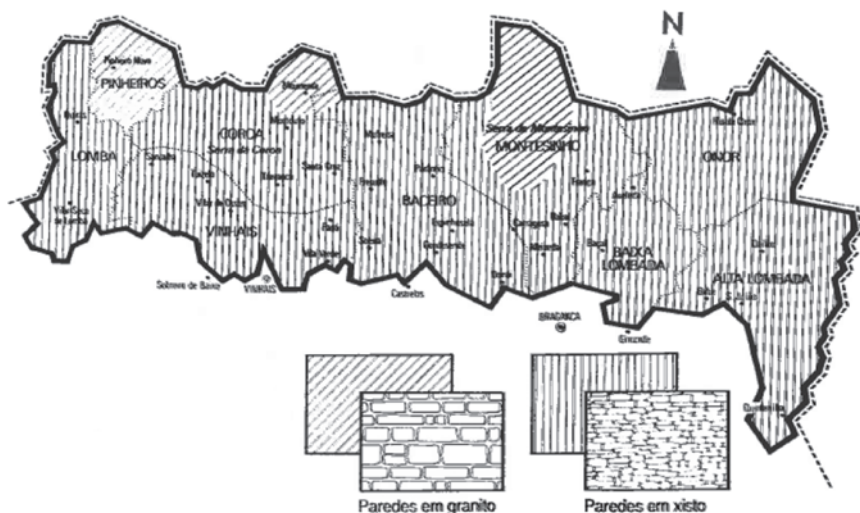





Figure 6. Characteristic materials of each MNP zone and respective masonry walls (Guerra 1994)

A key advantage of stone construction lies in its thermal inertia, constituting an essential bioclimatic solution in the region. Stone materials help moderate indoor temperatures by absorbing heat during the day and releasing it slowly at night, keeping interiors cooler in the summer and retaining warmth during the winter months. This passive thermal regulation significantly enhances traditional dwellings' comfort and energy efficiency.

In summary, Table 1 describes the use of schist and granite in the 13 villages studied by the INHAVIT Project (Arias Tapiero et al. 2024), in roofing and masonry walls.

Table 1. Use of granite in walls and roofs

	Roofing	Masonry Walls	Example
Aveleda, Guadramil, Rio de Onor	Schist	Schist	
Cova de Lua, Gimonde, Labiados, Moimenta, Montouto, Pinheiro Velho, Pinheiro Novo, Quintanilha, Sandim	Ceramic	Schist	
Montesinho	Schist	Granite	

Slate and Ceramic Tile Roofing

The roofing solutions of traditional buildings in Montesinho Natural Park were also adapted to the locally available resources. In areas where schist is abundant, roofs were built with overlapping stone slabs obtained through the foliation of schist (slate) – a technique of ancestral origin (Figure 7). This material created a naturally waterproof and fire-resistant covering, offering excellent performance against rain and wind.

In other localities, ceramic roofs were gradually introduced and are now more common. They are generally characterized by curved barrel tiles, which provide greater flexibility and represent a lighter alternative to stone slabs without compromising traditional aesthetics or thermal



Figure 7. Slate Roofing in Montesinho Natural Park

efficiency. This type of tile is part of a roofing system widely used in rural and historic architecture (Figure 8).

Villages such as Aveleda, Quadramil, Montesinho, and Rio de Onor predominantly use slate due to the proximity of schist outcrops (Geoportal LNEG 2025).



Figure 8. Ceramic/clay Roofing

In contrast, in villages near Bragança and Vinhais, ceramic tiles are more common for roofing (Figure 9). In some cases, such as in Moimenta and Montouto, slate and ceramic tiles coexist in the same building, reflecting external influences and more recent adaptations (Guerra 1994).

The recovery and valorization of the slate roofing technique have been encouraged in contemporary heritage rehabilitation projects (see chapter “Recommendations of retrofitting solutions for the vernacular built heritage of Montesinho Natural Park”). Moreover, in current



Figure 9. Aerial image of the village plan with different use of roofs, shale-ceramic (Google Earth 2025)

construction and rehabilitation works, its implementation is required by urban planning regulations. However, this type of work generally demands longer execution times and specialized labour compared to ceramic tile roofing. The urban planning restrictions imposed by the municipalities aim to protect and safeguard the vernacular architectural heritage. Thus, municipal regulations play a fundamental role in the restoration and maintenance of schist roofs.

The Montesinho Natural Park encompasses the northern parts of the municipalities of Bragança and Vinhais. The Regulatory Code of the Municipality of Bragança (in Portuguese “Plano Diretor Municipal” (ICN 2007) refers to roofing in the following terms: “In clusters of interest, identified in the Municipal Master Plan and not covered by a detailed plan, buildings must comply with the following conditions: (a) In the villages of Montesinho and Rio de Onor, roofs must be pitched and clad with black slate from the region” (ICN 2007).

Therefore, there is a legal obligation imposed by the municipal regulations of Bragança requiring the construction of pitched roofs covered with local black schist in the villages of Montesinho and Rio de Onor, with the aim of “protecting clusters of architectural, environmental, historical, or ethnological interest and preserving the homogeneous aspects of their image and the profile of the landscape” (ICN 2007).

On the other hand, the municipality of Vinhais does not impose the use of schist roofing, either in new constructions or in interventions for repairing or maintaining pre-existing buildings.

Carlos Guerra (Guerra 1994) shows the zones of MNP where ceramic, schist or both must be used on traditional houses in the Montesinho Natural Park, continuing as an actual reference for rehabilitation interventions of MNP's buildings (Figure 10).

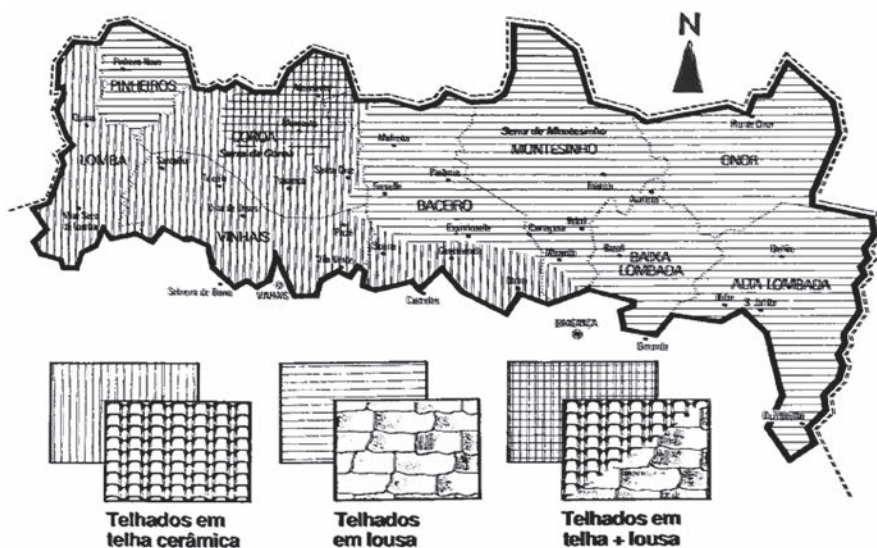


Figure 10. Characteristic materials of each MNP zone and Roofing style (Guerra 1994)

Wood and Timber Structures

Wood plays a fundamental role in the traditional architecture of Montesinho Natural Park, where it has been widely used for structural elements, roofing, and interior/exterior details. The region's vernacular buildings reflect an efficient use of locally available wood, primarily chestnut and oak, which are valued for their durability and resistance to harsh weather conditions.

From the perspective of sustainable construction and bioclimatic architecture, the use of wood in the traditional buildings of the

Montesinho region exemplifies an intelligent and context-responsive approach to material selection. Timber, sourced primarily from native oak (Figure 11) and chestnut forests, is not merely a structural element but a key contributor to the overall environmental performance and resilience of the built environment.

Chestnut and oak beams and rafters are strategically employed to support upper floors and roofing systems, taking advantage of their natural durability, load-bearing capacity, and resistance to biological degradation. The selection of chestnut wood, known for its inherent resistance to moisture and pests, is particularly significant in ensuring the longevity of exposed elements such as balconies and external staircases, which must withstand variable climatic conditions without compromising structural integrity.

Beyond their structural function, wooden components enhance the bioclimatic performance of buildings. The use of timber in doors, windows, and interior partitions provides additional insulation,



Figure 11. Oak landscape

improving thermal comfort and energy efficiency by regulating indoor temperatures and reducing heat loss. Furthermore, wood introduces a degree of flexibility and modularity to interior spaces, enabling adaptive reuse over time and contributing to the building's lifecycle sustainability.

The integration of wood into these traditional constructions also reflects a deep environmental consciousness, rooted in the sustainable management of local natural resources. By selecting materials that are both locally available and renewable, traditional builders inherently minimized the environmental footprint of construction, minimizing embodied energy, maximizing resource efficiency, and promoting harmony between built form and natural environment.

The use of timber emphasizes a material connection to the surrounding forested landscapes. This close relationship between material selection and environmental conditions exemplifies the sustainability and ingenuity inherent in the region's vernacular architecture.

One of the most common applications of timber in Montesinho's traditional constructions is in roof frameworks. Wooden beams and trusses provide structural support for slate or thatched roofs, ensuring both stability and insulation.

The structures that support the roof are made of wood, varying wildly in complexity as they depend on the span and often do not comply with pre-established regulatory structures. An element that could not be missing is the purlin or purlins, a wooden trunk taken directly from the tree trunk without cutting or treatment, often without the support of a traditional wooden trellis. Thus, in the simplest cases and with small spans, the purlins discharge directly onto the stone masonry walls, and, specifically, in the case of larger roofs and/or with more than two slopes, there are lattice structures with joint or metal connections.

Additionally, timber is frequently used in balconies, porches, and window frames, adding both functional and aesthetic value to rural homes (Figure 12, Figure 13, Figure 14).

Beyond its structural function, wood contributes to the thermal comfort of buildings. Wooden floors and ceilings help regulate indoor temperatures by providing insulation during cold winters. Furthermore,



Figure 12. Balconies, porches, and window frames



Figure 13. Timber in windows, doors and frames



Figure 14. Timber in windows

when used in flooring, supported by joists, and in ceilings beneath the roof structure, wood facilitates air circulation, preventing condensation, avoiding rising dampness, and enhancing interior comfort. This natural ventilation also helps prevent wood decay, extending the lifespan of the construction elements. This passive design strategy showcases how vernacular architecture naturally integrates with the environment.






Plaster and Joint Mortars

The mortars play a crucial role in both structural integrity and aesthetic finish. Most residential buildings use joint mortars for binding stones in masonry walls; however, only some use plaster mortars for coating and protecting walls. Joint mortars are essential for the stability of stone masonry structures because they ensure the bonding of the stones, allowing for slight flexibility and preventing cracks due to natural ground movements. Plaster mortars are utilized to coat interior and exterior walls, serving protective and decorative purposes. Exterior plasters protect the stone walls from weathering, while interior coatings help maintain thermal comfort by enhancing insulation.

In traditional architecture, the mortars primarily comprise locally sourced lime, sand, and clay, reflecting the region's sustainable building practices. Within the scope of the INHAVIT project, a series of "in-situ" and laboratory test campaigns were carried out in ten villages of MNP, which allowed a better understanding of these construction elements. For example, Table 2 show the results for building GM2 in Guadramil.

Traditionally, walls were built using stones bound with lime and earth-based mortar, allowing the materials to "breathe" and preventing moisture-related issues. Over time, the introduction of Portland cement in some constructions disrupted this natural respiration, leading to deterioration in certain buildings. Some agricultural structures, such as boundary walls and animal shelters, were built without mortar (dry stone construction, Figure 5), relying on precisely placed stones to ensure stability.

Table 2. Results for GM2 Building in Guadramil Village

	“In-situ” Non-Destructive Tests			Laboratory Tests
	Penetrometer	Scratch	Pendulum hammer	Compressive Test
				
	Mechanical Strength [MPa]	Durability	Classification	Comp. Strength [MPa]
	<0,4	Poor	Very Soft hardness	0,94

The Production of Lime in MNP

The known lime kilns in the region are located in Dine and Cova de Lua. Although schists, granites and metasediments dominate the Montesinho Natural Park, small limestone/calclitic outcrops are located in the Cova de Lua Zone, near Dine and the Espinhosela Zone (Figure 15,



Figure 15. Location of the lime kilns of Espinhosela, Cova de Lua and Dine, in the Montesinho Natural Park



Figure 16. Dine and Cova da Lua lime kilns

Figure 16). The kilns are rudimentary constructions in stone, generally schist, often excavated in hillsides. The limestone was fired at high temperatures (around 900 to 1000 °C) to produce quicklime, using firewood or pine needles as fuel.

In addition to the use of lime for both laying mortar and plastering, its use was more diverse, for example, in whitewashing houses, disinfecting stables and corrals and as an agricultural corrective for acidic soils.

Chemical tests carried out at the University of Minho using thermogravimetry (TGA) equipment allowed the analysis of mass variation in relation to temperature variation of mortar samples from ten villages (Figure 17, Figure 18). These tests concluded that most samples present lime as calcium hydroxide ($\text{Ca}(\text{OH})_2$) and/or calcium carbonate (CaCO_3), indicating that lime is the most common base material used to produce render and joint mortars in MNP.

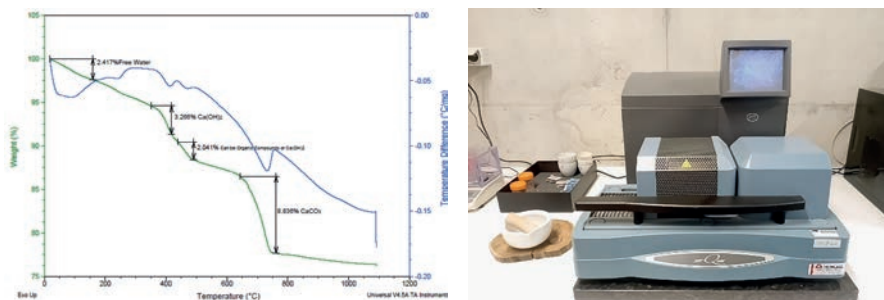


Figure 17. Graphic results for Montesinho mortar sample and TGA equipment

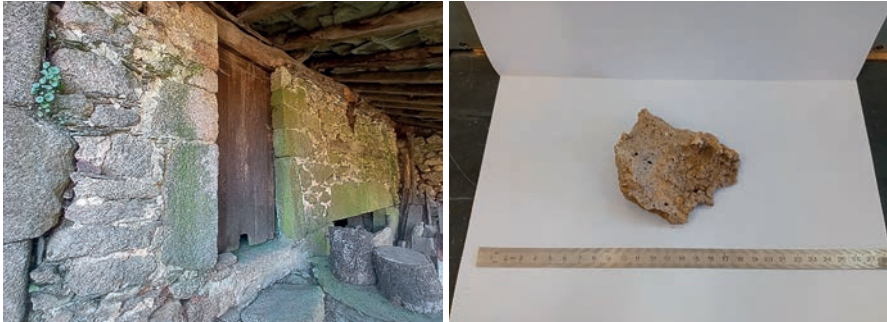


Figure 18. Tested Mortar of the Montesinho Building

Vernacular Architectural Solutions

Montesinho Natural Park is a remarkable example of architectural adaptation to the environment, where passive bioclimatic strategies and vernacular construction techniques play a fundamental role in the sustainability of buildings. Passive bioclimatic strategies are essential to ensure thermal comfort and energy efficiency without the use of active (mechanical) systems. The main Montesinho Natural Park's passive approaches are listed below.

The use of Local and Natural Materials

In Montesinho's vernacular architecture, the strategic use of locally sourced materials as a means to reduce environmental impact and enhance ecological integration is clearly manifested: schist and granite, abundantly available in the region, are the primary materials employed for walls and foundations. Chestnut and oak timber are used for roof structures and interior flooring. This selection not only reduces transportation-related emissions but also optimizes the building's thermal performance, contributing to enhanced indoor comfort across seasonal variations.

Thermal Insulation and High Thermal Mass

The thick stone masonry walls function as highly efficient thermal masses (with high thermal inertia). These walls absorb and store solar

heat during the day and release it gradually during cooler night periods, mitigating temperature fluctuations in summer and enhancing heat retention during winter. This significant thermal inertia stabilizes indoor thermal conditions, reducing reliance on active heating and cooling systems.

Optimized Site Planning and Solar Orientation

A core principle of bioconstruction is the optimization of building siting and orientation to maximize passive solar gains in winter and minimize solar direct exposure (heat gains) in summer. Montesinho's vernacular settlements exhibit this principle through the predominant south/southeast orientation of dwellings, minimizing northern exposure to cold prevailing winds. In compact urban layouts, buildings are clustered to optimize mutual thermal protection and the creation of favorable microclimates.

Solar Control and Shading Strategies

Effective shading is critical for achieving passive thermal comfort. In Montesinho, this is realized through pronounced eaves on pitched roofs, which prevent excessive solar radiation during summer months while allowing lower-angle winter sun to penetrate and warm interior spaces. This bioclimatic strategy is further complemented by the strategic use of vegetation to provide natural shading for exterior spaces. Also, elements such as eaves and stone walls help protect buildings from cold winds and excessive solar radiation.

Natural Cross Ventilation

Facilitating natural ventilation – the arrangement of openings to promote natural airflow, reducing the need for artificial climate control – is essential for passive cooling strategies. Traditional dwellings in Montesinho incorporate carefully positioned openings that promote effective cross ventilation, enhancing indoor thermal comfort during the warmer months. Additionally, the use of smaller window openings contributes to minimizing heat loss during the colder season.

Functional Integration and Community Resilience

The vernacular typologies of the region integrate multifunctional spaces—barns, animal shelters, and storage areas are often incorporated into residential buildings. This spatial organization optimizes the use of thermal energy (benefiting from heat produced by animals and stored biomass) and resource efficiency, resulting in enhanced environmental and economic resilience for local communities. Such an integrated approach aligns with the principles of sustainable and regenerative design.

Vegetative roofs and natural materials

Some buildings use vegetation-covered roofs or materials such as straw to enhance thermal insulation.

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Assessing the vernacular built heritage of Montesinho Natural Park: An ICT-enhanced survey methodology

5



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Introduction

Vernacular architecture stands as a physical manifestation of human resilience, reflecting a community's cultural identity and centuries of adaptation to local environments. Built using locally sourced materials and traditional techniques passed down through generations, these community-built structures embody invaluable knowledge of sustainable building practices, climate adaptation, and social customs (Fig. 1).

However, this architecture is threatened by global cultural and socioeconomic homogenization, leading to the adoption of industrial materials and techniques. This replacement of traditional construction methods and materials results in a progressive loss of local knowledge and skills, eroding both the physical structures and the intangible knowledge they represent. Vernacular buildings are particularly vulnerable to these issues, since they must also face challenges of obsolescence, internal balance and integration (ICOMOS, 1999). Consequently, many rural communities struggle to maintain and conserve their vernacular heritage, a challenge intensified in recent

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Figure 1. Vernacular settlement in MNP: Rio de Onor village



Figure 2. Vernacular architecture in the MNP: Montesinho Village

decades by rural depopulation linked to the decline of primary sector activities like agricultural production.

The Montesinho Natural Park (MNP) in Portugal, a 75,000-hectare area bordering Spain in the Trás-os-Montes region, is no stranger to these challenges. Its 88 villages, home to roughly 6,000 people (Comissão

de Cogestão, 2023), boast a rich vernacular heritage, with buildings constructed from locally available materials like stone, wood, and earth using traditional building techniques (Fig. 2). The MNP's vernacular buildings consists mainly of rural dwellings and small buildings used to support agriculture and livestock activities. These buildings are characterized by simple forms, stone masonry walls in granite or schist, exterior staircases, and slate roofs. Chestnut and oak were used for floors, balconies, and non-structural elements such as doors, windows, and balustrades. The stone walls were constructed using dry-stone, a building technique recognized by UNESCO as Intangible Cultural Heritage (UNESCO Intangible Cultural Heritage, 2024).

At present, these villages are undergoing a mischaracterization process that prioritizes modern architectural trends and industrial materials over traditional ones (Fig. 3). Furthermore, census data reveals that MNP's population has declined over the past few decades and continues to fall, with settlements experiencing abandonment due to an aging resident population and out-migration to urban and industrial centers.

Given this context, a primary activity within the INHAVIT project was to inventory the existing built heritage within the MNP villages. This



Figure 3. Mischaracterization process: Varge Village

inventory proved crucial for understanding the preservation status of the MNP's vernacular built heritage and the extent of abandonment of the park's villages. Furthermore, it provided a basis for developing project objectives, resulting in a comprehensive database that supported further activities such as characterizing the rural built heritage, assessing social and physical vulnerabilities, evaluating energy performance, and guiding conservation proposals. This inventory serves as a valuable record and constitutes an important resource for researchers, local authorities, and the communities.

An ICT-Enhanced Methodology

To inventory and characterize the vernacular built heritage of the extensive MNP region, a methodology was defined for regional-scale application. This methodology integrates accessible and low-cost Information and Communication Technologies (ICT) to facilitate data collection, processing, and spatial analysis, enabling the rapid and scalable documentation of large numbers of vernacular buildings across rural areas.

The methodology consisted basically in documenting the vernacular built heritage of selected villages within the MNP through a survey campaign. This involved using mobile devices to record the buildings and a GIS system to process the data (Fig 4). The approach relies on rapid, non-invasive visual assessment to gather data on building conditions including materials, interventions, current use and habitability. The methodology was designed for implementation in three phases, that are described as follows:

- **Phase I – Preliminary Work:** This initial phase focused on understanding the study area and planning the data collection campaign. It involved systematic review of literature on local architectural traditions, history, and geography, alongside the analysis of maps, photographs, and historical documents. The outcomes of this phase included establishing the inventory objectives, planning fieldwork itineraries (specifically, village

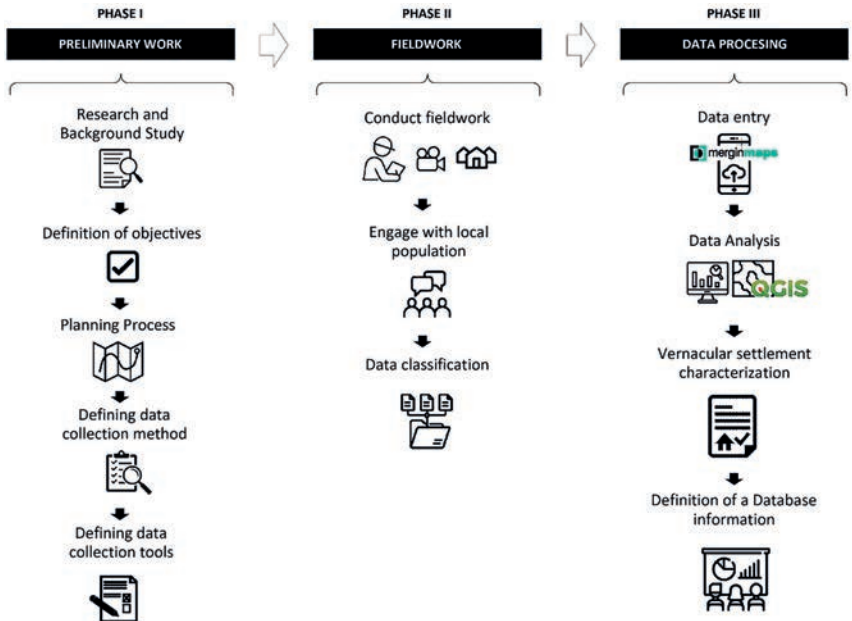


Figure 4. Methodology implemented. Source: (Arias Tapiero et al., 2024)

selection for inventory) and the design of a tailored survey form. This phase also involved selecting digital tools and software; therefore, it was determined that survey forms would be customized using QGIS and Mergin Maps, a mobile GIS application for data collection.

- **Phase II – Fieldwork:** The second phase involved the on-site visual documentation of MNP vernacular buildings using mobile devices such as smartphones and cameras. Following the established itineraries, videos and photographs were collected in each village visited. Each building was geolocated and assigned a unique code. Informal interviews with local residents provided valuable contextual information, enriching the survey process. All data were stored in the cloud via the Mergin Maps application, facilitating team collaboration.

- **Phase III – Data Processing:** In the final phase, the visual data collected in the field were processed and entered into the digital survey forms developed in Phase I. This involved reviewing the photos and videos, completing attribute fields (e.g., materials, use, conservation status), and correcting building geometric layouts on digital plans. The data were then integrated into a GIS database for spatial analysis. This facilitated the characterization of the MNP built environment by identifying typological patterns, conservation needs, most recurrent interventions and regional constructive trends.

Inventory Results

The methodology was implemented in 13 villages within the MNP. The villages were selected after an initial visit to the park, prioritizing those with a significant number of vernacular buildings. The selected villages are situated throughout the park, built with both schist and granite. Comprising around 15% of MNP's total of 88 villages, these settlements represent the park's diverse architectural heritage. The surveyed villages are within the jurisdiction of Bragança and Vinhais municipalities. Bragança comprises the villages of Gimonde, Quintanilha, Guadramil, Rio de Onor, Labiados, Montesinho, Aveleda and Cova da Lua, whereas Moimenta, Montouto, Pinheiro Velho, Pinheiro Novo and Sandim are part of Vinhais.

An extensive survey of over 2000 buildings, encompassing more than 20,000 entries, provided a general assessment of the park's built heritage. This data yielded insights into various aspects of the park's current condition, including structural systems, construction materials, number of floors, openings, type of use, occupancy status, conservation level, architectural condition, interventions, and façade typology. It is important to note, however, that the inspection was conducted solely from the exterior of the buildings. This limitation hindered the evaluation of the structural systems, state of conservation, and occupancy status;

nonetheless, it allowed for a characterization of the MNP villages' built environment and their extent of abandonment.

Building classification

The buildings were characterized into five principal categories: Unaltered vernacular buildings, Vernacular buildings restored without dissonances, Vernacular buildings restored with dissonances, vernacular buildings with foreign influences and Non-vernacular buildings (Fig. 5). Granite masonry buildings are more prevalent in northern villages such as Pinheiro Novo, Pinheiro Velho, Moimenta, and Montesinho, while schist is the dominant building material in the remaining villages. This study revealed a significant concentration of Non-vernacular buildings in villages near the city of Bragança such as Gimonde, Labiados, and

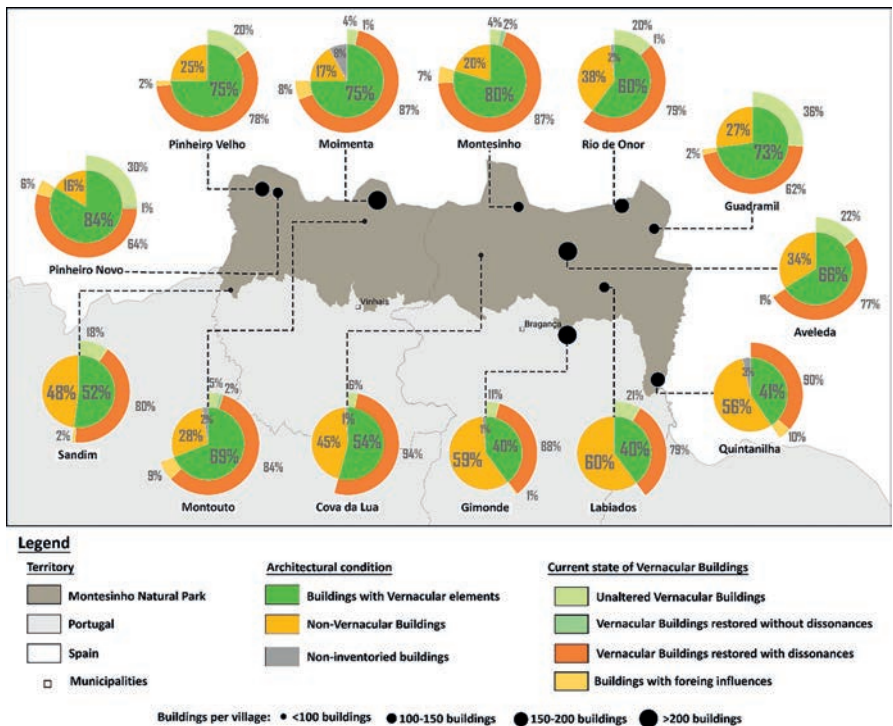


Figure 5. MNP built environment characterization. Source: (Arias Tapiero et al., 2024)

Quintanilha. Conversely, villages within the park’s interior and near the Spanish border show higher percentages of vernacular features. Finally, compared to Bragança municipality, the villages in the municipality of Vinhais display a greater proportion of vernacular constructions.

Recurrent interventions

The results showed that substituting slate roof material is the most prevalent intervention, as it was observed in 32% of the vernacular buildings surveyed (Fig. 6). This was followed by the substitution of traditional windows and doors with non-traditional materials (20%), probably to improve thermal performance and indoor comfort. Other common alterations included filling masonry joints with cement-based mortars (15%), adding concrete structural elements (13%), and undertaking volume reconstructions (16%). Less frequent, but still significant, was the complete replacement of traditional roof structures with concrete slabs (4%). While often driven by functional needs, these interventions risk compromising the buildings’ structural integrity and their authenticity. In conclusion, these findings suggest that while some upgrades may enhance durability, they also contribute to the loss of the unique heritage character of the region’s vernacular architecture.

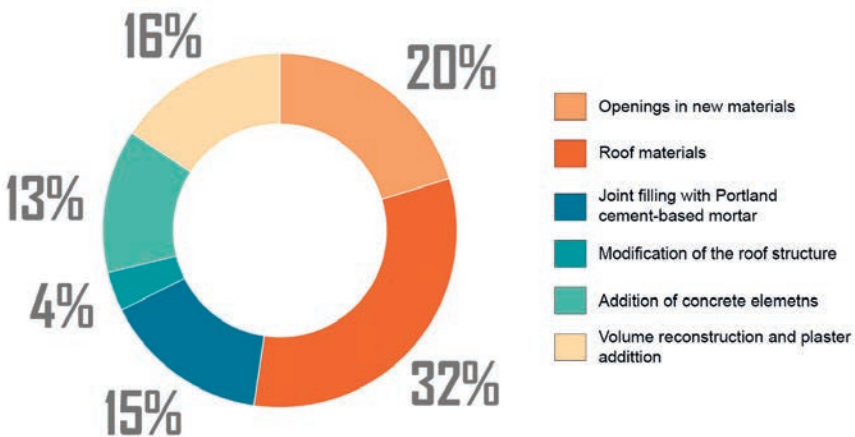


Figure 6. Interventions in the MNP vernacular buildings. Source: (Arias Tapiero et al., 2024)

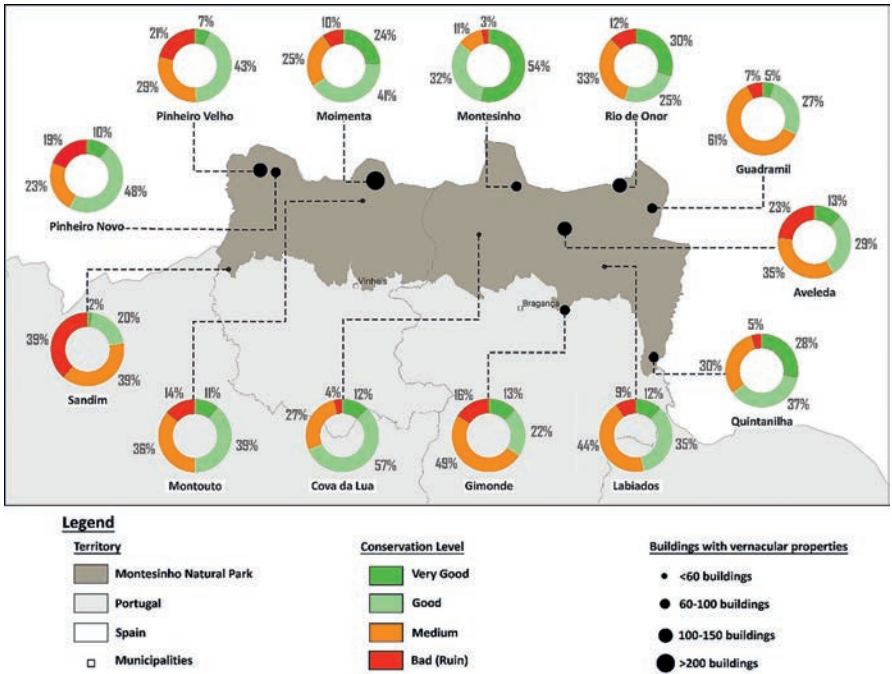


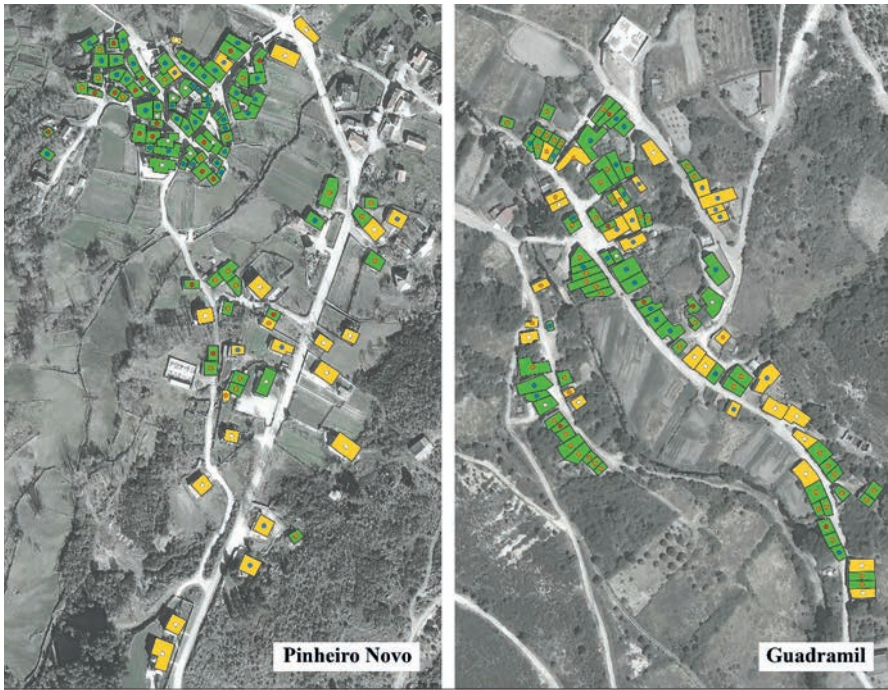
Figure 7. MNP vernacular building conservation level. Source: (Arias Tapiero et al., 2024)

Conservation Level

To assess the conservation level of the vernacular buildings in the surveyed MNP villages, each building was categorized as very good, good, medium, or bad (ruin). This was done using criteria such as structural integrity, visible decay and non-structural elements damage. Results show significant variation between villages. Northern border villages (near Spain) have a high proportion of well-preserved buildings (Fig. 7). Conversely, the most depopulated settlements show extensive decay, with many buildings severely damaged or in ruins.

GIS Analysis

Integrating collected architectural data into a Geographic Information System (GIS) offered significant analytical advantages (Fig. 8). Mapping surveyed buildings and linking them to attributes like architectural




Architectural Condition

 Buildings with Vernacular Elements

 Non-Vernacular Buildings

Conservation Level

 Very Good

 Good

 Medium

 Bad

Figure 8. Correlation between the architectural condition and the conservation level for Pinheiro Novo and Guadramil. Source: (Arias Tapiero et al., 2024)

condition and conservation status enabled spatial visualization and comparison across villages. For example, Pinheiro Novo's vernacular buildings are concentrated in the historical core, exhibiting varied but generally good conservation levels. Non-vernacular buildings and altered structures lay on the periphery. Guadramil's layout remains largely unchanged, with few non-vernacular buildings; conservation levels showed no clear spatial pattern, except for better maintenance among the buildings located in the main street. GIS tools revealed these spatial trends, illustrating the distribution of heritage preservation and

degradation within the settlements. This spatial perspective improves understanding of the villages architecture configuration and may support planning and conservation efforts.

Correlation between village transformation and abandonment

Two indices were introduced to analyze the relationship between the vernacular built environment transformation and depopulation in the MNP villages: the Village Transformation Index (VTI) and the Level of Abandonment (LoA). The VTI quantifies the proportion of non-vernacular or altered vernacular buildings within each village, while the LoA reflects the percentage of abandoned buildings. Results revealed a clear inverse correlation: villages with higher transformation levels tend to exhibit lower abandonment rates (Fig. 9). This suggests that the village transformation processes, while compromising architectural authenticity, reduce abandonment rates, potentially preventing complete abandonment. These findings highlight the complex balance between preserving the building's authenticity and ensuring the continued occupation and sustainability of rural heritage settlements.

This transformation process can be partly explained by the distance of villages from major administrative cities like Bragança and Vinhais. Villages on the northern border with Spain, however, show a higher

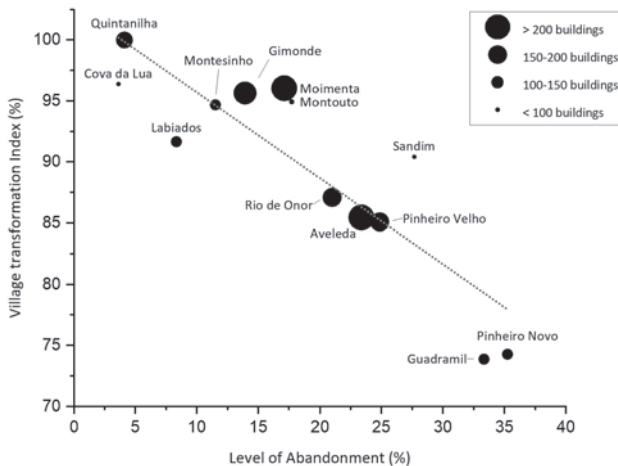


Figure 9
Correlation between the Village Transformation Index (VTI) and the abandonment of selected villages in the MNP. Source: (Arias Tapiero et al., 2024)

percentage of vernacular buildings. This difference arises because proximity to cities reduces commuting time, encouraging settlement and the subsequent adaptation of buildings to higher habitability standards. Socioeconomically, villagers near urban areas, often seeking better employment, may have the resources to build larger, more comfortable, and thermally efficient homes reflecting their lifestyles. Furthermore, the social perception of new, modern buildings as symbols of affluence and prosperity likely persists as a significant motivating factor.

Final remarks

The findings indicate that many MNP villages are experiencing a significant loss of architectural authenticity, resulting in the loss of both tangible and intangible cultural values associated with traditional construction techniques and craftsmanship. Although most villages retain a high percentage of vernacular buildings, the majority of these buildings show dissonant interventions, diminishing their heritage value, authenticity, and integrity. However, some villages, such as Pinheiro Novo, Pinheiro Velho, Guadramil, and Rio de Onor, still preserve a significant number of unaltered vernacular buildings. While most MNP buildings retain their original residential function, a considerable number now serve as seasonal or holiday residences. Therefore, effective conservation strategies must address the complex challenge of improving living conditions in these vernacular settlements while simultaneously preserving their architectural authenticity and heritage values.

This methodology integrates various information and communication technologies (ICTs) to create a GIS-based database. Its relative simplicity requires minimal technological capital and skill investment, yet it yields preliminary findings from extensive data across large areas. Furthermore, its flexibility allows integration with other data recording methods, such as photogrammetric surveys and deep learning algorithms.

Acknowledgments

This work was financed with national funds through the Portuguese funding agency, FCT - Fundação para a Ciência e a Tecnologia, within the INHAVIT project (<https://doi.org/10.54499/MTS/BRB/0086/2020>), the PhD scholarship 2021.07522.BD of the first author (<https://doi.org/10.54499/2021.07522.BD>) and the scholarship BI/DECivil/INHAVIT granted by University of Aveiro.

This work has also been supported by the FCT / MCTES through national funds (PIDDAC) under the R&D Unit Institute for Sustainability and Innovation in Structural Engineering (ISISE), under reference UIDB/04029/2020 (<https://doi.org/10.54499/UIDB/04029/2020>), and under the Associated Laboratory of Advanced Production and Intelligent Systems ARISE under reference LA/P/0112/2020.

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6 Documenting the Montesinho Natural Park vernacular architecture: Photogrammetry as a tool for management and preservation

6



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Introduction

In recent decades, digital technologies have opened new perspectives for studying, preserving, and disseminating cultural heritage. Among these, photogrammetry—a technique that generates 3D digital models from 2D photographs—has become widely used for its versatile documentation capabilities. This technique, combining precision and visual representation, enables the creation of highly accurate models of historical sites, buildings, and landscapes. Within the INHAVIT project, it was used to document representative villages in the Montesinho Natural Park (MNP) as part of the project's built environment characterization research.

Pinheiro Novo, Guadramil, Moimenta, and Montesinho were selected for documentation based on inventory findings and a systematic evaluation of the built environment within 13 vernacular settlements in the MNP presented in the previous chapter. These four settlements were chosen for their high degree of integrity and authenticity, reflecting the best preservation of local architectural styles, materials, and cultural practices integrated into their natural settings. They have retained not

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only their traditional construction techniques and materials that define vernacular architecture in the region, but also the spatial organization and morphological features. This makes their documentation especially valuable. The photogrammetric survey, focusing on exemplary cases, aimed to highlight the significance of the local building culture and the urgent need for its preservation amidst ongoing development. Ultimately, by using digital tools to visualize and explore this unique architectural heritage, the INHAVIT project aims to foster greater understanding and collaboration in scientific research, community engagement, policy regulations and heritage preservation.

Processing the 3D models

The villages were surveyed using an Unmanned Aerial Vehicle (UAV), commonly known as a drone. This device was equipped with an RTK module for centimetre-level GPS accuracy and precise mapping. To further enhance the accuracy of the photogrammetric survey, several ground control points (GCPs) were established across each village using a GPS rover. The coordinates of these GCPs, recorded in the Portuguese geodetic system (ETRS89, EPSG:3763), provided real-world reference points for integrating the resulting 3D village models with other maps and GIS tools. High-resolution aerial photographs of the settlements were taken with 80% overlap to ensure multiple angles were captured. This approach allowed to cover the entire settlements, including rooftops, buildings, streets, and surrounding landscapes. These images were then processed using standard photogrammetric techniques and software to create 3D models of the villages. The resulting models are shown in Figures 1-4.

The aerial survey of Pinheiro Novo was complemented by a terrestrial survey to enhance the quality and detail of the resulting 3D model. Among the MNP villages, the analysis of the inventory data indicates that Pinheiro Novo has better preserved its vernacular character. This village, therefore, provides a richer basis for digital documentation. Given the vulnerability of the MNP vernacular architecture and the

high risk of its loss due to ongoing mischaracterization processes, prioritizing Pinheiro Novo ensures more accurate documentation of a greater number of vernacular buildings.

The resulting high-detail 3D digital model of Pinheiro Novo contained 700 million polygons. This extreme detail, however, posed significant



Figure 1. 3D photogrammetric model: Pinheiro Novo



Figure 2. 3D photogrammetric model: Guadramil



Figure 3. 3D photogrammetric model: Montesinho



Figure 4. 3D photogrammetric model: Moimenta

computational challenges, often exceeding the capacity of standard visualization software. To improve usability, the model was decimated to 46 million polygons, while maintaining visual realism and precision through 1-centimeter-per-pixel texturing (Fig. 5).

A reduced-polygon model (approximately 1 million polygons), is available in the following link to facilitate dissemination:

<https://skfb.ly/pyowL>

These digital representations, created through photogrammetry, serve both scientific and heritage purposes. They constitute valuable digital records of each settlement's current state, contributing significantly to the MNP cultural heritage documentation. The models facilitate the monitoring of changes over time, allowing for comparisons that reveal gradual deterioration or alterations due to environmental factors or human activity. This permanent archive of the MNP vernacular architecture, potentially at risk from abandonment, neglect, or physical alterations, can guide future conservation and restoration efforts. Furthermore, the resulting 3D models can be integrated into interactive virtual tours and online platforms, facilitating dissemination and raising awareness of the MNP settlements' cultural significance, and extending their value to education and public engagement. Finally, this spatial documentation could also support planning and management activities, helping to balance heritage preservation with sustainable development.



Figure 5. Pinheiro Novo: High-detail 3D model

A digital management solution

The extensive data derived from the MNP villages' inventory presented in the previous chapter, combined with the villages' 3D models, resulted in the development of a prototype application to support management activities. The main concept involved integrating the inventory data with the 3D models of the village buildings within a Game Engine. Pinheiro Novo was selected as the appropriate case study for implementation. Conceived as an immersive and interactive virtual experience, the application prioritizes intuitive navigation and clear data visualization to document and manage Pinheiro Novo's vernacular built heritage. Offering user-friendly tools, the application allows for dynamic exploration of the village from a realistic pedestrian perspective. Users can virtually examine architectural features, landscape, and urban organization—including street patterns, public spaces, and building distribution—gaining a comprehensive understanding of the village's spatial layout (Fig. 6).



Figure 6. Pinheiro Novo: Prototype application visualization

As a prototype designed to validate application functionalities, test data integration, and identify technical challenges, only a representative group of buildings were given interactive functionalities. This approach allowed for validation of the application efficacy while exposing scalability challenges inherent in a full implementation. To distinguish

interactive buildings from non-interactive ones, the latter were left without textures for easier differentiation.

This application provides an interactive way to explore and analyze building’s inventory data. By clicking on a 3D building model, users can directly interact with it and view its associated data from the inventory (Fig. 7). For easier data analysis, the application lets users query inventory data via a filtering system (Fig. 8). These queries dynamically filter the 3D building models, displaying only those that meet the



Figure 7. Interactive inventory data visualization

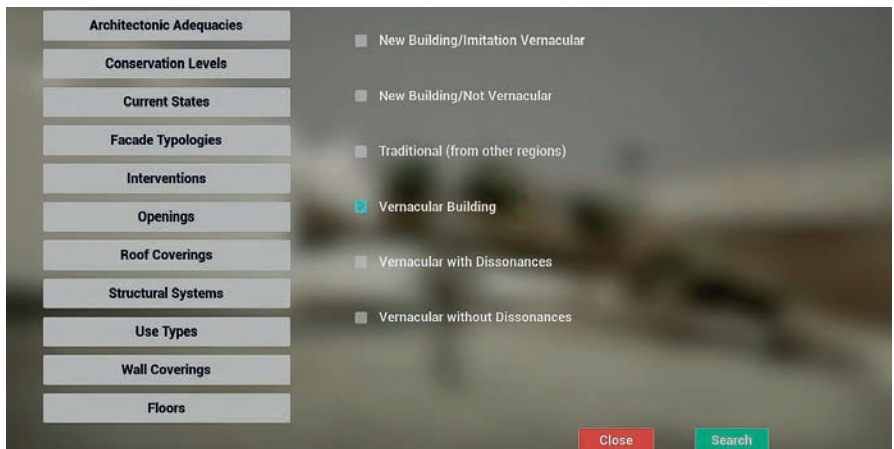


Figure 8. Application filtering data menu

specified search criteria. Users can focus on specific building groups, enabling researchers and stakeholders to quickly identify and analyze building data based on specific parameters.

An intuitive menu system supports the interactive user interface, designed for both management and user experience. This system provides information about the application, explaining its use and the data displayed during interactions. It also provides information about the Montesinho Natural Park, including its heritage, significance, and management plans (Fig. 9).



Figure 9. Application interactive menu

This application prototype significantly advances the preservation and promotion of Pinheiro Novo's vernacular architecture. Its user-friendly interface encourages exploration and understanding, contributing to the long-term safeguarding of this valuable heritage. The intuitive system combines interactive exploration with advanced filtering, allowing access and analysis of the village's building data. Using this approach, Pinheiro Novo's inventory data becomes clearer, enabling data-driven decisions through easy-to-understand visualizations. While immersive game-engine environments for historical sites are common, integrating analytical management tools within them is largely novel; thus, this prototype represents a significant advancement.

Final remarks

The three-dimensional digital models of these villages comprise a significant documentation resource, providing both high precision and accessibility, and potentially representing the only existing digital models. As digital records, they document the villages' condition at the time of the photogrammetry surveys. Moreover, beyond documenting architectural details and spatial relationships, the models contextualize intangible cultural aspects—including traditional building methods, social customs, and environmental responses—within their physical context. The models digital format significantly facilitates distribution and dissemination, thereby showcasing the importance of vernacular settlements and MNP vernacular architecture.

The source 2D photographs used to create the photogrammetric 3D models constitute a significant documentation asset, preserving information that may be missing from the derived three-dimensional model. This includes contextual details such as movable elements, vegetation, and repairs, as well as lighting conditions that highlight topographic features and reveal weather conditions.

The significance of these documentation records is amplified by subsequent events affecting the villages' layout since the 2023 photogrammetric survey. For example, Pinheiro Novo has been reshaped by two major events significantly impacting its vernacular character. First, the demolition of vernacular structures to accommodate a new building compromised the settlement's homogeneity, introducing incompatible materials, scales, and architectural forms that deviate from established traditional design principles (Figures 10-12). This alteration has affected the settlement's visual, structure, and authenticity. The second issue is the collapse of a building, caused by roof damage resulting from insufficient maintenance and ongoing precipitation. This has disrupted the settlement's spatial and formal unity, leaving the structure vulnerable to improper interventions or even total replacement (Fig. 13).



Figure 10. Building intervention record 1: (a) photogrammetry model (2023); (b) current state (2025)

These two events highlight the vulnerability of MNP vernacular constructions, primarily due to two factors: the alteration of vernacular buildings with standardized industrial materials and construction techniques, and the acceleration of decay through village abandonment. The former leads to a mischaracterization process that ignores local practices and natural context, resulting in the loss of distinctive



Figure 11. Building intervention record 2: (a) photogrammetry model (2023); (b) current state (2025)

traditional building practices that characterize MNP architecture and contributed to the villages' cultural identity. Meanwhile, village abandonment within the park accelerates the decay of these vernacular buildings through neglect, often leaving them in ruins and ultimately resulting in a further loss of authenticity and cultural identity within the settlements.



However, the digital models acquired through photogrammetry could aid in mitigating the authenticity loss from mischaracterization and abandonment. Their digital nature facilitates virtual planning and visualization of proposed building intervention, allowing for impact assessment on the villages' vernacular character before approval by local authorities. This is important for avoiding irreversible damage



Figure 13. Building collapse record: (a) initial state (2023); (b) ruin state (2025)

on the settlements configuration and for regulating unrestricted interventions with non-traditional materials presented as preservation. Furthermore, these digital records provide a valuable resource to support future efforts in conservation and reconstruction initiatives, and sharing them can raise awareness and support for their preservation. Finally, these models can also serve as valuable educational tools in regional architectural programs, teaching future practitioners about the importance of contextual and vernacular design of the MNP settlements.

Faced with the pressures of modernization and neglect, the MNP architectural heritage necessitates innovative preservation strategies. Integrating documentation techniques like photogrammetry is therefore essential for safeguarding the park's vernacular architecture and transmitting its embedded intangible knowledge to future generations.

During the development of the INHAVIT project, the data obtained from the photogrammetric surveys models were used to analyze detailed building features, including construction materials and otherwise inaccessible areas like rooftops and those unreachable from street level. The models facilitated comparisons between different building typologies and their correlation with surrounding constructions and landscape features. Furthermore, they provide a comprehensive set of measurements of various dimensions at both building and settlement scales, including building footprints, floor levels, wall and roof heights, openings, inter-building distances, street widths, building plot, and open space configurations. The models were also used to provide a physical vulnerability assessment of each documented building. Finally, derived photogrammetric data also enabled an assessment of Wildland-Urban Interface fire exposure affecting the documented vernacular settlements.

Acknowledgments

This work was financed with national funds through the Portuguese funding agency, FCT - Fundação para a Ciência e a Tecnologia, within the INHAVIT project (<https://doi.org/10.54499/MTS/BRB/0086/2020>)

and with the PhD scholarship 2021.07522.BD of the first author (<https://doi.org/10.54499/2021.07522.BD>).

This work has also been supported by the FCT / MCTES through national funds (PIDDAC) under the R&D Unit Institute for Sustainability and Innovation in Structural Engineering (ISISE), under reference UIDB/04029/2020 (<https://doi.org/10.54499/UIDB/04029/2020>), and under the Associated Laboratory of Advanced Production and Intelligent Systems ARISE under reference LA/P/0112/2020.

Challenges and pedagogical strategies to approach the constructive values of vernacular construction

7



J. Mendes Silva¹

1. From the abandonment of vernacular construction to its recognition as built heritage

The collective interest in vernacular constructions has evolved greatly in recent decades (European Commission 2021; ICOMOS 1999). In Portugal, the great change took place fundamentally in the 70s or 80s of the twentieth century, when the technical and scientific community began to be more aware of an unconventional built heritage, namely current construction in its most diverse forms, which includes popular, traditional and vernacular construction (Amaral 1988). It is not the objective of this paper to discuss in detail the semantic difference of these various designations which, although formally distinct, share many of the concerns and concepts of this approach.

This interest in vernacular construction in Portugal arises when most of the villages where these constructions were more frequent, mostly in rural territories, had reached very high levels of desertification, including many cases of total abandonment.

This process of desertification resulted, above all, from the migratory flows of the 40s to 60s of the last century, to the center of Europe and to Brazil and the United States of America, motivated by very unfavorable living conditions, with high levels of poverty, severe climate, unhealthy and uncomfortable housing, subsistence agriculture and very limited access.

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At the end of the 80s, only three or four of the 11 schist villages of Serra da Lousã still had some inhabitants, always in a very small number (Schist Villages 2024; Dias & Rebelo 1985).

2. The return to villages with vernacular construction

The return of the populations to these villages occurred, in some cases, slowly, with the return of emigration, because of improvement in individual living conditions, but in a less consistent and lasting way.

The return of some of these families was followed by their progressive move to the closer and more organized urban agglomerations, with better infrastructures, as is the case of Vila da Lousã, in the Schist villages, as well as the demographic reduction due to the aging of the remaining population.

Thus, the consistent reoccupation of these villages occurs later, with people of different origins, coming from the large centers or the most relevant urban centers in the vicinity, in a logic of temporary or leisure housing. Although there are no known research results on this matter, it is admitted that, in the case of the Lousã mountain, this new wave of interest in vernacular buildings began with people with no connection to the place, attracted by their uniqueness, contact with nature and the possibility of moments of pause in contrast to the hustle and bustle of urban life.

The same happened with foreign groups, especially from Northern Europe, who sought this connection to the natural environment, with very low costs in view of the abandonment of the locals and the difference in the scale of their retirement income or social support in their countries of origin, where, earlier than in Portugal, movements of alternative community life were born, with a strong environmental inspiration and without major constraints from the point of view of rules and social organization.

After that, new occupants emerged from closer populations, with emotional connection to these places (relatives of former residents or

owners), now residing in an urban context, seeing in these places the possibility of resuming these ties and creating leisure spaces.

This was followed by the progressive settlement of permanent residents, especially retired or young people with a professional activity compatible with the distance from the large centers, the installation of commercial activities and, inevitably, the tourist demand (Alves 2014).

This whole process is accompanied by the need for new public infrastructures, of which the water and drainage networks, the electrical networks and the like stand out, with direct implication in the public space and in the buildings themselves, now faced with the need to create the corresponding networks and building installations.

Everything, in fact, is a sign of change, because many of the functions of each building have also changed or required different ways of satisfying them. See, as extreme examples, the cancellation of the guard of the cattle on the ground floor, the elimination of kitchen spaces with open fire, under an unlined roof and without a chimney, and the replacement of interior partitions made of wood, with very limited performance from the point of view of occupant privacy.

The transformations that resulted directly from these function changes have effects at the structural, constructive and architectural levels. The ceiling height of the lower floor is increased, the floor is waterproofed, the wooden structure of the roof is modified or abandoned and the hygrothermal conditions are altered. The introduction of new materials is often assumed as an added value, without prior proof of their effectiveness and compatibility with the pre-existence.

For many years, ceramic tiles roofs with wooden structure were one of the most affected construction elements in these changes, because of the stigma to which they were subjected due to their vulnerability to the action of water and fire, which is even more evident the greater the degree of abandonment of these buildings.

Its degradation often leads to the destruction of the building itself, either by the horizontal impulse, perpendicular to the facades, which its excessive deformation or collapse causes, or by its progressive

ineffectiveness in protecting the top of the walls against the action of water, destroying the masonry.

The lack of knowledge of the functioning of these original structures, of their virtues and weaknesses, did not allow, for a long time, their recovery and reinforcement or their reconstruction with improved solutions followed by regular maintenance actions, which would preserve their identity and material and technological coherence.

Alternatively, continuous or framed reinforced concrete structures were built, altering the loads, rigidity and structural functioning of the roof, with very negative effects on the behaviour of the building, particularly in the event of an earthquake.

3. Preservation and enhancement of vernacular construction

In European societies, there was a rupture with all the roots of vernacular construction: intuitive construction with local materials, subsistence agriculture and livestock as the main economic activity, local social organization without the support of society and its infrastructures.

Times have changed, people have changed, roles have changed, demands and expectations have changed. In this scenario, the key question is no longer whether it is possible that buildings do not undergo significant changes, which are inevitable, but how to do them with respect for pre-existence and its values (Mouraz et al. 2023).

The transformation of vernacular construction buildings is, therefore, a huge challenge for all actors: researchers, architects, engineers, public entities and owners. It is difficult to find common denominators in the perceptions, recognition of values and objectives of these different actors and, above all, with different types of villages and territories.

All generalizations not based on statistical data have major weaknesses. However, it is possible to present some general perceptions about the perspective of different actors.

It is admitted that researchers, architects and engineers can privilege, in a first phase, the identification of the identity, architectural,

constructive and material values of these buildings and, for each of these values, or for their whole, identify what are the potentialities and added values for a future time, as well as their weaknesses and incompatibilities faced with the current demands and expectations, as well as the technological resources of the construction sector.

Other agents who have begun to express interest in these constructions have, in general, different perspectives, namely when looking for a second home for leisure time, where they intend to reproduce, albeit in a moderate way, the levels of comfort and safety of their main residence, with some difficulty in reading and understanding the matrix values and the added value of this vernacular construction.

Different perspectives are, in general, associated with tourism agents, focused on nature activities and extreme sports, gastronomy and other attractive thematics, all of which require infrastructures with their own characteristics, which tend to bring the space and buildings closer to standardized models with few points of contact with pre-existing reality.

4. A pedagogy for transformation

In projects to transform vernacular construction, in a rural environment, the general rule of SEE-JUDGE-ACT must be applied. In a first phase, it is essential to know the object, the context and the territory where it is inserted (SEE), to identify its values and weaknesses, and, already in an initial phase of the analysis (JUDGE), to make a first assessment of the feasibility of achieving the defined objectives.

This premise is also applicable to other types of rehabilitation projects, but is often simplified by the fact that there is a more detailed formal and public knowledge of the traditional, so-called erudite, construction of different eras.

The promotion of detailed knowledge of vernacular construction and its material and immaterial values requires a specific pedagogy, adapted to the various agents, where it is important to distinguish the motivation strategies, the pedagogy itself (i.e. the teaching and learning model) and the results or objectives to be achieved (i.e., the contents).

Three pedagogical experiments to explore vernacular construction in the schist and limestone villages of central Portugal are briefly presented now (see Figures 1, 2, and 3). In all of them there are two starting premises: (i) there is a hidden intelligence in the constructive solutions that we do not know yet and that it is important to discover; (ii) the identification and hierarchy of values are not deterministic and can only be the result of a collegial analysis.

Pedagogic activity 1

Stories of textures, colours, sounds, smells and knowledge of the Schist Villages

This action, aimed at engineers and architects starting master's or doctoral courses in the fields of building rehabilitation or management of built heritage, Municipality Technicians and cultural agents in the region, aimed to introduce them to the vernacular construction through a playful and sensorial approach, starting from immaterial values and progressively evolving to material and constructive values.

The participants received a working script for the visit to the village, by groups, where they should find and record, for later sharing and discussion: 6 typical images of an illustrated postcard, 6 trees, 6 smells, 6 sounds, 6 colors of nature, 6 colors created by man, 6 natural graphic textures, 6 graphic textures built, 6 plants in building finishings, 6 construction details, 6 images of construction edges, 6 corners and 6 windows.

Throughout the visit, at key moments, a technician or a local inhabitant presented in detail the unique characteristics of a previously selected building.

After the visit and the sharing of the results, a brief discussion of the technical perspective of the construction details observed took place and a preliminary list of material and intangible values to be safeguarded was drawn up.

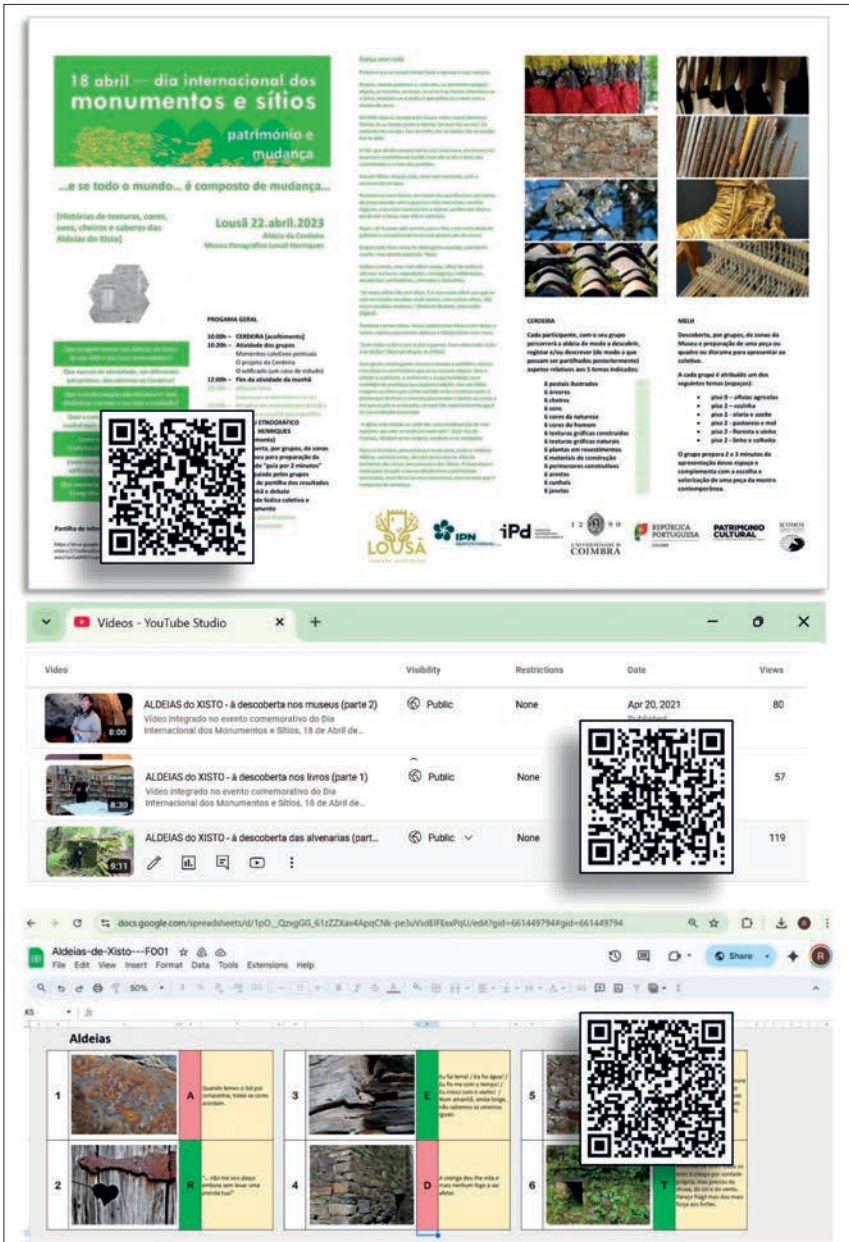


Figure 1. Videos and online game in pedagogical action 1, from the pandemic period (lines 1 and 2); Motivation Guide for Pedagogical Action 2, based on immaterial values (line 3).



Figure 2. Key elements to the field study of limestone villages (#01 to #05) in pedagogical action 3 (Silva et al. 2021)



Figure 3. Key elements to the field study of limestone villages (#01 to #05) in pedagogical action 3 (Silva et al. 2021)

Pedagogic activity 2

Changing Perspectives on Heritage

The action took place online, during the pandemic period when collective activities were prohibited. Short technical videos were made in three different locations: in schist villages, in the Lousã library and in the local ethnographic museum, with the accompaniment of an engineering professor, a geology professor, a PhD student, an art historian and an archaeologist.

The videos were presented, online, interspersed, by a tourism technician, focusing the attention of the participants on aspects related to the geology and technology used in the construction of masonry walls, on aspects of the history of the place and on the memories of the support agricultural activity that, for decades, marked life and also local constructions.

An activity was, then, proposed to synthesize the experience through an online game to establish the correspondence between images of the virtual tour and allusive captions. This was followed by the discussion of the results of the game. This activity used the resources of “simultaneous rooms” of the ZOOM platform, the hosting of videos on the Youtube platform and an interactive GoogleSheet. The participants were organized in small groups.

Pedagogic activity 3

Discovering architecture, construction, techniques, materials, the past, the present and the future

A group of architecture professors and students from the University of Coimbra, in conjunction with the municipalities of the Sicó area, began a process of detailed study of the limestone villages for which an initial pedagogical contribution was requested from the perspective of engineering, which has been materialized in a sequence of challenges (Silva et al. 2021).

First, it was the time to discover and understand the coherence within the diversity in the immense universe of stone masonry constructions. Then, in a second stage, to discover the strong common denominator in the materials, as if it were a kind of food wheel, which can be combined in different ways, but which positively contaminate the way of building (stone, wood, earth, lime and clay, with glass and iron accessories and the presence of the natural plant component that, although often parasitic, it ends up being part of the constructions).

The third challenge, already with a greater degree of abstraction, guides the study towards the knowledge necessary to explore the behavior of any type of stone masonry construction: the type of stone, the masonry apparatus, the transversal structure of the walls, the corners, the openings, the ornaments, the arches and, especially, the natural arch effect and the way in which the loads are applied and routed.

This path of technical approximation, of a generalist nature, leads to the fourth and most important challenge: fieldwork. Here, the objective is the detailed knowledge of specific characteristics of the limestone constructions in the region, already mastering the essential information and the observation strategies and techniques, through a script with ten study targets, previously illustrated and discussed: [#01] The plasters and mortars; [#02] Details, organization and hierarchy of masonry; [#03] Roofs with traditional solutions; [#04] Outdoor stone stairs; [#05] Ornaments; [#06] The interior of the houses; [#07] The uniqueness of the “false” lintels; [#08] The structure of the windows; [#09] Triangular paddocks in doors and niches; [#10] Vegetation and biological colonizations in stone and masonry.

5. Evolution of vernacular construction villages

It is easier to accept that villages in different territories with different cultures, with different local building materials and different histories and activities evolve in a very different way than to accept that the same

happens in villages in the same territory, with an intense sharing of their matrix elements.

Why can two villages in the same territory, with strong neighbourly relations and sharing the same historical path, evolve in very different ways, when, at the present time, they are still subject to the same legislation and the same administrative, social and economic status?

Four schist villages in Serra da Lousã, that share all the above characteristics and the same regulatory framework (Municipality of Lousã 2013) but that are following different paths, with regard to the evolution of their vernacular buildings, were analyzed.

In a simplistic way, and only for the sake of communication of a general sensibility, we can say that the village of Talasnal is “tourist”, the village of Candal is “urban”, the village of Cerdeira is “coherent” and, finally, the village of Chiqueiro is “matrix”.

What characteristics were considered for the formation of this sensitivity about the evolution of these four villages? What reasons are at the basis of these different paths of transformation? Would it be desirable or expected that all of them would have a similar evolution?

Talasnal – the “tourist” village

The village of Talasnal, after the abandonment of the 40s and 60s, was the one that most quickly attracted people from outside, especially from the city of Coimbra, recovering small buildings in a very rudimentary way, without major changes or improvements, for leisure housing (see Figure 4).

The evolution of this occupation followed exactly the model described at the beginning. The first group of new residents was joined by people with a memory relationship with the place, through family connections with former residents, and, little by little, the tourist demand and the commercial activity, that is always associated with it, emerged. This dynamic has led to the need to improve infrastructures and diversify agents, with different perspectives, with different speeds of action, with different levels of investment.



Figure 4. Images of the village of Talasnal ("tourist" village), above, and of the village of Candal ("urban" village), below.

Quickly the village began to incorporate, from a constructive and architectural point of view, solutions inspired by other places and regions, without great coherence between them and ignoring the pre-existence and its values. It is fair to admit that the lack of study, knowledge and dissemination of the values of the place and its buildings played a decisive role in this uncontrolled evolution, further enhanced by the speed of change and the diversity of actors.

This deficit of critical knowledge about the local buildings led to a mimetic effect of some of the most impactful initial interventions, creating movements of uncritical repetition of solutions totally alien to the local identity.

An example of this is the introduction of exterior covered balconies, with a wooden structure supported by large columns, in total contrast with the small and scarce original balconies supported on the façade with two inclined struts, in front of small openings on the upper floors. In addition to their visual impact and their difficulty in integrating into the local constructive and architectural logic, the new balconies clearly point to other climates and other ways of living.

Other constructive elements and characteristics of the construction followed equally erratic paths, erasing important testimonies of the history of the village and its constructive identity, which would certainly not go unnoticed by those who had participated in any of the pedagogical and awareness-raising actions described above.

The uncritical alteration of the masonry apparatus, the geometry and materials of the openings, corners or stairs, shows the total lack of understanding of the way these structures and materials work, but it is probably imperceptible to a less prepared eye. Also, the lack of knowledge of the natural evolution of these buildings sometimes led to the attempt to reprimise to an earlier stage, for example by removing plaster from the walls that had been covered in the last years of their occupation by the initial populations.

Candal – the “urban” village

It should be noted that the plastering of some houses in these villages was not an anomaly, nor a disrespect for pre-existence, but rather a sign of natural evolution. In general, this change was the testimony of the return of someone who, after emigration in America or France, achieved a better economic condition and, in this way, was able to fulfill the dream of having a house with greater comfort, healthiness and durability.

This reality transports us to the village of Candal (see Figure 4). The village of Candal, more coherent in terms of construction, is located next to a national road, which accelerated its transformation, namely through the construction of buildings with a more robust structure and buildings where the functional relationship with rural activity was less present.

Very early on, buildings were also built with plastered exterior walls and with more elaborate and efficient window frames, which gave them a more “urban” look.

After the periods of near abandonment, with the arrival of new inhabitants, the transformations were, at first, less visible, less shocking and less disruptive.

Paradoxically, this greater initial proximity of the constructions to a current model, motivated a movement (perhaps involuntary and naïve) of alteration to introduce visual elements considered typical of a vernacular (or even picturesque) environment, but totally decontextualized and which, for the most part, are nothing more than expressions of an individual imaginary, related to an environment in which they have never lived.

Given the reduced number of projects with the intervention of architectural and engineering technicians, many of the interventions are guided by the intuition of builders, who tend to replicate constructive solutions that best adapt to their professional experience.

Cerdeira – the “coherent” village

The village of Cerdeira is, within this group, the most coherent village, but, probably, the one that has undergone the most transformations. It is a village with more difficulties of access than the others, today served by a modern road, but winding and of reduced dimensions, which ends in a small square, where the chapel is located, about 500 meters from the nearest buildings. Access to the village centre is still pedestrian only (see Figure 5).

The village of Cerdeira, located in the same territory, with the same history of life, decline and abandonment in the mid-twentieth century, is subject to the same legislation as the others, but has had a very different evolution, marked by a collective idea of transformation of the initial small group of new inhabitants.

This new occupation of the village was made by a group of artists and intellectuals of German and Dutch origin, who were progressively joined by people of other nationalities, including Portuguese, attracted by the idea of creating a space conducive to artistic activity and the promotion of a way of life with urban characteristics, but privileging the relationship with the natural environment and environmental sustainability.

The buildings, many of which were in ruins, were reconstructed, seeking a balance between the original materials, technology and functions with the new expectations. In the interventions with the greatest impact, technicians and workers with knowledge of working in stone masonry and wood were sought, capable of introducing new techniques, in a coherent way, which progressively became models of intervention.

The desired coherence for the constructive solutions of these buildings does not necessarily mean total homogeneity. Coherence can and should accommodate the diversity of solutions that results from different functions and contexts in urban dynamics.

The evolution of Cerdeira deserves an in-depth study of the process, techniques and results. There will naturally be many questions that need



Figure 5. Images of the village of Cerdeira (“coherent” village), above, and of the village of Chiqueiro (“matrix” village), below.

to be answered. Have these transformations maintained the identity and vernacular character of the village and its buildings? What instruments (technical manuals, regulations, ...) and what actions (awareness-raising events, project sharing...) are necessary for the inevitable evolution of the village to maintain the coherence that is currently observed, without excessively conditioning new development projects?

Chiqueiro – the “matrix” village

Finally, the village of Chiqueiro, which we call “matrix”, due to its apparent proximity to the original matrix, both in the internal organization and in the shape, structure and materials of many of its small buildings (see Figure 5).

The great transformations that the village had were made by the original inhabitants themselves until the 70s and, therefore, the inconsistencies that also exist, with the introduction of masonry that does not respect the stereotomy of the original masonry or with the use of incompatible, ineffective or incoherent coatings (for example with cement plaster and glued stone slabs), are isolated cases that result, in fact, from a vernacular attitude.

It is not a question of importing models, it is not a question of market pressure, it is not an attempt to attribute functions to buildings that they cannot perform, but of a more isolated and decontextualized evolution, in a community that, over time, has been losing references on how to build or that, in the face of economic weakness, has adopted the solutions that, at the time, seemed most accessible.

Here, in Chiqueiro, it is possible to find multiple examples of masonry with a well-executed apparatus, of corners with the proper locking, using large stones (generally greywacke, instead of schist) and window lintels in curved wood, using tree trunks, whose deformation was accentuated through their immersion in water with the application of high bending loads.

As in the other villages, not all constructive solutions can be fully maintained when these buildings are rehabilitated to perform new functions, with new inhabitants, new demands and new expectations,

but the choice must always be based on a prior identification of values and limitations, which only an in-depth study can do.

6. Final note

For the coherent transformation of these constructions, it is necessary to know the starting point (the vernacular construction and its framework of values), the point of arrival (the characteristics and performance of future use) and, of course, the algorithm of this transformation.

In general, we know the point of arrival better than the starting point, which can easily lead to the choice of the wrong algorithm, that is, to the adoption of a design strategy that does not reconcile the values and potentialities of the pre-existence with the expectations of the future, resulting in significant economic, environmental and heritage costs.

The detailed knowledge of the constructive solutions, technology, geometry and their adequacy to the stability and comfort functions of these buildings, referring to the time of their construction and past use and to the present time, is very limited, although progressively improved by research works.

Public and reasoned sharing of project experiences is also reduced, largely due to insufficient critical knowledge of the values and weaknesses of the starting point.

These are the main reasons for proposing a reinforced commitment, on the part of the academic community and regulatory agents, to the awareness of all agents and the search for a specific pedagogy to act on a reality that, having nothing new, remains unknown.

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Vernacular architecture in Italy: Regional diversity, historical significance, and contemporary relevance

8



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Abstract

This article delves into the profound significance of vernacular architecture in Italy, underscoring its role as a historical testament and a paradigm for future sustainable development. By studying how this interest has changed over time, we can see how scholars and institutions have reacted to it. This goes from the early 20th century, when there were exhibitions about different cultures, to today, when people are interested in how well buildings can deal with problems in the environment. The article emphasises the regional diversity of Italian vernacular Heritage, from the ‘Trulli’ of Apulia to the ‘Masi’ of the Alpine valleys, and demonstrates how these structures reflect the local communities’ adaptive strategies in response to geography, climate and culture. The focus here is on the relevance of vernacular architecture to today’s challenges, especially climate change and the need for designs that are low-impact and resilient. The article makes a case for the revaluation of this heritage as both a cultural legacy and a resource for rethinking the built environment in terms of sustainability, local materials and social inclusiveness.

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Rediscovering the Vernacular: Theory and Historical Trajectories

Oliver (1997, 2003) defines vernacular architecture as a variety of local construction configurations related to the land and specific living requirements, as well as to different climatic conditions and the materials available.

The art of building in harmony with the climate, the characteristics of the natural environment and the building materials, with characteristics that change from place to place and from age to age, is something that is practised (Slongo, 2012).

Buildings blend in with their surroundings to the point of becoming almost indistinguishable. Zucconi (2005) stated that no element of the construction conflicted with or contrasted the state of things.

Architecture has always adapted to its natural surroundings. The site's morphology dictated the site's shapes and dimensions, while the climate, economy and local culture influenced the construction methods and materials used.

The result of a layering of practical knowledge (Oliver, 2006) used to meet the need for survival, vernacular architecture is therefore the product of a process of trial and error.

In 20th century Italy, the concept of rural architecture -often mistakenly referred to as 'minor architecture'- and its interactions with ethno-anthropological sciences began to be reflected upon.

The Italian Ethnography Exhibition was among the first events to take place, having been organised in Rome in 1911. Lamberto Loria was the curator, and Gustavo Giovannoni, Marcello Piacentini and Vittorio Ballio-Morpurgo were his collaborators. The exhibition was organised to celebrate the first fifty years of Italian unification. A section on heritage and architecture was included in addition to the ethnographic section of the exhibition.

On 12 January 1920, a pamphlet entitled "Circular n. 13: Collection of decorative elements of Italian peasant art" was published by the Director General of Antiquities and Fine Arts in Rome, Arduino Colasanti. Colasanti was convinced that Italian country folk culture

should be admired for the amazing diversity of its local types and, more than anything else, for its possible input to a national decorative style.

Colasanti wanted to protect peasant art that might be lost or destroyed. He wanted to protect not just objects, but also buildings. He did this before the 1920 exhibition of decorative arts in Stockholm. Peasant art received the importance it deserved on this occasion, and in the spring of 1921 architect Marcello Piacentini dedicated three rooms of the Rome Biennial to it (Circular n. 13, 1920).

The Stockholm exhibition was considered one of the most significant exhibitions of the early post-war period by Antonio Maraini and others. The first exhibition of vernacular Italian architecture was reviewed by Maraini. It had been organised in Rome by Gustavo Giovannoni, Vittorio Morpurgo and Marcello Piacentini, and was entitled “Exhibition of Rustic Art” in 1921.

In 1922, an important year for the preservation of vernacular architecture, Edwin Cerio organised the Landscape Conference, held in the summer.

The recent approval of a law for the protection of “natural beauty” was announced by the organisers. Amended and approved in 1939 alongside another law protecting Italy’s artistic and architectural heritage, this legislation was the first to safeguard the environment in relation to architecture. The Italian scene was dominated by two central figures, the architects Giuseppe Pagano and Guarniero Daniel. A debate aimed at promoting tradition and the vernacular from a rationalist point of view was raised by them through the photographic exhibition “Rural Architecture” at the 1936 Triennale.

Pagano opposed the classicist and ostentatious architecture built under fascism, proposing the simplicity of the vernacular as an alternative.

An accompanying catalogue was published in the Triennale’s Quaderni. Using black-and-white photographs, the catalogue showcases a wide range of vernacular buildings representing the different regions of Italy (Sabatino, 2008).

However, it was the Austrian architect Bernard Rudofsky who brought vernacular architecture to international scholarly attention. In 1964, he inaugurated the influential exhibition *Architecture Without Architects* at the Museum of Modern Art in New York, which was later displayed in eighty-four museums worldwide.

The term “vernacular” was first used in an architectural context as a synonym for “spontaneous” on this occasion.

The exhibition revealed the existence of architecture that was both pedigree-free and indigenous, with a strong rural character, from across the globe. This architecture was constructed in accordance with the prevailing climatic conditions and utilised locally available materials and technologies (Rudofsky, 1964, 1966).

The ensuing publication delved into the realm of vernacular architecture and the solutions devised when the profession of architect was yet to come into existence. Technological solutions, in response to specific exigencies, such as climatic ones, were employed.

From Trulli to Trabucchi: Regional Expressions of Vernacular Architecture in Italy

Italy has a long-standing tradition of vernacular architecture, reflecting a strong identity and a principle of resilience that adapts to ever-changing environmental conditions.

This tradition is very varied. It differs from region to region, just as the regions of Italy differ from each other (Sabatino, 2008).

Across the country, you will find that the defining features of vernacular architecture are consistently present. These features include compactness, adherence to the ground, the use of essential materials and functionality. However, the way in which they are used varies depending on the location, being influenced by the particular conditions of each area, such as the climate, the geography, and the local materials available (La Regina, 2013).

Exceptional examples can be found in southern Italy, for example. The Apulia region has the so-called ‘Trulli’ (Fig. 1), which are traditional limestone houses found in the Itria Valley in the Murge area. The valley

is home to a variety of dwellings, from the secluded rural trulli to the sprawling settlements of connected houses. The largest of these settlements is Alberobello, a town that boasts a unique and charming character. There are three types of trullo house: the first is rectangular with a pyramidal roof, the second is circular with an ogival roof, and the third is the typical rectangular structure with a conical roof. These edifices manifest in a variety of forms, ranging from detached single-storey structures to complexes of circular buildings amalgamated into a unified entity, often serving as residential dwellings or agricultural outbuildings (La Regina, 2013).

These rural buildings are symbols of Apulia's architectural heritage. They were mainly built in the 15th century to adapt to the region's hot, dry climate. Apulia is also home to typical farmhouses (Fig. 2), which were used as agricultural centres and dwellings. These large, fortified farms are a defining feature of the Apulian countryside and are built from local stone. They are characterised by large courtyards. Such complexes often include dwellings, stables and storage areas, surrounded by olive groves and cultivated fields. Apulia and the neighbouring regions of Basilicata and Calabria, as well as Sardinia and Liguria, are still using a prehistoric building technique known as dry stone construction. Erected without the use of mortar, low walls, with stones overlapping to delineate the boundaries of agrarian land, stand as testament to the manner in which local communities leveraged natural resources to fashion dwellings and agricultural topographies. In the Calabria region, for example, these dry stone structures are used to support cultivated land on hillsides. They are known as 'cumuli'. The term is employed because the formation of cumuli is the process that immediately succeeds the clearance of stones from the terrain and is the preparatory process for the construction of dry stone walls (Di Fazio; Modica, 2008).

Circular structures built with reeds and straw, known as 'pagliai' (haystacks) (Fig. 3), are also commonplace. These structures were traditionally used to shelter livestock or store hay.

The original pagliaio is cylindrical in shape: it consists of a pole around which hay is piled up. The development of a dome or conical shape was driven by the necessity to shield the hay from the weather, ensuring effective water drainage without allowing it to soak inside (Pagano; Daniel 1936).

An exemplary form of architecture that showcases human adaptation to the environment can be found in the nearby region of Basilicata, where dwellings are built inside natural cavities. Matera's city is known for its 'Sassi' cave dwellings (Fig. 4).

The initial dwellings were natural caves, but the inhabitants swiftly initiated modifications by either obstructing the ingress or extending the caves by utilising the excavated material from within the cave itself. The extended cave dwellings were the last type to be developed, and they were used by humans for many years. The houses were designed with doors and windows that were shaped to allow sunlight to enter during the winter months, but to prevent it from entering during the summer. A system was also made to collect water, which makes it an example of a settlement that works perfectly with its land and ecosystem (La Regina, 2013).

The remarkable ensemble of ancient underground structures that has been preserved in the village of Pietragalla, which is located in the inland area of the Province of Potenza in Basilicata, is unique within the context of Italian rural architecture. Dating back to the early 19th century, these tuff-carved caves, known as 'Palmenti', are arranged across different elevations and traditionally used for wine production. Their distinctive shape allows them to maintain a constant internal temperature, which is ideal for the fermentation of must. Each typically housed two or three vats for pressing and fermenting grapes.

Another notable example of vernacular architecture and urbanism in Basilicata is the 'Rabatana' quarter in Tursi. Throughout the ages, the locale experienced constant reshaping and reutilisation, with changes extending up to the 19th century. The architectural fabric of the region today is characterised by a harmonious adaptation to the sandy-clayey terrain, reflecting a vernacular Mediterranean style. This architectural



Figure 1. Trulli of Alberobello
(© G. Pagano, D. Guarniero. Catalogue of the exhibition "Italian Rural Architecture, 1936)

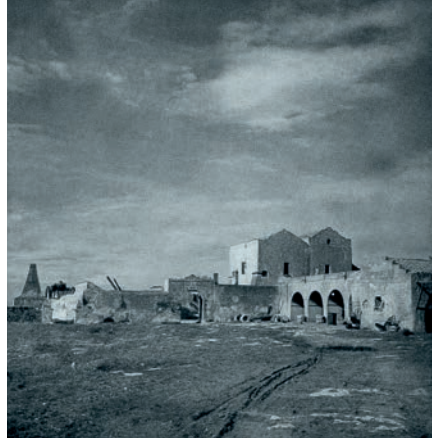


Figure 2. Apulian farmhouses
(© G. Pagano, D. Guarniero. Catalogue of the exhibition "Italian Rural Architecture, 1936)



Figure 3. Calabrian pagliagio
(© G. Pagano, D. Guarniero. Catalogue of the exhibition "Italian Rural Architecture, 1936)



Figure 4. Sassi of Matera
(© G. Pagano, D. Guarniero. Catalogue of the exhibition "Italian Rural Architecture, 1936)

language displays a variety of construction solutions, ranging from structural to formal aspects (Masini, 2004).

As for the Sicilian islands, the 'caseddhi' are stone houses that are typical of the Sicilian countryside. They are often single rooms with pitched roofs.

Their main purpose was to provide temporary shelter for farmers and shepherds while they were working on the land or moving their flocks from one place to another. Today, many *caseddhi* have been or are being restored, thus preserving an important part of Sicily's architectural heritage.

Sardinia also has a predominantly rural landscape, characterised by scattered settlements where family life, sheep farming and agriculture coexist. This trend is best exemplified by Gallura, as it is the region with the largest number of rural buildings, known as 'stazzi'. A stazzo refers to both the building and the surrounding property, and is a plot of land of varying size with one or more buildings in the centre, ideally on high ground. Outbuildings, enclosures for livestock, vegetable gardens and vineyards surround the main buildings (Achenza 2019).

Venturing towards the heart of Italy, along the Adriatic coast of Apulia, Abruzzo and Molise, one can behold the venerable fishing structures known as 'trabucchi' (Fig. 5).

Trabucchi are short-lived constructions of uncertain loveliness, symbols of the Adriatic coast and models of effective building, constructed with regional materials and workforce at no cost.

Their structure is an ingenious example of sustainability, incorporating self-construction, the use of local wood, respect for the environment, and reversibility.

These vernacular fishing structures were designed by local populations. They were used to intercept and capture schools of fish. These schools of fish were passing along the coast. This meant that the local populations no longer had to go out to sea in boats.

In central Italy, you can also admire the vernacular architecture of the Tuscan countryside. These farmhouses and farms (Fig. 6) are often surrounded by vineyards and olive groves, and are built using local stone and bricks. They are representative of the agricultural heritage and the needs of rural life, as well as local traditions.

These agrarian settlements are predominantly associated with sharecropping, a practice that dictates the architectural character of the dwellings and outbuildings, such as stables and barns.

The forms are determined by the material, climate and agricultural economy.

The rural house is a type of construction that is closely linked to the economic conditions in which it is built, as well as the self-sufficient farming habits of those who build it. Stones, tuff, bricks or wood are used depending on the availability of materials on site. The edifice's material composition is derived from the terrain upon which it is erected, thereby establishing an intimate synergy between architectural form and the encompassing landscape (Benedetti, 1966; Martinelli, 2023).

Conversely, in Emilia-Romagna, there exist exemplars of vernacular architecture that have exhibited an innate capacity to adapt to the climate and seamlessly integrate with the environment. Typical of agricultural areas, these are rural buildings with an internal courtyard.

Emilian farmhouses can be divided into two main types based on their shape and appearance: the open courtyard house, which is widespread in the eastern part of the Emilian plain, and the single-body type. The individual edifices facilitate unencumbered space for creatures and carts to traverse, accompanied by a stable and a residence.

The self-sufficiency of the inhabitants of each farmhouse was ensured by the presence of service buildings: a well for water, an oven for baking bread, a chicken coop and a woodshed.

Emilian rural houses are built of brick, and barns often feature brick latticework decorations in the form of geometric honeycomb perforations. This ensures air circulation (Celli, 2017).

These buildings reflect local traditions and are a testament to the area's culture, climate and available resources (May, 2011).

Finally, we move north to Trentino Alto Adige. Here, we come across the 'fienili' (Fig. 7). These are wooden buildings. They are used for storing hay and agricultural tools.

The construction technology used is blockbau. Solid wood logs are the main material used in this system, and they are readily available in the local area.

This method of construction made sure that air could flow naturally, so it was mostly used for barns or other buildings used for storing foliage (Iachelini, 2024).

In the mountainous regions of northern Italy (South Tyrol and Piedmont), one encounters alpine farms known as 'Masi' (Fig. 8). These edifices, constructed of wood and stone, often boast sloping roofs, meticulously designed to ensure the seamless descent of snow.

These buildings are used as homes and stables and are typically surrounded by idyllic landscapes, benefiting from the spring water systems and agricultural land typical of these areas.

The buildings are made of stone or rock, either plastered or exposed, or of logs or frames with cladding, or more often, a combination of construction technologies. The utilisation of a combination of technologies is driven by the diverse categories of materials, contingent on the practical objectives of the farmstead.

The way these old buildings are made lets us put them into three groups: *haus* (a group of houses), *hof* (farmsteads) and *hit* (rustics) (Moretti, 2024).

In Piedmont and Lombardy, there are also typical rural buildings known as 'Cascinali'. These are agricultural complexes comprising houses, warehouses, and stables. These brick or stone structures are designed to house families and animals.

Isolated farmhouses were usually smaller and located on hilltops with good sun exposure. Consisting of a single building incorporating a house, stable, barn and cellar, these farmhouses were typically two storeys high with a gabled roof (Marchiano; Cavallo, 2019).

Along the Ligurian coast, particularly in Portofino and the Cinque Terre, you will find picturesque fishing villages where maritime traditions remain intact amidst narrow alleyways and fishing boats.

The characteristic feature of these villages is the presence of pastel-coloured houses built overlooking the sea.

Built on cliffs to make the most of the space and following the topography of the area, these dwellings were mostly built by fishermen and farmers. They also used local materials.



Figure 5. Trabucco

(© G. Pagano, D. Guarniero. Catalogue of the exhibition "Italian Rural Architecture, 1936)



Figure 6. Tuscan farmhouses

(© G. Pagano, D. Guarniero. Catalogue of the exhibition "Italian Rural Architecture, 1936)



Figure 7. Fienili

(© G. Pagano, D. Guarniero. Catalogue of the exhibition "Italian Rural Architecture, 1936)



Figure 8. Maso

(© G. Pagano, D. Guarniero. Catalogue of the exhibition "Italian Rural Architecture, 1936)

Italy's rich vernacular architectural heritage reveals a deep interconnection between human adaptation and cultural identity. Local conditions -be they climatic, geological, social or economic- are precisely responded to by each architectural form. Though often modest out of necessity, these constructions demonstrate remarkable technical solutions, sustainable practices and a refined sense of spatial organisation developed over centuries. They are living archives

of community resilience, agricultural customs, and environmental stewardship, not merely buildings.

Learning from the Past: Vernacular Architecture for a Sustainable Future

In today's world, climate change and urbanisation are among the most pressing challenges facing contemporary societies. Within this context, vernacular architecture is gaining increasing importance as a model for creating sustainable built environments (Pardo, 2023; Shri Harine et al., 2024). There is growing recognition that the historical evolution of vernacular architecture offers valuable insights into a city's development, including transformations in its social and urban fabric (Rong & Bahauddin, 2023).

As architectural design increasingly embraces sustainability in response to the detrimental impacts of modern technologies, vernacular architecture provides time-tested lessons for creating efficient, ecological, and contextually appropriate solutions (Garg et al., 2024). Its principles continue to serve as a relevant source of inspiration for contemporary design (Creangă et al., 2010).

Nevertheless, the survival of non-standard or traditional architectural forms is under significant threat. Factors such as the industrialisation and globalisation of construction methods, the abandonment of customary structures due to evolving standards of comfort, the pressure of urban sprawl, and restrictive regulatory frameworks all contribute to this decline (Pardo, 2023).

Where once raw materials met the cultural, social, and economic needs of communities, today they can be reinterpreted as tools for fostering social engagement, sustainable development, and cultural continuity (Golden, 2017). Accordingly, studying vernacular practices offers valuable guidance for managing landscapes in a more sustainable and long-term manner (Cervelli et al., 2025).

Contemporary discourse increasingly identifies vernacular architecture as a foundation for envisioning a more sustainable future (Frey, 2010; Withers, 2022). This shift presents both challenges and

opportunities for architects, builders, and policymakers. It calls for policies that support local production, as well as the development of new technical and social solutions (Shove, 2018).

Yet, without widespread knowledge and understanding of the values and techniques embodied in vernacular architecture, conservation efforts may be severely compromised (Masini, 2006). Promoting this awareness not only strengthens social cohesion, but also affirms that sustainability must be understood as a collective responsibility—one that extends beyond the environmental to encompass cultural and social dimensions (Leporelli et al., 2025).

It is therefore essential to recognise the significance of vernacular architecture as both a heritage of the past and a resource for the future. Prioritising its integration into local development strategies is vital for creating resilient, inclusive, and sustainable communities.

Conclusions

Vernacular architecture is far more than a collection of regional building styles; it is a living archive of environmental knowledge, social values, and cultural identity. In Italy, its diverse expressions—ranging from dry-stone trulli and pagliai to alpine masi and Ligurian fishing villages—reflect a profound historical understanding of place, climate, and community needs. In the face of today's dual challenges—environmental degradation and cultural homogenisation—the insights embedded in traditional architecture are once again emerging as a vital source of knowledge. Contemporary construction often lacks the qualities of sustainability, resilience, and harmony with nature, yet these traditional buildings offer tangible models of all three. While safeguarding the past and investing in a sustainable, culturally grounded future are crucial objectives, they are not the only reasons we must recognise, conserve, and reactivate this heritage-

The task ahead is to bridge the past and the future, ensuring that the wisdom embedded in everyday architecture informs the design of tomorrow's built environment. Moving forward, it is essential to integrate

traditional principles into contemporary architecture—particularly in designing climate-responsive buildings, reimagining existing structures for new uses, and fostering a circular economy where materials are reused sustainably. In doing so, vernacular architecture can continue to serve not merely as a memory of the past, but as an active, vital resource for shaping landscapes that are more resilient, inclusive, and environmentally conscious.

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Understanding rural vulnerability to climate hazards: A case study from Montesinho Natural Park

9



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Recognizing a Fragile Landscape

Mediterranean vernacular heritage, especially prominent in rural areas, is the result of centuries of rural communities adapting to their climatic, geographic, cultural and social contexts. These buildings, constructed without architectural or engineering design, and using locally available materials such as dry stone, wood, mud, lime, and ceramic tiles, embody an accumulated knowledge that responds to environmental conditions. They integrate passive climate-adaptive strategies: thick walls for thermal regulation, sloped roofs to manage rainfall, internal courtyards and balconies that promote ventilation, and vegetation used for natural shading (Bianco, 2016; Fernandes et al., 2014). Beyond their residential function, these spaces hold deep community value. Shared infrastructure such as village chapels, fountains, and communal ovens, served as places of encounter, cooperation, and social cohesion. Hence, the vernacular-built landscape is a living expression of balance between human needs and nature.

Over recent decades, many rural territories across Southern Europe have undergone continuous depopulation. The outmigration of younger generations in search of economic opportunities has left behind aging populations, vacant homes, and weakened community configurations. This

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ongoing demographic decline has eroded local capacities – economic, social, and institutional – reducing the ability of these communities to maintain their heritage or respond collectively to challenges.

This already vulnerable scenario is now being intensified by the growing impacts of climate change, particularly the rise in abnormally high temperatures and the increasing frequency of extreme weather events (Fig. 1). Heatwaves arrive earlier, last longer, and reach record-breaking intensities; wildfire spread faster and with greater severity; and flash floods follow prolonged droughts, overwhelming outdated infrastructure. These evolving hazards increasingly affect communities and their vernacular-built heritage, which were never designed to withstand such extremes (Graus et al., 2024).

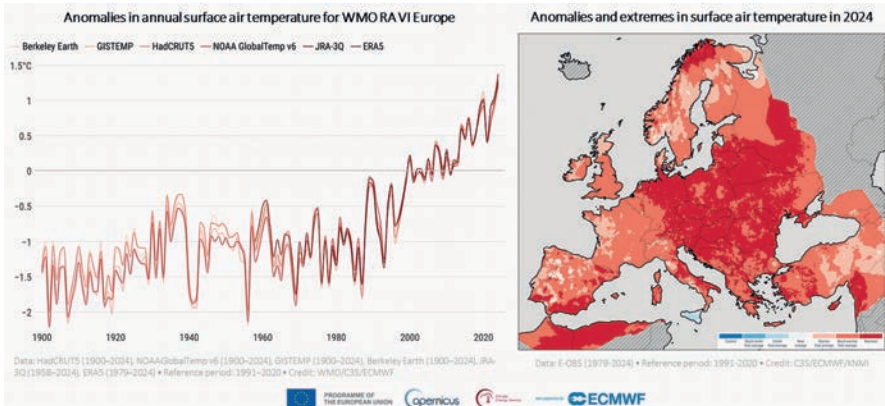


Figure 1. Temperature variations – European State of the Climate 2024.

The convergence of depopulation and climate stress puts at risk not only the physical fabric of vernacular architecture, but also the ancestral knowledge, cultural identity, and traditional ways of life embedded within it. As buildings are left without care and maintenance, their deterioration accelerates. Meanwhile, the fading of communal spaces and shared practices undermines the social ties that once supported collective resilience and local response capacity.

In response to this ongoing situation, this chapter presents a methodological framework developed within the INHAVIT project,

to better understand the multiple vulnerabilities affecting rural communities and their built heritage. Through a clear and adaptable methodology, this research seeks to develop an integrated vulnerability index that combines two essential dimensions: the physical condition of vernacular buildings, and the social characteristics of the communities who inhabit them. To do this, the study follows three main steps:

- (a) Identifying and classifying building features that influence vulnerability to heatwaves, wildfires, and floods.
- (b) Analysing social vulnerability based on factors such as population aging, isolation, and the strength of social networks.
- (c) Bringing both dimensions together into a single index that highlights areas of greatest vulnerability and potential action.

Ultimately, the goal is to offer a replicable, easy-to-use tool that supports decision-making in rural areas, especially those with valuable but fragile vernacular architecture, where climate hazards and social fragility overlap.

How did we measure vulnerability?

After defining the conceptual basis of the index, this section explains how the methodology was built, from the selection of indicators to their application in the case study area. The approach is organized into two main components:

- **Physical vulnerability:** related to the characteristics of traditional buildings and their susceptibility to heatwaves, wildfires, and floods. This dimension follows a multi-hazard approach. It includes three sub-indices, each one corresponding to a specific hazard:
 - **PV_H** – Physical Vulnerability to Heatwaves
 - **PV_W** – Physical Vulnerability to Wildfires
 - **PV_F** – Physical Vulnerability to Floods

Each sub-index is composed of 7 to 9 parameters, including features such as wall thickness, type of roofing material, shading elements, vegetation proximity, or state of conservation. All parameters are classified using a qualitative scale from A to D (1-4) and weighted using the Analytic Hierarchy Process (AHP), taking into account expert opinion. The current model allows hazard-specific vulnerability scores to be mapped and compared across buildings.

- **Social vulnerability:** based on demographic, economic, and community-based indicators that reflect the fragility or resilience of rural populations. The social dimension of the index focuses on the human factor, particularly how rural communities are affected by aging, economic inequalities, and the erosion of collective capacities. It is structured into three dimensions (sub-indices):
 - Vulnerable groups (e.g., elderly, people living alone, dependent populations)
 - Socioeconomic status (e.g., employment, housing conditions, access to services)
 - Social capacities (e.g., community engagement, mutual aid networks)

Fifteen indicators such as age, household composition, employment, or support network, were selected and validated through expert consultation involving professionals from engineering, social sciences, and territorial planning. These indicators were also weighted using the AHP method. The result is a social vulnerability index that can be mapped spatially to identify the most fragile areas within each community.

To apply and refine this methodology, four villages in the Montesinho Natural Park, a mountainous rural area in the district of Braganca in northeastern Portugal, were used as pilot case studies (Fig. 2). These settlements were selected based on three main criteria: (i) Presence of



Figure 2. Montesinho Natural Park location and typical village

traditional vernacular architecture; (ii) Evidence of depopulation, aging, and abandonment; (iii) Location in a Mediterranean climate zone prone to heatwaves, wildfires, and seasonal floods.

Initial fieldwork began in 2022 with a broader survey across 13 villages and over 2,000 buildings, aimed at characterizing building typologies and settlement patterns (Arias Tapiero et al., 2024). In a second fieldwork campaign carried out in 2023, the focus was a detailed assessment of four selected villages, surveying 650 vernacular buildings through visual inspection supported by drone photogrammetry.



Figure 3. Samples of surveyed vernacular buildings in schist and granite

These surveys allowed the team to document a range of architectural typologies, conservation state, and spatial arrangement of typical of vernacular buildings in the region (Fig. 3).

Simultaneously, data were collected to evaluate social vulnerability at the household level by conducting interviews with residents, allowing for a direct assessment of demographic fragility, economic conditions, and local support networks. Across the four villages, approximately 180 residents remain, and the study achieved an average participation rate of 90% per village, enabling a robust analysis of community conditions and needs.

By combining technical data with social context, this multi-dimension approach enabled a comprehensive understanding of vulnerability. The results from this case study provide a foundation for future replication in other Mediterranean rural areas.

Results and discussion

This section presents selected results from the application of the vulnerability index in four villages within Montesinho Natural Park. The findings are grouped into two areas: physical vulnerability and social vulnerability, respectively in following subsections.

Physical Vulnerability: A Multi-Hazard Outlook

Heatwave Vulnerability (PV_H): Among the four villages (Fig. 4), Village 3 stands out with the highest percentage of buildings in high vulnerability to heatwaves. The key factors here are the lack of external shading and the age of the buildings, mostly of them built before 1990 and thus lacking any thermal regulation. In contrast, Village 4 has the highest portion of medium vulnerability, suggesting a more widespread but slightly less intense physical vulnerability. Villages 1 and 2 also show high vulnerability, mainly due to the absence of protective shading features like overhangs. Overall, the results highlight a shared thermal weakness across all villages, with different triggers depending on their construction age and passive design elements.



Figure 4. Heatwave vulnerability comparison

Wildfire Vulnerability (PV_w): Village 1 clearly holds the highest wildfire vulnerability (Fig. 5), with more than a quarter of its buildings classified as highly vulnerable. The main issues include flammable wooden doors, complex pitched roofs that trap embers, and dense, unmanaged vegetation dangerously close to the buildings. While Villages 2, 3, and 4 show a more moderate profile, they still share the same structural vulnerabilities.



Figure 5. Wildfire vulnerability comparison

Floods Vulnerability (PV_w): Although flood vulnerability appears lower overall compared to the other hazards, Village 1 emerges as the more vulnerable, with over 60% of its buildings falling under medium vulnerability. This outcome is driven primarily by large ground-level openings like garage doors and the material of walls (schist). These features make buildings more prone to water infiltration and long-term damage. The other villages revealed to be more resilient to this hazard, with most buildings in low vulnerability categories. Still, the prevalent presence of floor-level big openings across all villages makes this a concern that should not be overlooked (Fig. 6).



Figure 6. Flood vulnerability comparison

These examples illustrate that vulnerability is multifactorial and place specific. While Village 3 faces the highest exposure to heat, Village 1 concentrates most of the wildfire and flood vulnerability. This reinforces the need for tailored, hazard-specific adaptation strategies, rather than a one-size-fits-all approach.

Social Vulnerability: A Diverse Landscape

The four villages show signs of social vulnerability but with varying intensity according to the studied dimensions, as detailed in the following.

Vulnerable Groups (D1): Village 1 shows the highest vulnerability (Fig. 7), with a predominantly elderly population, many with special needs and limited access to support services. Village 4 also presents high scores in this dimension due to isolated older adults and weak household structures.



Figure 7. Vulnerability comparison - D1

Socioeconomic Status (D2): Village 1 ranks highest again, marked by low income and unemployment. Village 4 follows closely, with

economic hardship and reliance on subsistence agriculture. In contrast, Village 2 benefits from external incomes and tourism-related activities, lowering its vulnerability (Fig. 8).



Figure 8. Vulnerability comparison – D2

Social capacity (D3): Village 1 faces serious deficits in emergency preparedness, with poor access to communication tools and no participation in awareness programs. Village 4 shares similar challenges. On the other hand, Village 3 benefits from local drills and stronger support networks (Fig. 9).



Figure 9. Vulnerability comparison – D3

Global Social Vulnerability: When all dimensions are combined (Fig. 10), Village 1 stands out as the most socially vulnerable, followed by Village 4. Village 3 exhibits moderate vulnerability thanks to its active community and better preparedness. Village 2 is the least vulnerable, supported by stronger economic conditions and access to services, despite gaps in vulnerability awareness.

The results of the physical and social vulnerability assessments reveal a complex and place-specific landscape of vulnerabilities across

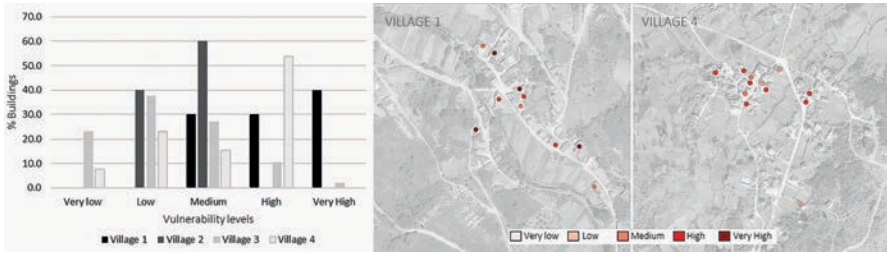


Figure 10. Vulnerability comparison - Global

the four studied villages. While some areas face severe structural vulnerability to hazards considered in this investigation, others are more severely affected by demographic fragility or lack of preparedness. Village 1 emerges consistently as the most critical village, combining high vulnerability across almost all dimensions. These findings underscore the importance of adopting tailored, multi-hazard strategies that address not only the physical weaknesses of the built environment, but also the social capacities of the communities threatened.

Final reflection

The interaction between climate change, rural depopulation, and architectural vulnerability requires new tools to understand where vulnerabilities concentrate and why. This chapter proposes a context-sensitive methodology that sheds light on both the physical and social dimensions of vulnerability in vernacular rural settlements. Unlike many existing assessments based on national census data, this analysis operates at a finer spatial and social scale, capturing the distinctions of community structure and building conditions that often go unnoticed in broader datasets. By documenting and analysing the case of four villages from Montesinho Natural Park, it demonstrates how data-driven insights can support more equitable and targeted interventions. As the methodology continues to evolve toward full integration, it strengthens the recognition of vernacular heritage not only as a cultural asset, but also as a key component of climate adaptation and territorial resilience.

While the two components have been successfully applied independently, the formulation of the integrated vulnerability index remains in progress. Preliminary efforts have been made to combine heatwave and wildfire exposure into a single multi-hazard score, and to overlay heatwave vulnerability with social fragility. However, developing a comprehensive model that consolidates all three hazards with social factors poses conceptual and methodological challenges.

The next phase of the research focuses on testing different integration methods guided by analyses and expert input. The final goal is to operationalize a unified, scalable index capable of highlighting areas where structural weaknesses and social fragilities intersect. This would enable more effective targeting of adaptation resources in both heritage conservation and social resilience strategies.

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Social vulnerability in peripheral rural Portugal 10



João Sarmento¹

Introduction

Social vulnerability is a multidimensional concept that refers to an exposure to harm through social, economic, and environmental stressors and is further compromised by relatively weak capacities or resources to cope and recover (Cutter et al., 2003). It highlights the resilience of communities when confronted by external stresses, such as natural or human-caused disasters. It also refers to the inability of people, organisations, and societies to withstand the adverse impacts from multiple stressors to which they are exposed. In other words, it may reflect a state of powerlessness and marginality, and a lack of capacity to adapt. Social vulnerability is more acute in specific groups, which can be seen through categories such as poverty, class/caste, race/ethnicity, religion, gender, age (elderly and children in particular), disability, health, language/literacy, structure of households and families (single-parental, for instance).

Social Vulnerability can be looked at from several dimensions. These may include the level of poverty, the lack of or limited access to resources such as information, knowledge and technology, the lack of or limited access to political power and representation; the lack of or limited social capital including social networks and connections, inadequate beliefs, customs and attitude in response to risk or disasters,

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vulnerable residential settings, frail and physical limited individuals, the lack of or limited access to critical services and infrastructures such as communication, transportation, power supply, water supply, sanitation, etc.

This necessarily brief text will review some characteristics of social vulnerability in peripheral rural Portugal, pointing at four major key issues that characterise these territories: depopulation; economic marginalisation; poor services and infrastructure access; and ineffective policies. The last part will focus on a particular peripheral rural space in the Northeast of the country, the territory of Montesinho Natural Park.

Social Vulnerability and the Rural

It is a common place to argue that peripheral rural areas are particularly affected by multiple forms of social and spatial vulnerabilities, including a lack of public and private services, a weak economic base, poor accessibility, and detrimental demographic changes. The 2008 *Poverty and Social Exclusion in Rural Areas* report (European Commission, 2018) identifies four categories of problems that characterise rural areas and determine the risk of poverty and social exclusion. They include demography, i.e. the exodus of residents and the ageing population; remoteness, such as lack of infrastructure and basic services; education, i.e. the lack of creche services and difficulty in accessing primary and secondary schools; and labour markets, i.e., low employment rates, persistent long-term unemployment and a large number of seasonal workers. The most vulnerable groups are children, young people, women, older workers, low-skilled workers and the unemployed.

Portugal's peripheral rural territories are increasingly threatened by climate change hazards, including drought, wildfires, and soil erosion (Oliveira, Gonçalves & Zêzere, 2021). These environmental concerns undermine agricultural and forest livelihoods. Forest fires are a recurrent issue, especially in the north and central regions of Portugal, and they often expose the vulnerability of rural populations to environmental

risks and the failures of land management policies (Silva, Bica & Soares, 2018). Land abandonment, which in great part is a consequence of demographic decline and economic stagnation, increases environmental risks, as the unmanaged land and forests are more prone to fires. The Rural has changed dramatically in the last decades (Baptista, 2006; Ferrão, 2018), yet across diverse regions, there are common threads of structural disadvantage.

Depopulation

Depopulation is among the most severe problems facing rural Portugal. Municipalities have been in decline for decades, primarily due to rural exodus or emigration, mostly among younger cohorts who are in search of better employment and education opportunities (INE, 2021). Between 2011 and 2021, over 80% of Portugal's municipalities lost residents, especially in northern and central interior areas. Some municipalities in the North, Centro and Alentejo regions registered over 40% population decline in the past 30 years. The combination of low fertility and outmigration created a progressively older composition of the population, with median ages greater than 50 years in some municipalities (INE, 2021). An ageing population also means increased need for social services and health care, which, within rural communities, are scarce or unavailable. Elderly persons residing by themselves are particularly vulnerable to social isolation, poor health, mental health, and poverty (Santana, 2002; Moreira e Pinheira, 2023). Social vulnerability also has deep psychosocial factors. Loneliness and solitude are common, especially in the ageing population (Burlina & Rodríguez-Pose, 2023). The decline of rural communities and the loss of traditional social structure decrease the opportunity for involvement and support. Mental illness remains poorly addressed in rural areas: poor knowledge, high stigma, and poor delivery lead to numerous individuals not receiving any treatment. Economic deprivation, social isolation, and lack of efficient social interaction worsen the burden of the mental disorder. Many adolescents in rural areas suffer from psychological distress stemming from limited opportunities, which

results in feelings of hopelessness or forced migration to urban centres. One way to reverse the depopulation trend is to encourage in-migration.

Economic marginalisation

Portuguese rural peripheral economies are largely agricultural, forestry, and small industry-based ones, which have been unable to remain competitive in today's globalised economy. The depletion of traditional agriculture and the absence of rural diversification have led to high unemployment and underemployment. The European Union's Common Agricultural Policy (CAP), while it does offer some aid, has long favoured larger corporations at the expense of small farmers. Rural poverty is one of the most concerning aspects, and data from Eurostat (2022) shows that Portugal's risk-of-poverty rate in predominantly rural areas is much greater in comparison to the urban regions. Importantly, one of the key characteristics of rural poverty is its invisibility. As Commins (2004: 61) argues, "rural poverty is widely dispersed rather than concentrated in limited geographical areas as in urban 'blackspots' (...). Yet, it is no less pressing, manifested as substandard housing and access limitations for transportation and services". Public authorities must promote further economic restructuring in rural areas if they want them to be lived in, and not just be used for tourism.

Poor services and infrastructure access

Rural vulnerability is determined by access to basic services. In the past decades, there have been several closures of rural schools, post offices, banks, and health centres, under the rationale of reforms for efficiency and austerity measures. These closures increased rural marginalisation. Residents in rural areas must travel far to access various services, and healthcare in particular is critical. The availability and quality of healthcare are also limited by the shortage of professionals. Restricted access to basic and secondary education also occurs. School closures created longer travel times for children and led to school dropouts among young people. Young people in rural areas often have limited pathways into the higher education system,

reinforcing disadvantage. Digital exclusion is also a growing concern. Although broadband coverage at the national level is high, there are still large segments of rural communities with slow or no internet access (European Commission, 2022). This limits online access to services, remote education, and digital work. These shortcomings became quite evident during the COVID-19 crisis.

Ineffective policies

The European Union has promoted rural areas with LEADER initiatives and programmes from the 1990s to the present. European Rural Development and Cohesion policies have attempted, throughout the years, to positively influence the living conditions of rural areas. The EU Rural Development Policy goes beyond agriculture and forestry and targets wider rural economic development, including a priority such as “promoting social inclusion, poverty reduction and economic development in rural areas”, as one of the six EU priorities for rural development. Portugal has introduced national and EU-funded rural development programs, providing funding for innovation, modernisation of agriculture, and rural tourism, among others. In 2020, the approval of the new regulation governing the European Regional Development Fund permitted Member States to allocate resources to sparsely populated municipalities with population densities of less than 12.5 inhabitants per km² or that have lost, at least, 1% per year of the population between 2007 and 2017. Many of these policies have been criticised by researchers and practitioners as too top-down and insufficiently attentive to local needs (Ferrão, 2018). Bureaucratic hurdles and policy fragmentation are likely to weaken the performance of funding instruments. On the positive side, bottom-up initiatives have been promising. Cooperatives, social enterprises, and local development associations have implemented projects in organic farming, cultural revitalisation, and sustainable tourism. Teleworking trends after the pandemic have also led some municipalities to promote rural lifestyles through tax incentives and infrastructural improvement, although they have yet to demonstrate their success.

Social Vulnerability in Montesinho Natural Park

Established in 1979, Montesinho Natural Park (MNP) is one of the largest protected areas in Portugal, covering approximately 75,000 hectares. Located in the extreme northeast of the country, in the district of Bragança, it encompasses territories from two municipalities: Bragança (43,637 hectares) and Vinhais (30,592 hectares), which correspond to 37% and 44% of the total land of those municipalities, respectively. The park borders Spain, specifically with the provinces of Castile and León, is about 90 km.

The Park is home to a total population of 6303 people (3866 in Bragança municipality and 2437 in Vinhais municipality), scattered in 88 villages, many of which under 100 residents. Several of these villages are made up of a handful of elderly people: Guadramil, with roughly 20 inhabitants or Mofreita, with roughly 30 inhabitants, are just two examples. Birth rates are very low, and youth have largely migrated to the cities or abroad. Ageing indices in Bragança municipality are significantly higher than the national value – 192 vs 265, and almost fourfold in Vinhais – 192 versus 732 (INE, 2021). Naturally, these low numbers do not mean only a reduction of people living in an area, but the exceeding of thresholds that fall below minimum levels of reproductive social, economic and environmental capacity and sustainability. All parishes within the park are considered to be rural, and the territory is characterised by extreme demographic frailty. Human communities established in the park are facing high levels of social and economic vulnerability. The geographical isolation of the park – with deficient road networks and harsh winter conditions – adds to this demographic vulnerability.

The economy of Montesinho is dominated by subsistence agriculture, livestock, forestry activities and the tourism sector. In recent years, chestnut production has become a significant complement of agricultural activities, and is regularly part of local product fairs and festivals, which also include various types of smoked meats. Although these activities produce some income and attract many people from

outside the region on very specific dates, they are labour-intensive and less attractive to newer generations (Pato & Teixeira, 2016). Although nature tourism and eco-tourism have great potential within the park, their complete realisation is generally hampered by the lack of investment, marketing, and local capacity. At the same time, while tourism can be used as a way to diversify the sources of income in a number of cases, and even mitigate out-migration, tourism alone is not the solution for the problems of rural areas.

Public services in the park's villages are extremely limited. Most of the villages do not have a local health centre, school, or public transportation. Citizens often need to travel long distances to access basic services in Bragança or Vinhais. The digital divide is also present, with limited internet and mobile network coverage across vast parts of the territory, which constrains the use of digital services and telework (European Commission, 2022). Montesinho is also a case study in the intersection of environmental vulnerability and rural depopulation. While the protected status of the park ensures some degree of preservation, great swaths of land go unmanaged due to declining population. This has increased the risk of wildfires and biodiversity loss (Rego & Silva, 2014). Land uses that were once fundamental to the equilibrium of ecosystems – such as pastoralism and rotational farming – are in decline. Various residents are in favour of the installation of wind turbines on their land, as it would provide a complementary source of income. Yet, despite wind turbines existing very close by, on the other side of the border, due to the fact that the territory is a protected area, wind turbines are not allowed. At the same time, and in the context of the European Union Critical Raw Materials Act from 2024, several territories are under pressure because of possible future mining. Revelhe (affecting the nature park) and Valongo2 (within Natura 2000 Network and the Meseta Ibérica Transboundary Biosphere Reserve) are two projects in the process of prospecting requests (for Gold, Silver, Copper, Lead, Zinc, Nickel and Cobalt, among others), and are raising several concerns among inhabitants and environmental groups. Prospects received an

unfavourable opinion from the Institute for Nature Conservation and Forests.

Despite these challenges, Montesinho is rich in intangible cultural heritage, including community celebrations and traditional agrarian knowledge. Some local initiatives exist with the aim of preserving cultural identity and promoting sustainable development. These, nevertheless, lack institutional support and long-term investment. Montesinho emphasises the need for comprehensive rural policies that take into account both environmental and social sustainability. Environmental conservation plans must go hand in hand with social investment – in mobility, health, education, and economic diversification – to render human life viable in protected rural areas. The park also provides the potential for redesigning models of eco-tourism, climate resilience, and rural innovation in abandoned regions.

While in the past years several improvements in road accessibility have been made, paradoxically, some of the most peripheral villages of the park, bordering Spain are, in absolute distance, close from two major transport infrastructures in neighbouring Spain, that run parallel to the border: highway A52 (Autovia das Rías Baixas), connecting Galicia to Castilla and León, and the highspeed train (AVE), connecting Vigo to Madrid. From A Gudiña train station, for example, it is possible to reach Madrid in about 2 hours by train. Thus, the remoteness of these territories encapsulates possibilities of change which cannot be disregarded under different spatial and political developments.

Concluding remarks

Portugal's rural vulnerability is a complex, multidimensional issue requiring an integrated response. Demographic decline, economic marginalisation, poor infrastructure, and environmental hazards form an interlocking network of disadvantage. Long-term sustainability depends upon concerted development policies placing rural well-being at their centre. This includes participatory policy-making, investment in public services, sustenance of local economies, and recognition of rural space

as central to national identity, culture, and sustainability. The future of peripheral rural Portugal cannot be framed in terms of dissolution but as an opportunity for regeneration, founded upon social justice, environmental sustainability, and local empowerment. Furthermore, additional integration with Spanish territories and cross-border institutional cooperation, and tourism growth, may foster cohesion and development that contributes to solutions to fight social vulnerabilities. It is nevertheless important to find other innovative solutions to maintain the provision of public services in sparsely populated areas and to promote the role of public-sector agencies in assisting firms and researchers, to build networks and relationships with actors both within and outside the region, with the aim of encouraging innovation and business development. Unquestionably, migration must be seen as one possible solution for counterbalancing depopulation and combating social vulnerability, and can be part of a strategy for rural regeneration and reconfiguration. Political will and a progressive and open are key to the implementing and success of such a strategy.

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Wildland-Urban Interface fire exposure of rural settlements

The case of Montesinho Natural Park

11



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1. Introduction

Wildfires pose a significant threat to biodiversity, populations, and exposed assets (Gill et al. 2013; Syphard et al. 2009; Syphard et al. 2012). A range of factors, including extreme temperatures, alterations to atmospheric dynamics resulting from climate change, and human interference, have contributed to the occurrence of significant wildfires. Just in between 2001 and 2021, for example, more than 29,000 km² were consumed by fire in Portugal (ICNF 2021) and several lives were lost (Pastor et al. 2020). Of note, the number of fatalities in interface zones between natural vegetation and population centres have been particularly significant (Molina-Terrén et al. 2019), underscoring the need for precise identification of vulnerable zones to clarify areas that represent a greater threat to inhabitants.

Larger wildfires tend to depend on extensive areas of wildlands and favourable climatic conditions. Despite being refuges for natural conservation, natural parks often concentrate on characteristics that increase the risk of fire spreading. This has been repeatedly observed (Molina et al. 2017; Morais 2008; Terêncio et al. 2018) in regions like the Montesinho Natural Park (ICNF 2022).

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The Wildland-Urban Interface (WUI) is a term used to define zones in which natural vegetation and settlements intersect or cohabit in the same space (Johnston et al. 2019; Radeloff et al. 2005; Dao et al. 2022). These zones are prominent in traditional villages that historically used these interfaces for economic and social activities.

To investigate the exposure of WUI zones, a topological approach known as WUIX methodology (Caballero 2019)] is used herein to quantify the interface between vegetation and buildings simply by dividing aerial images into a grid to compute the continuity of vegetation and the friction with buildings (i.e., the proximity or contact between vegetation and buildings). The product of these two components yields the WUIX index, which enables the discrimination and classification of vegetal fuel patterns on the interface and, based on this, the quantification of the level of exposure to wildfire.

This study aimed to evaluate the changes in WUI zones in three villages of the Montesinho Natural Park between 2018 and 2021. The analysis presented in this chapter relies on the comparison of two techniques for the identification of the green cover in the orthoimages and on its use as the input for the application of the WUIX (Caballero 2019) to evaluate the exposure of the buildings located in WUI zones.

1.1. Villages under study

Montesinho Natural Park has several traditional villages with different conservation and occupancy conditions. Some of these villages have already lost part of their original vernacular identity due to the need to adapt those buildings to modern housing standards. Furthermore, the continuous depopulation of these villages with the migration of the population to urban areas led to the gradual abandonment of a significant number of buildings, which are currently unoccupied.

Aerial images and on-site surveying were used to identify the villages of Montesinho Natural Park that still preserve their original vernacular value. This first selection of villages was subsequently checked against the overall wildfire hazard of the region (ICNF 2022) (Fig. 1), leading to

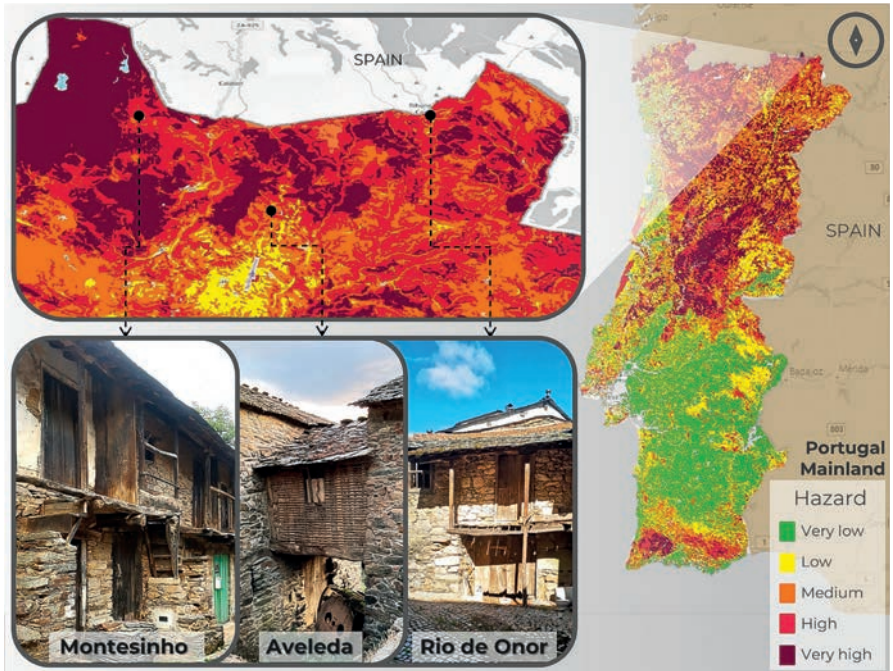


Fig. 1. Definition of villages for the case study: wildfire hazard map by INCF, adapted, and examples of typical buildings for each settlement (Silva et al. 2024).

the selection of the final set of villages to be investigated in this work, namely: Montesinho, Aveleda and Rio de Onor. Although, as mentioned before, the Park's villages present different conservation levels, there are still similarities in what concerns their overall features. For this reason, the results obtained from the application of the methodology to these three villages are assumed to be representative of the overall level of wildfire exposure of many rural settlements in this region.

2. Methodology

The Wildland-Urban Interface Index (WUIX) (Caballero 2019) method links the fire propagation potential to the vegetation continuity zones with its proximity to residential areas and the possible exposure

to wildfires. The analysis is carried out using aerial or satellite images of the study area and georeferenced building polygons.

2.1. Inputs of the WUIX methodology

The definition of calculation matrices is the first step in obtaining the values of continuity and friction. The study area is divided into matrices containing two levels, both with different resolutions, as illustrated in Fig. 2. In the example presented in Fig. 2, the study area is subdivided into several square matrices with cell size R_f by R_f , which, when multiplied by N , compose one larger cell size R_g by R_g . The sum of these larger cells corresponds to the entire study area.

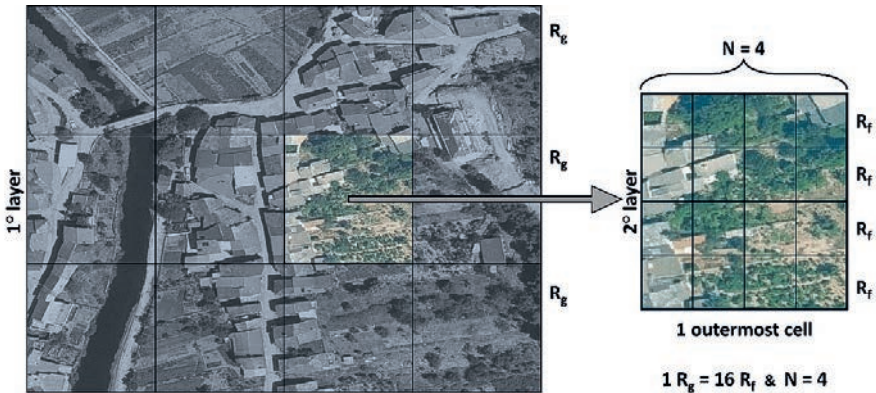


Fig. 2. Example of splitting an image into calculation matrices. On the left, 12 large cells (R_g) represent the entire image. On the right, one of the large cells is split into 16 fine cells (R_f) (Silva et al. 2024).

The purpose of the grid resolution is twofold. Firstly, the size of the fine resolution (R_f) after that compiling into an R_g cell enhances the visualisation of the results at the global level. Continuity and Friction are computed from fine cells. The unitary Continuity (C_i) in a cell is based on vegetation in neighbouring cells. A value of 1 is assigned for vegetation in cardinal directions (N, E, S, W) and 0.5 for diagonals. If all cells contain vegetation, C_i reaches a maximum of 6.

The unitary Friction (F_i) follows a similar method but considers vegetation overlapping buildings. Cardinal directions receive a value of

1, diagonals 0.5 (if convex), and overlapping vegetation also adds 1. The maximum F_i value is 7.

After calculating C_i and F_i for each fine-resolution cell (R_f), values are compiled into large-resolution cells (R_g). The WUIX index is then derived by multiplying continuity and friction values, applicable to each large cell (W_g).

2.2. Aerial image collection and creation of vegetation rasters

Orthophoto maps from the DGT (General Direction of the Territory) platform were chosen to perform vegetation extraction and, ultimately, to apply the WUIX. A Python script was developed to automatise the process of importing and converting the three images into matrices. These images refer to the naturally coloured image, the artificially coloured image CIR and the vector of buildings.

From images with the four spectral bands, it is possible to calculate the amount of vegetation present in the area, as well as its relative density and vitality. The methods derived from the spectral band differentiation are currently used for forest monitoring, agricultural applications and related purposes and commonly enable the comparison of vegetation in different periods in time (Remote Sensing Phenology 2018).

Based on an orthophoto of a part of the study area (the Montesinho region), NDVI (Normalised Difference Vegetation Index) (Silva et al. 2024) and GNDVI (Green normalised difference vegetation index) equations were applied to determine which approach was more accurate in identifying vegetation and removing potential noise that could interfere with the application of the matrices. These indices are widely used in selecting vegetated areas in orthoimages by the ratio of the difference between the colour and NIR bands (Weier 2000; Zheng et al. 2018; Gitelson et al. 1995).

3. Results

Based on the vegetation, the WUIX method was applied to the villages of Montesinho, Aveleda and Rio de Onor. Vegetation continuity,

friction and WUIX assessment maps have been plotted for each village, helped by the QGIS software, with the ultimate aim of comparing the years 2018 and 2021.

As can be observed in Fig. 3, the most significant concentration of buildings with contact interface and, consequently, higher WUIX values were obtained for Aveleda. Such a concentration is particularly noticeable in the SE and NW areas of the village. As for Rio de Onor, although there is a higher concentration of vegetation in the SW area, this does not lead to a high WUIX index mainly because of the distance between the buildings and the vegetation, which is always greater than the 3 meters established by the $R_f = 1.0$ m.

For comparison, it is worth noting that the WUIX values mapped with $N=30$ are slightly lower than those calculated for the localities of Puentelasierra in Spain (Caballero 2019), where the values slightly exceed 0.45 m^{-2} and 0.6 m^{-2} , respectively. Puentelasierra is the reference area on which the methodology is based, and it produced higher index values than those obtained in the present study. This is primarily due to the local typology, where houses are surrounded by trees and other types of vegetation (Moritz et al. 2014).

From the analysis of Fig. 3, it is also evident that most of the inner zones of the villages have the lowest WUIX values (less than 0.5 m^{-2}), while the outer zones have the highest values (greater than 1.5 m^{-2}). The method's developer (Caballero 2019) established that the interface values should be divided into four classes: low, medium, high, and very high. These classes were determined after evaluating different experiments, where values below 1.5 m^{-2} were considered low, and those above 4.5 m^{-2} were considered very high, with the intervals $1.5\text{-}3.0 \text{ m}^{-2}$ and $3.0\text{-}4.5 \text{ m}^{-2}$ completing the graduation for specific WUIX.

It is important to note that this scale does not permit direct application of the values obtained for the villages in the Montesinho Natural Park, given that the highest result slightly exceed 1.5 m^{-2} . This may be explained by two different aspects of the tests evidenced by the author. Firstly, there is almost a complete absence of intermixed

vegetation in the villages studied in this work, as already evidenced earlier. Furthermore, the buildings of the villages of Montesinho are typologically different from those tested by Caballero (Caballero 2019). In this case, the buildings typically share side walls or have only very narrow gaps between them, which, for the purpose of evaluating the surrounding vegetation, converts them into one block with larger dimensions.

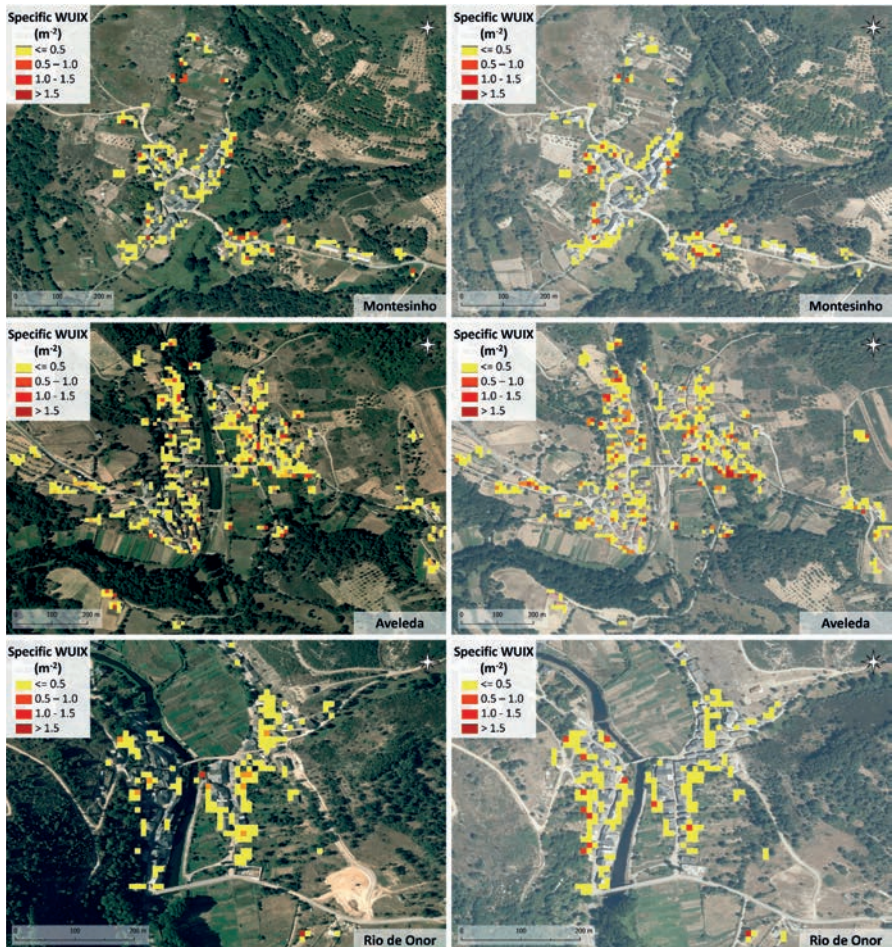


Fig. 3. WUIX results mapped for the three villages: Montesinho, Aveleda and Rio de Onor, respectively. On the left, for 2018. On the right, for 2021 (Silva et al. 2024).



Fig. 4. Two random details for comparing WUIX and friction results between 2018 and 2021 (Silva et al. 2024).

The differentiation of the index in the adopted scale is important to visually demonstrate the areas with greater prominence of urban-forest interface and to point out the spots that should be prioritised for fuel treatment in case of need, especially close to the dwellings.

Two random details taken from the village of Montesinho are presented in Fig. 4. The map with the layer of mask for classification of the index is on the left, and its respective original (without mask) is on the right. Each detail frame is completed using four images representing the same area: two for 2018 and two for 2021.

Some interesting observations can be drawn based on these two frames given in Fig. 4. Firstly, a softening of both the friction and WUIX indices is perceptible in the lower frame of the figure. In this case, the deforestation of an area in 2018 is evident, and since the vector of the buildings was composed of the year 2021, the previous year was automatically identified as being one of high friction (for a building that was not yet built). This deficiency is rarely observed once the area is not expanding. The villages are losing inhabitants, and the construction of new buildings is becoming less frequent.

Regarding the upper frame in Fig. 4, it is possible to observe that the growth of the vegetation between 2018 and 2021 led to an increase in the level of friction areas; up to 50% for 2018 and 75% of normalised friction for 2021. This aspect is critical for the increase of the specific WUIX, which becomes higher in the surroundings of the buildings. This fact is associated with the advance of some canopies of trees above the buildings in the natural growth of the plants and could suggest changes in the resilience measures put in force by the Portuguese government after the catastrophic wildfires occurred in Portugal (ICNF 2021; Pastor et al. 2020) in 2017, and, together with the results shown in the plots given in Fig. 5, demonstrate a slight tendency for the increase of major indices of friction and specific WUIX. However, a longer time span is required to prove this possibility.

The plots in Fig. 5 compare the recurrence of values calculated for each cell in the years 2021 and 2018. Since the methodology assigns a value of zero to cells with no data, only positive values (greater than zero)

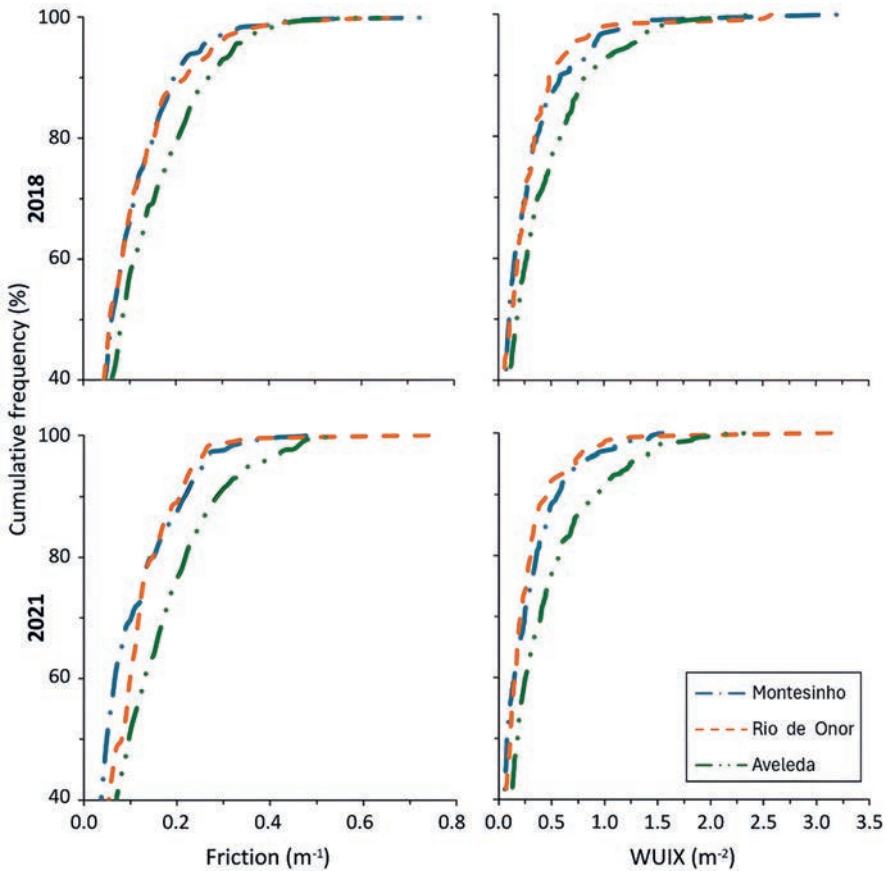


Fig. 5. Comparison of WUIX results for the villages across years (Silva et al. 2024).

were used to construct the plots, in order to avoid an overconcentration of zeros in the histograms.

The values shown in Fig. 5 demonstrate a certain patterning of the indices according to which, for example, the values of friction for all villages accumulate to around 10-20 cm per square metre, with Aveleda presenting a more significant concentration of higher values. This fact reflects the WUIX results, where Aveleda has a higher accumulated exposure, especially in 2021, as shown in the last plot in Fig. 5.

These results numerically confirm what can be seen in Fig. 3, where the contact between the southeast and northwest of the village and a line of vegetation is noticeable. Controversially, when these results are compared to the wildland fire hazard map provided by the ICNF (Fig. 1), Aveleda is the village with the smallest associated affectation, followed by Rio de Onor and Montesinho. This last has a very high hazard related to it due to the extensive areas of natural vegetation and the lack of other close villages to stop the potential of fire spreading.

4. Final remarks

This study assessed the exposure of rural settlements to wildfires in the wildland-urban interface using the WUIX methodology. The process of handling aerial images was adapted to be automated and replicable for different settlements, allowing for comparisons over the years. As a result, WUI exposure maps were generated for various villages for the different study years.

The findings show that WUI exposure increased between 2018 and 2021, and the most significant incr was observed for Aveleda. Although the time frame is relatively short for setting solid conclusions, the WUIX index demonstrated good potential for identifying rural settlements exposed to wildland fires at the mesoscale. In other words, it helps to effectively map areas of greater exposure in small villages, pointing specific locations of occurrence.

The simplicity of the methodology for applying may encourage authorities to use it as a fast screening to support fuel management. Other methods are usually adapted to macro areas to support vulnerability identification, where the satellite images do not allow closer resolution. For instance, the ICNF hazard identification methodology for Portugal typically covers larger areas. In this perspective, WUIX can be used complementarily, serving as an indicator for inhabitants and authorities to identify high-risk areas and mitigate the exposure of houses to wildfires.

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Long-term Thermal Monitoring of Vernacular Buildings in Montesinho Natural Park: Preliminary Insights from the INHAVIT Project

12



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Abstract

This chapter presents the preliminary results of a field-based study on thermal performance in vernacular buildings located in Montesinho Natural Park, Portugal. Continuous environmental monitoring was conducted across three case studies, with air temperature and relative humidity recorded in selected rooms over a one-year period. The data were analysed using the Portuguese adaptive comfort model to assess seasonal thermal comfort conditions under real occupancy scenarios. The findings indicate a general mismatch between indoor conditions and adaptive comfort thresholds, particularly during winter, where discomfort predominates even in buildings with modest thermal buffering. Summer periods show improved performance, though results vary according to spatial orientation, thermal mass, and occupant presence. These variations reflect the interplay between architectural form, passive strategies, and operational performance — revealing that traditional buildings alone do not inherently ensure comfort throughout the year. The study forms the basis for future simulation-based research

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on energy efficiency and thermal retrofitting, with an emphasis on context-sensitive bioclimatic solutions tailored to the architectural and cultural landscape of rural mountain environments.

Introduction

The vernacular architecture of Montesinho Natural Park (MNP), located in northeastern Portugal, presents a compelling model of bioclimatic adaptation developed over centuries in response to dry summers and cold wet winters (ICN, 2007; AAVV, 2011; Khei et al., 2024). Characterised by thick granite masonry walls, compact urban forms, small windows, and limited mechanical systems, these buildings were designed to minimise heat loss and exploit available solar and thermal mass resources. However, as modern comfort expectations evolve and winters remain long and harsh, the performance of these traditional dwellings, particularly in the absence of consistent heating, is increasingly being questioned.

Recent literature has emphasised the value of vernacular strategies for sustainable and low-energy architecture. Yet, there remains a notable lack of quantitative, in-situ monitoring data from cold climate rural heritage sites (Fouzanmehr & Vellinga, 2011; Anjo, 2011; Fernandes et al., 2019). While prior studies have demonstrated the potential thermal buffering effects of granite walls and compact layouts, they have also highlighted the limitations of these strategies in maintaining acceptable indoor temperatures during extended cold periods (Khei et al., 2024).

Renovation strategies such as internal insulation and window upgrades are increasingly applied to improve energy performance in vernacular buildings, which differ from formally recognised historic structures due to their local materials, informal construction, and context-specific use. While insulation can enhance winter comfort, it may also lead to overheating in summer, especially in small rooms with limited ventilation and/or high solar gains. For instance, (Lozoya-Peral et al., 2023) observed that renovated traditional Mediterranean houses experienced increased summer heat accumulation despite winter

gains. Moreover, as (Sargazi & Tahbaz, 2022) highlight in their review of vernacular architecture, occupants' adaptive behaviours (such as opening windows, adjusting shading devices, or adjusting clothing) are essential to maintaining thermal comfort. Nevertheless, these aspects are often overlooked in performance assessments of building renovation interventions.

This chapter presents insightful results from an environmental monitoring campaign of three vernacular buildings within MNP, focusing on their thermal performance across all seasons. The primary objective is to evaluate the extent to which these buildings meet adaptive thermal comfort thresholds, particularly during winter and summer, under real-life conditions of partial heating, intermittent occupancy, and varying levels of envelope intervention.

By comparing a fully uninsulated dwelling (Case 1) with two insulated buildings (Cases 2 and 3), this study aims to:

- (a) Identify performance differences under extreme seasonal conditions;
- (b) Analyse the influence of passive bioclimatic strategies (e.g., wall orientation, thermal mass, insulation);
- (c) Inform context-sensitive retrofitting strategies for cold climate vernacular heritage.

Case Study Description

Three representative vernacular buildings in MNP were monitored to compare thermal performance across different renovation states and occupancy patterns (Figure 1). Case 1 serves as an unmodified reference, while Cases 2 and 3 demonstrate partial renovation solutions. Their contrasting characteristics (summarised in Table 1) enable analysis of how insulation strategies and usage patterns influence building physics.

Table 1. Case studies basic description

Parameter	Case-1	Case-2	Case-3
Village	Pinheiro Novo	Montesinho	Montesinho
Front Facade Orientation	~Northeast	~Northwest	~Northwest
Typology	2S (2-Storeys)	Mixed	Mixed
Occupancy	Residential, 1-person (~76 yrs.), Full Time	Residential, 2 persons (> 55 yrs.), Part Time	Commercial (Guest House), Irregular occupancy
Wall Type	Granite Ashlar Masonry	Granite Stone Masonry (internal plastering)	Granite Stone Masonry (internal plastering)
Roof	Gable (wood structure, late & ceramic cover)	Gable (slate cover)	Hip (slate cover)
Insulation	None	Internal (wall + roof)	Internal (wall + roof)
Windows	Single glazed	Double glazed	Double glazed
Heating System	None (firewood stove in kitchen only)	Mobile electrical heater (wood fireplace at living room)	Hydronic panel (wood fireplace at living room 2)
Sensor Location	T1: Bedroom (upper floor)	T7: Bedroom (upper floor)	T12: Bedroom (upper floor)



Figure 1. Case studies (from left: 1, 2 & 3)

Methodology

Case Selection

The selection of case studies followed a rigorous process to identify representative vernacular buildings that met three key criteria: preservation of traditional construction features, willingness of occupants to participate in long-term monitoring, and diversity in retrofit status and occupancy patterns. After extensive fieldwork in MNP, three buildings were selected to form a comparative sample – one unmodified dwelling serving as a baseline (Case 1), and two partially retrofitted buildings with different usage profiles (Cases 2 and 3). This strategic selection allows for meaningful comparison of how vernacular structures perform under both traditional and modified conditions.

Bedrooms were chosen as the primary monitoring locations for several important reasons. As spaces where occupants spend extended periods in thermally sensitive states during sleep, bedrooms provide critical data on comfort conditions. Their typically compact dimensions in vernacular architecture, particularly evident in Case 3's smallest guest

room, also represent the traditional spatial scale of these buildings. This focus on sleeping quarters ensures that recorded data reflects the most thermally significant occupant experiences while maintaining consistency across cases.

The recruitment process revealed significant practical challenges inherent to building studies. Securing participant consent for year-round monitoring in private homes required extensive community engagement and trust-building. The final sample, while smaller than initially planned, successfully captures the essential variables needed for comparative analysis – from completely traditional dwellings to those with selective modern interventions, across different patterns of use.

Monitoring strategy

This study examines the seasonal thermal performance of three vernacular buildings in MNP, Portugal. Case 1 is located in Pinheiro Novo village, while Cases 2 and 3 are situated in Montesinho village. The buildings are presented to reflect a range of envelope conditions and occupancy patterns: Case 1 remains in its original uninsulated state and is occupied year-round by an elderly resident; Case 2 has undergone partial internal retrofitting and is intermittently occupied by a couple; Case 3 is an insulated guesthouse, with heating used only when guests are present.

Environmental monitoring was conducted using TESTO 174H sensors, which record air temperature and relative humidity at 30-minute intervals. These sensors are widely used in building performance research for their reliability in field applications, with an operating range set at -20°C to 70°C and 0–100% relative humidity. In each building, multiple sensors were deployed to monitor thermal conditions, but this paper focuses only on those placed in bedrooms: T1 (Case 1), T7 (Case 2), and T12 (Case 3). These locations were selected to reflect real-life occupancy scenarios and representative thermal zones. Sensor positioning avoided direct solar radiation and proximity to windows, appliances, or ventilation paths.

All sensors were calibrated before installation. Data was collected over a one-year period to capture diurnal and seasonal variations. Where rare data interruptions occurred, extrapolated values were cautiously applied using adjacent data patterns to preserve analysis continuity—e.g., a segment of summer data in Case 2. External temperature data were sourced from an onsite sensor in Case 3 and partially reused for Case 2 during a known gap period (refer to footnote ** in Table 2).

Adaptive Thermal Comfort Assessment

Indoor thermal comfort was evaluated using adaptive comfort models proposed by (Matias, 2010) for the Portuguese climate (also applied by (Fernandes et al., 2019)), which relate acceptable ranges of indoor temperature to the 7-day running mean outdoor temperature (Θ_{rm}). For Case 1, which is entirely unheated and naturally ventilated, comfort limits were calculated using the adaptive model for naturally ventilated buildings:

$$\Theta_0 = 0.43 \Theta_{rm} + 15.6 \pm 3.0^\circ\text{C}$$

This model reflects occupants' thermal adaptation to naturally fluctuating indoor conditions without active heating or cooling. For Cases 2 and 3, where intermittent active heating is present, an alternative adaptive model accounting for the presence of mechanical heating systems is used for the corresponding shift in occupant thermal expectations:

$$\Theta_0 = 0.31 \Theta_{rm} + 17.8 \pm 3.5^\circ\text{C}$$

These two models reflect the different thermal expectations of occupants in unheated versus intermittently heated buildings, with the latter typically exhibiting higher comfort temperatures due to occasional mechanical conditioning.

Indoor air temperature was used as a proxy for operative temperature in all cases. In Case 1, where there is no active heating and surface temperatures are relatively uniform, this assumption aligns with adaptive comfort approaches applied to naturally ventilated, thermally

massive buildings (Fouzanmehr & Vellinga, 2011; Fernandes et al., 2019). In Cases 2 and 3, small-scale active heating systems (electric and hydronic) were occasionally used, which may introduce minor deviations between air and operative temperatures. However, due to the low radiant output and intermittent use of these systems, air temperature remains a reasonable approximation for the scope of this seasonal thermal comfort analysis.

Seasonal Analysis and Interpretation

The analysis was performed on a seasonal basis, with months grouped as follows: winter (Dec–Feb), spring (Mar–May), summer (Jun–Aug), and autumn (Sep–Nov). For each case, the percentage of 30-minute data intervals falling within or outside the adaptive comfort limits was calculated.

Results and discussion

These results are reported in Table 2, and seasonal variations are illustrated in Figure 2. Figure 2 illustrates the long-term indoor temperature profiles for Case 1 (Pinheiro Novo) and Cases 2 and

Table 2. Thermal comfort for selected bedrooms
(3 Case Studies) based on Portuguese adaptive comfort model

	Case-1: Pinheiro Novo		Case-2: Montesinho**		Case-3: Montesinho	
	Adaptive Comfort Limits (%)					
	Within	Outside	Within	Outside	Within	Outside
Winter	0.00	100.00	13.93	86.07	7.81	92.19
Spring	0.00	100.00	21.88	78.12	72.97	27.03
Summer	59.49	40.51	94.30*	5.70*	52.97	47.03
Autumn	0.14	99.86	14.32	85.68	35.21	64.79

* 17/07/2024 17:00:00 to 10/08/2024 00:30:00 (Extrapolation T7 Bedroom air temperatures)

** 05/12/2024 16:30:00 to 23/01/2025 15:30:00 External Temperatures extracted from Case-3

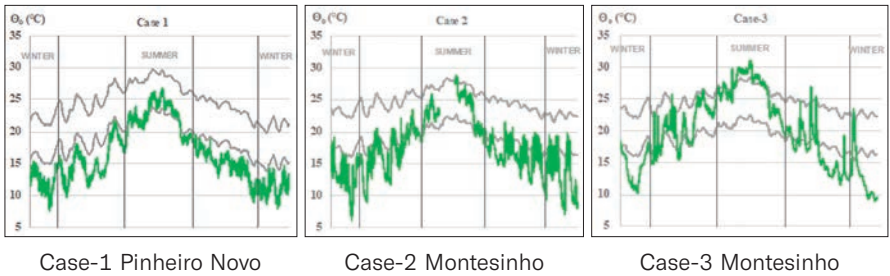


Figure 2. Long-term monitoring temperature data

3 (Montesinho), overlaid with the adaptive thermal comfort limits indicated by the grey bands. In general, it can be seen that summer conditions are comparatively more aligned with the adaptive comfort zone, where several weeks fall entirely within the acceptable range. However, all three cases show a marked deviation below comfort limits during winter, indicating widespread cold stress, particularly in Case 1 where temperatures remain consistently below the lower threshold.

Seasonal Comfort Outcomes and Bioclimatic Reflections

The seasonal thermal comfort results in Table 2 offer critical insights into how vernacular buildings in MNP perform under adaptive thermal criteria. The winter and summer periods, representing climatic extremes, are of particular interest, and they reveal important contrasts in both passive performance and the influence of occupant behaviour.

In winter, all three buildings experience significant thermal discomfort, though for different reasons. Case 1, the only uninsulated building and the one occupied year-round by an elderly resident, shows complete non-compliance with the adaptive comfort model (0.00% within limits). Despite having substantial thermal mass through thick granite masonry, the bedroom sensor (T1) consistently records cold temperatures due to a combination of minimal solar exposure, unheated conditions, and weak internal heat gains. The room is positioned internally, without external windows, and while it benefits from party walls with adjacent homes and is buffered by surrounding spaces, the lack of direct heat input renders these advantages insufficient in the face of prolonged cold. The

wooden roof structure likely contributes to nocturnal heat loss, and the northeast orientation of the front façade limits winter solar gains. Thus, even in full-time residential use, Case 1 demonstrates how vernacular thermal inertia can delay but not eliminate indoor cold stress.

Case 2, although retrofitted with internal insulation and double glazing, still performs poorly in winter, with only 13.93% of monitored periods falling within the adaptive comfort range. This outcome is not a reflection of envelope failure, but of occupancy patterns: the couple residing in this house is present only fortnightly. When present, they use a mobile electric heater in the bedroom, which likely raises temperatures locally during occupied nights. However, these comfort gains are diluted in the seasonal data by the unoccupied and unheated periods. The monitored room (T7) is located on the upper floor and bounded by an external wall that faces northwest — a direction that receives limited solar radiation during winter. Despite the improved envelope, the room's orientation and episodic heating result in persistently cold indoor conditions during extended absences.

Case 3, a larger guesthouse with a hydronic wall panel (HWP) heating system, shows only 7.81% comfort compliance in winter. Like Case 2, this is not solely due to underperformance of the envelope or the heating system, but rather to potentially inconsistent occupancy. Heating is switched on only when guests are present, and during unoccupied periods the building is intentionally left unheated to conserve energy, especially during low-season winter. The monitored bedroom (T12) is smaller relatively to other rooms, in line with vernacular typologies, and this compact volume could allow for rapid heating during guest stays. However, the room is also located on the upper floor with a northwest-facing external wall, exposed to prevailing winter winds and low solar input. This configuration, combined with periods of non-use, explains the low comfort percentage during the cold season.

In contrast to winter, the summer period presents less critical thermal stress, especially in buildings that retain vernacular features. Natural ventilation is more feasible during this season, through open windows or cross-breezes, often preventing overheating. Case 2

performs exceptionally well, with 94.30% of the time within the adaptive comfort range, demonstrating the benefits of insulation, thermal mass, and stable occupancy. A brief portion of the data was extrapolated due to sensor interruption, but this does not significantly affect the overall trend. The room's southeast-facing external wall may allow morning solar gains, but effective thermal buffering and possibly user-led ventilation appear to maintain acceptable indoor conditions.

Case 1 also performs relatively well in summer, with 59.49% comfort compliance with the best of all seasons for this building. Its thick granite walls and fully internal room (without external windows) reduce direct solar exposure and protect against overheating. However, the remaining 40.51% of discomfort primarily occurs at the lower end of the comfort band, in which, indoor temperatures falling below the adaptive threshold, especially during the cooler early and late summer weeks. This cold-side deviation, although less critical than winter discomfort, indicates the limitations of a thermally inert envelope without solar gains or other controls.

In contrast, Case 3 shows only 52.97% summer comfort compliance, with most discomfort events occurring at the upper end of the comfort zone, such as overheating. Several factors may contribute: the room (T12) is compact and has a southeast-facing external wall, increasing exposure to early-day solar radiation. Combined with internal insulation, this may lead to heat accumulation, especially due to the absence of effective night ventilation. The room has only one window, eliminating the possibility of cross ventilation, and guests typically close the door while sleeping, making it unlikely that the door would be opened to promote ventilation during these periods. Additionally, as a guesthouse with intermittent occupancy, inconsistent ventilation practices may further exacerbate indoor temperature peaks during warmer spells.

These results underscore the influence of orientation, room placement, envelope design, and user patterns. While the southeast-facing walls in Cases 2 and 3 introduce some summer solar exposure, Case 2 benefits from thermal moderation and consistent use, whereas Case 3, despite retrofitting, struggles with internal heat build-up.

Case 1, by contrast, avoids overheating but tends toward underheating due to isolation from external gains. Overall, vernacular bioclimatic strategies — such as thick masonry, compact volumes, and minimised glazing — prove effective in buffering summer heat but may require complementary ventilation strategies to address both ends of the comfort spectrum.

Overall, Table 2 reinforces the broader observation that thermal comfort in vernacular buildings remains highly variable across seasons and cases. Passive strategies, while helpful, are insufficient on their own, especially under prolonged cold conditions. Intermittent occupancy in Cases 2 and 3 leads to low winter comfort not because of poor design, but due to the absence of heating when spaces are unused — a logical and energy-conscious decision. Conversely, full-time use in Case 1 without adequate heating results in sustained discomfort. In summer, insulation and orientation offer clear benefits, particularly when combined with moderate internal heat gains and passive cooling strategies. These dynamics underline the need for integrated, context-sensitive interventions that consider both envelope performance and user behaviour in vernacular retrofitting approaches.

Conclusions

This study presents a preliminary evaluation of the seasonal thermal performance of three vernacular buildings in Montesinho Natural Park, monitored over a full annual cycle using in-situ sensors. The selected buildings represent different levels of envelope intervention and occupancy patterns, ranging from a fully uninsulated, continuously inhabited dwelling to two insulated buildings with intermittent heating use and variable occupancy. Through adaptive comfort analysis and seasonal data interpretation, the study offers a comparative understanding of how traditional construction, retrofitting measures, and occupant behaviour jointly influence indoor thermal conditions.

The results indicate that thermal comfort is not consistently achieved throughout the year in any of the three buildings. Winter emerges as the

most critical season, with all cases experiencing prolonged discomfort despite varying degrees of insulation or heating. Case 1 highlights the limitations of passive vernacular design in the absence of active heating, while Cases 2 and 3 demonstrate that insulation can significantly reduce heat loss — but only achieves meaningful comfort when supported by regular heating use.

In contrast, summer performance generally improves, with insulated buildings maintaining longer periods within the comfort range. However, the analysis also reveals that insulation may increase the risk of overheating during hotter periods, particularly in smaller, southeast-facing rooms with inconsistent ventilation. In such cases, heat gains may become trapped, reducing the effectiveness of the intervention. This underscores the importance of adaptive actions, such as window opening and cross-ventilation, in managing indoor temperatures during summer and preventing discomfort caused by accumulated heat.

Spatial orientation and room positioning also influence thermal outcomes: while southeast-facing walls provide useful solar gains in winter, they can contribute to overheating in summer if not properly mitigated. These findings reinforce the notion that vernacular strategies, such as thermal mass, compact form, and reduced openings, offer valuable buffering effects but are not sufficient on their own to ensure year-round thermal autonomy. Instead, their effectiveness depends on both user behaviour and the integration of context-sensitive adaptations.

This paper serves as a foundational step toward a broader research agenda. Future work will involve dynamic simulation of energy performance, thermal efficiency, and thermal comfort, using the monitored data to validate building models. These simulations will inform retrofit strategies that prioritize bioclimatic principles while respecting the architectural heritage and climatic context of the region. By combining field-based evidence with simulation-driven design exploration, the aim is to develop low-impact, adaptive interventions that enhance indoor environmental quality in cold-climate vernacular buildings — advancing both conservation and climate resilience goals.

Acknowledgments

This work was funded by FCT / MCTES through the R&D project Sustainability-led approaches for the rehabilitation and revitalization of the cultural built heritage of Montesinho Natural Park (INHAVIT), reference MTS/BRB/0086/2020 (<https://doi.org/10.54499/MTS/BRB/0086/2020>). Additional support was provided by FCT through a PhD grant (reference 2024.01482.BD), and by FCT / MCTES through national funds (PIDDAC) under the R&D Unit Institute for Sustainability and Innovation in Structural Engineering (ISISE), reference UID/04029/ Institute for Sustainability and Innovation in Structural Engineering (ISISE) and under the Associate Laboratory Advanced Production and Intelligent Systems (ARISE), reference LA/P/0112/2020. Special thanks to Dr. Jorge Fernandes for his advices in applying the adaptive model, which was a key contribution to this paper.

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Cost-effective energy renovation of residential buildings: from urban districts to small municipalities

13



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Introduction

Buildings and urban planning play a very important role in the environmental impact of human activity on the planet. The main uses of buildings have remained almost unchanged since ancient times, but the impact of the construction industry on the environment has increased significantly in the age of industrialized society. International reports on energy consumption indicate that, in Europe, approximately 50 % of energy consumption is accounted for by buildings and that they are responsible for 30 % of greenhouse gas emissions.

Given that climate change, generated mainly by this type of emissions into the atmosphere, is a global problem, states and supranational institutions are permanently implementing and updating policies and strategies to reduce the environmental impact of buildings, both the newly constructed and the existing ones that are being rehabilitated. These actions are aligned with the 17 Sustainable Development Goals set out by the United Nations General Assembly in the 2030 Agenda, which have been adopted in their legislation by the signatory countries.

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Strategies to improve the energy efficiency of buildings and reduce their environmental impact are very varied and there are economic, environmental, social, technological, urban planning and administrative indicators to assess this type of action. Among the lines of action proposed for an efficient use of energy and for the creation of sustainable cities and communities, some of the most important are the actions to energetically rehabilitate the existing building stock and its decarbonization. Especially for their capacity to improve people's quality of life and health, as well as to reduce energy poverty.

The environmental sustainability of a building has many approaches, but it could be defined as the design and construction of a building that uses methods and materials that do not compromise the environment or the health of its occupants, workers, or the general public, both of the current and future generations. The implementation of this idea must be carried out in each and every phase of the building and its urban area of influence: design and conception, construction, operation, maintenance and demolition, and must be quantifiable and evaluable.

In this sense, the simulation of a building's behavior plays an increasingly important role in the design and operation of that building to achieve low energy consumption and reduced environmental impact. It is based on the use of computational mathematical methods to represent the building's physical characteristics, its current or future operation, control strategies and energy systems. The use of building simulation is widespread in the design and conception phase of a building, while its use for evaluating the operation, control or rehabilitation of an existing building is more limited.

There are many building energy simulation programs available and they are used to answer a wide variety of questions from architects, engineers, builders, users and other building stakeholders. It is therefore important to select the right simulation program for the respective purpose in order to avoid modelling errors. In addition, a thorough knowledge of the program in question is required for the definition of simulation models of a certain complexity.

Similarly, the use of appropriate building data for the building simulation is very important. For example, when modelling new buildings, the professional simulator must anticipate how the building will be used and accurately define the simulation objectives. In contrast, when simulating existing buildings, field inspections, tests and energy audits can be used to establish reliable input data for the energy models. Without good input data it is impossible to make a good energy simulation of the initial state of a building, nor to analyze technically, functionally and economically feasible improvement measures.

Background: Project IEA EBC Annex 75 – Cost-effective building renovation at district level combining energy efficiency & renewables

The transformation of existing buildings into low-emission, low-energy buildings is paramount in cities, where many buildings continue to rely too heavily on the use of fossil fuels for their thermal facilities. In addition, there are specific opportunities to develop and leverage district-level solutions at the urban scale.

In this context, the International Energy Agency Research Project: IEA EBC Annex 75 – Cost-effective Building Renovation at District Level Combining Energy Efficiency & Renewables, closed on October 10, 2023, has had as its main objective to determine the cost-effectiveness of various approaches combining energy efficiency improvement measures and renewable energy implementation measures at district level. Finding the balance between both types of actions for the existing building stock has been complex. Furthermore, guidance has been provided to policy makers, companies working in the field of energy transition as well as building owners to cost-effectively transform the current pattern of energy use in the existing building stock in cities towards low-emission and low-energy solutions.

Approximately fifty researchers from thirteen countries have participated in this Project, and the Principal Investigator (PI) has been Dr. Manuela Almeida, from the University of Minho (Portugal). All the information related to this Project, as well as the publications, are

available in open access from its web page: <https://annex75.iea-ebc.org/>.

The following is a brief description of the work done in two existing housing neighborhoods, Picoto in Portugal and Adurtza in Spain, to understand the process and assess how to apply it to the small towns that make up the Montesinho Natural Park in northern Portugal. More detailed information can be found in the following publication: Briones-Llorente R et al. 2024. Two case studies of district-level refurbishment combining energy efficiency and renewable energies. *Anales de Edificación*, Vol. 10, N. 2, 33-39, DOI: 10.20868/ade.2024.5468.

A similar procedure has been followed for the study of both neighborhoods. In a first part, the existing documentation of the execution projects has been studied, on-site visits have been made to verify the previous data and to complete the information, and some infrared thermography tests have been carried out.

Based on this previous information, we proceeded to the geometric and constructive characterization of the buildings. Energy simulations of the current state of the buildings in each neighborhood have been carried out using the SG SAVE program, which is combined with Open Studio, and which is supported by SketchUp for 3D modelling.

Finally, and in view of the results obtained, energy efficiency improvement measures have been proposed at district level, focusing on thermal envelopes and, in Adurtza, also on ventilation with heat recovery. Multiple energy simulations have been carried out with these measures, and the combination of the best sets of improvement measures with options for the renovation of their energy facilities, prioritizing renewable energies, has been studied.

The Picoto Housing Complex (Braga, Portugal) consists of fifty double-height single-family semi-detached social housing units, grouped in seven blocks on a hillside site, as can be seen in (Figure 1a). (Figure 1b) shows the energy modelling of one of the townhouse alignments. The approximate construction date is 1990, and its state of preservation is quite poor. The living area of 1,767 m².

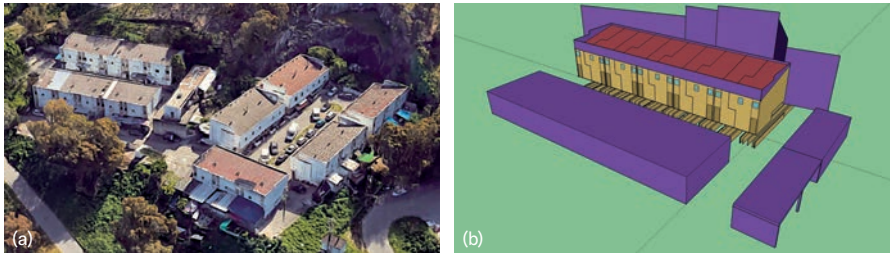


Figure 1. Images of the Picoto Housing Complex: (a) Aerial view. Source: Google Maps. (b) Energy modelling

The city of Braga is located in the interior of the extreme north of Portugal, less than 40 kilometers from the Atlantic coast, and at an altitude of 215 meters above sea level. It has a temperate climate, with wet winters and dry summers.

The thermal envelope of the dwellings consists of single-leaf ceramic masonry façades without thermal insulation, aluminum carpentry without thermal break and with single glazing, and roofs with uninsulated asbestos cement panels. With respect to the facilities, they only have hot water heaters powered by natural gas and portable electric radiators.

Five packages of thermal envelope improvement measures have been studied, based on:

- Implementation of thermal insulation on the outside of the façades (EPS or MW), with thicknesses ranging from 80 mm to 200 mm.
- Replacement of carpentry with aluminum or PVC frames, with thermal break, and double glazing, in some cases with solar control and low emissivity.
- Replacement of the pitched roof with metal sandwich panels with thermal insulation core (PUR or MW), with thicknesses between 30 mm and 100 mm.

Five new energy supply systems have been proposed for the facilities:

- Conventional decentralized.

- Centralized with air heat pump.
- Centralized with biomass boiler.
- Centralized with air heat pump and solar thermal energy.
- Centralized with air heat pump and photovoltaic solar energy.

Multiple results have been obtained related to indicators such as primary energy consumption, CO2 emissions, and annual cost including investment and maintenance expenses.

The cost-effectiveness study, which serves to compare the current state, improvements in the envelope, and interventions that do not improve the envelope but only the facilities, and combinations of all of them is of special importance.

In addition, investment, energy and maintenance costs over 30 years have been taken into account. A lifespan of 30 years for the envelope, and 15 to 20 years for facilities, have been considered. An annual 4 % has been applied to both the discount rate and the increase in the price of energy. It is important to note that the reference case, the current state, also has maintenance costs, even if they do not imply any energy improvement, so that not rehabilitating always has a cost.

(Figure 2) presents the results for the Picoto neighborhood. The lowest annual cost is achieved by combining a package of reduced insulation improvement measures with the centralized energy system

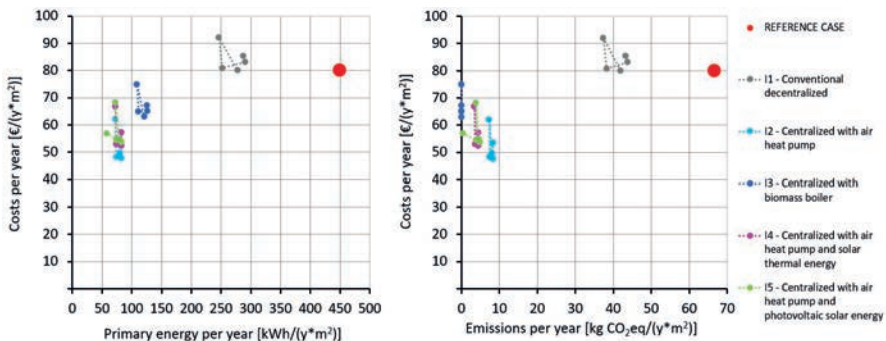


Figure 2. Summary of the combinations of energy envelope improvement packages with new energy systems for the Picoto Housing Complex. Source: IEA EBC Annex 75 (International Energy Agency)

with heat pump; the lowest primary energy consumption is achieved by combining a package of medium insulation improvement measures with the centralized energy system with heat pump and solar PV; and the lowest CO₂ emissions, almost zero, are achieved by combining any package of envelope improvement measures with the centralized energy system with biomass boiler.

The central part of the Adurtza neighborhood is made up of twenty-two residential blocks of five and three floors and two different typologies, as shown in (Figure 3a). (Figure 3b) shows the complete energy modelling of the neighborhood. The construction spans the 1950s and 1960s, and the buildings have not been renovated since then. The total living area is 13,870 m².

The neighborhood of Adurtza is located in the city of Vitoria-Gasteiz, which is located in the interior of the Basque Country, less than 80 kilometers from the Cantabrian coast, and at an altitude of 540 meters above sea level. Its climate is oceanic, with cold, wet winters and cool summers.

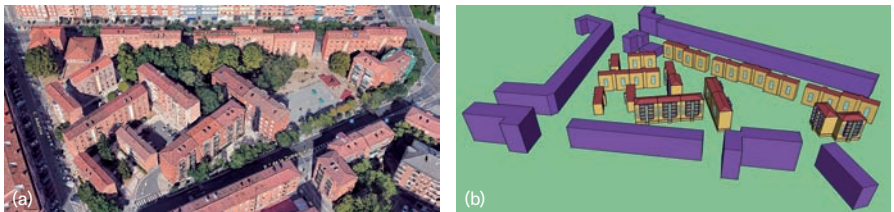


Figure 3. Images of the Adurtza Neighborhood: (a) Aerial view. Source: Google Maps. (b) Energy modelling

The thermal envelope of the dwellings consists of double-sheet ceramic masonry façades without thermal insulation, aluminum carpentry with thermal bridge break and double glazing, and uninsulated ceramic tile roofs. The thermal facilities are individual and mixed for heating and domestic hot water, with 90 % of the boilers being natural gas and the other 10 % electric.

Six packages of thermal envelope improvement measures have been studied, based on:

- Implementation of thermal insulation on the exterior of the façades (EPS), with thicknesses ranging from 65 mm to 125 mm.
- Replacement of carpentry with PVC frames with thermal bridge break and double glazing with low emissivity.
- Inclusion of thermal insulation (EPS) under the sloped tile roof, with thicknesses between 80 mm and 190 mm.
- In two of the best combinations above, ventilation systems with heat recovery have been added, with an efficiency of 85 %.

Seven new energy supply systems have been proposed for the facilities:

- Mixed decentralized with air heat pumps.
- Decentralized with air heat pumps for domestic hot water and electric heating.
- Centralized mixed for buildings with air heat pump.
- Centralized mixed for buildings with biomass boiler.
- Centralized by district with biomass boiler.
- Centralized by mixed district with geothermal heat pump.
- Centralized by district mixed with air heat pump.

In a similar way to that described for the Picoto neighborhood, several indicators have been obtained and a cost-effectiveness study has been carried out. (Figure 4) shows the results for the Adurtza neighborhood.

The lowest annual cost is achieved by adding a district energy system with biomass boiler to the current state; the lowest primary energy consumption is achieved by combining the higher insulation improvement package with the district energy system with geothermal; and the lowest CO₂ emissions are achieved by combining the two higher insulation improvement packages with the centralized building and district energy systems, both with biomass boiler.

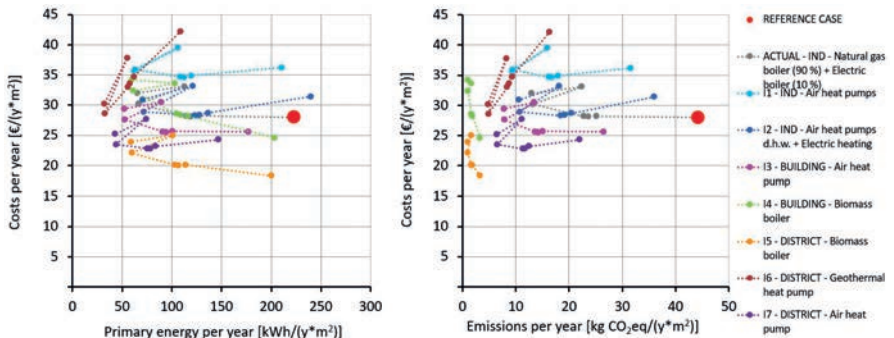


Figure 4. Summary of the combinations of energy envelope improvement packages with new energy systems for the Adurtza neighborhood. Source: IEA EBC Annex 75 (International Energy Agency)

In both case studies, Picoto and Adurtza, the results confirm the technical and economic feasibility of the proposed rehabilitations. In neither of the two neighborhoods does the current state obtain the best cost-effectiveness, the lowest primary energy consumption or the lowest CO₂ emissions. Thus, this procedure has been validated to facilitate the decision making of the various actors involved in energy renovations at the neighborhood level. It will be interesting to increase the number of measures tested to strengthen the database of each neighborhood, as well as to incorporate the Life Cycle Analysis of the improvement measures and of the proposed energy systems.

Proposal: Application of cost-effectiveness studies to the small municipalities of the Montesinho Natural Park

The Montesinho Natural Park is located in the region of Trás-os-Montes in northeastern Portugal, in the northern part of the municipalities of Bragança and Vinhais, which are part of the Terra Fria Transmontana. It has an area of 74,230 hectares, where about 8,000 people live distributed among 88 municipalities. It presents, therefore, a low population density, with dispersion, and an aging population.

This context is totally opposite to that of the two cases studied in the Annex 75 project, which are in densely populated urban environments

with all the available infrastructures. The construction typology is always the same in each of the two neighbourhoods, in both cases from the second half of the twentieth century, which facilitates their characterization.

In the work developed to analyse the building typology of the municipalities of the Montesinho Natural Park, more than 2,000 buildings were studied, identifying 23 different categories among 13 localities of the park: Montouto, Sandim, Pinheiro Velho, Pinheiro Novo, Moimenta, Montesinho, Aveleda, Rio de Onor, Guadramil, Labiados, Quintanilha, Gimonde and Cova da Lua. In most cases, they are alignments of individual houses, representative of the vernacular architecture of this territory, and examples of self-construction. This circumstance makes the constructive characterization of the buildings difficult, as well as their analysis and monitoring, since we have to deal with many owners.

For the time being, three case studies of dwellings in the villages of Pinheiro Novo and Montesinho have been selected. The three buildings are small, two-story dwellings, built with traditional materials, masonry or granite ashlar walls and wooden floors and roofs (Figure 5). One of them is used as a permanent dwelling (Figure 5a), another as a seasonal dwelling (Figure 5b) and another as tourist accommodation (Figure 5c). The latter building is the one that has undergone the most constructive alterations in architectural renovations, although all of them maintain the traditional stone masonry walls and wooden slabs as the main construction system.



Figure 4. Summary of the combinations of energy envelope improvement packages with new energy systems for the Adurtza neighborhood. Source: IEA EBC Annex 75 (International Energy Agency)

At the time of writing this publication, the geometric and constructive description and the monitoring of the three buildings to obtain annual data on indoor and outdoor temperatures and relative humidity have been carried out

As a first approximation, simplified static energy calculations are being carried out, taking monthly average values for both climate data and output variables. This, although it offers less detailed and rigorous results, has a lower computational cost, and can be used for a later sensitivity study.

In addition, dynamic hourly energy modelling is starting to be designed, to obtain much more accurate results of demands, consumptions, CO₂ emissions, and other variables related to indoor comfort. Once the current behavior of the three case studies is known, and calibrated with the data obtained from the monitoring, it will be possible to study packages of measures to improve energy efficiency, focusing on the reduction of energy demands through passive measures. By means of a cost-effectiveness study, the best ones, which must also be technically, functionally and economically feasible, will be selected.

The latter process, unlike the cases of the two neighborhoods, presents some additional challenges:

- The identity of the traditional architecture of the municipalities must be maintained, which limits some actions that would be of immediate application and very beneficial in energy terms, as is the case of insulation systems on the exterior of the façades.
- They are old buildings, and in some cases, with lack of maintenance, so it may be necessary to include rehabilitation work.
- The small size of the buildings, their variety and their geographical dispersion define a dispersed urbanism, so the scale factor of the energy rehabilitation works of the most dense and uniform urban districts is lost.
- An attempt should be made to carry out the rehabilitation of buildings in batches, grouped by municipalities, in order

to obtain better prices for the supply and execution by the contracting companies.

- Regarding the facilities, it would be very interesting to study the possibility of establishing small energy communities based on renewable energies and self-consumption, which would also help in the maintenance and management of the forest masses and with it, the generation of local employment that implies the settlement of the population.
- Likewise, the use of local raw materials of sustainable origin should be analyzed to improve the sustainability of the actions, as well as to have an impact on the objectives of employability and population maintenance.



The impact of glazed balconies on thermal comfort in vernacular northern Portuguese architecture

14

Jorge Fernandes¹, Ricardo Mateus¹



Introduction

Construction is one of the largest and most active sectors of the global economy, having a significant impact on the economy, energy use, and greenhouse gas emissions (European Commission 2022). As such, it is also a strategic sector for implementing measures to increase energy efficiency and promote the use of renewable energy sources. In response to this issue, the European Union has established ambitious targets to decarbonise the building stock by 2050. As part of this effort, recent regulations under the Energy Performance of Buildings Directive (EPBD) mandate the assessment of life-cycle Global Warming Potential (GWP) for new buildings, starting in 2030 (European Parliament 2023). In this regard, the Directive states that it is important to ensure that measures aimed at improving the energy performance of buildings do not focus solely on the building envelope, but include all relevant elements and technical systems, notably passive strategies aimed at reducing energy demand for heating/cooling, lighting, and ventilation, thereby improving indoor environmental quality. The Directive also emphasises the importance of promoting research into solutions that can enhance the energy efficiency of buildings while preserving and conserving cultural heritage. To improve building performance, it is therefore necessary to reduce the reliance on active systems—which

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have a significant influence on buildings' life-cycle impacts—and to prioritise architectural form (adapted to the climate) and passive systems.

In this context, vernacular architecture is a type of construction that warrants analysis, as the strategies developed to respond to local climatic conditions operate passively, have a low technological profile, and do not rely on fossil fuels to function. This makes them particularly suitable for application in contemporary buildings, especially in the design of passive buildings (Fernandes et al. 2020; Martín et al. 2010).

Among the various passive design strategies, glazed balconies have emerged as a promising solution for improving thermal performance in residential buildings across diverse climatic contexts, particularly in regions with cold winters. This article presents the results of a study on the influence of glazed balconies—as an example of a passive heating strategy—on the thermal comfort of vernacular buildings in northern Portugal, emphasising their contribution to energy efficiency, the importance of preserving such strategies, and their potential application in new constructions.

Glazed balconies as a passive heating strategy

In the northern interior of Portugal, in response to a climate with harsh winters, vernacular architecture developed specific mitigation strategies. Glazed balconies, typical of the northern region—particularly in the areas of Beira Alta and Trás-os-Montes (Fig. 1) — are an example of such passive techniques. Buildings in these regions are typically oriented to take full advantage of solar exposure in order to maximise heat gains during the cold season. The balconies are usually well positioned between south and west, the quadrant that receives the most hours of intense sunlight during winter, and which is also the most sheltered from prevailing winds. They are always located on the upper floors to maximise solar exposure and function as an indirect gain system (greenhouse effect), helping to heat adjacent interior spaces.

Being an attached element that is physically separated from the interior living spaces, the glazed balcony simultaneously captures solar gains and reduces heat losses. In situations where heat gains are undesirable, such as during summer, the balcony space—by opening its windows—can promote natural ventilation for cooling and act as a shading device for the interior and lower walls (Fig. 2). Additionally, considering the low levels of natural light and thermal comfort in many of these buildings, balconies were traditionally used not only as extensions of the living space, but also as privileged areas for work, taking advantage of solar warmth and natural light, particularly on winter days.



Figure 1. Glazed balconies in Beira Alta – (left) Granja do Tedo, Tabuaço; (right) Salzedas, Tarouca.

Although balconies are the most relevant passive technique in this type of building, they were often combined with other strategies (e.g., reducing heat losses through thatched roofs and low shape factor; high thermal inertia; or harnessing the heat from animals kept in ground-floor shelters). This combination aimed to improve overall thermal performance. The range of strategies highlights the harsh living conditions and the need to understand and make use of available resources to mitigate the cold. Quantitative studies on the performance of glazed balconies and their impact on the thermal comfort of buildings in this region have demonstrated their effectiveness and potential to reduce heating energy needs, as will be presented below.

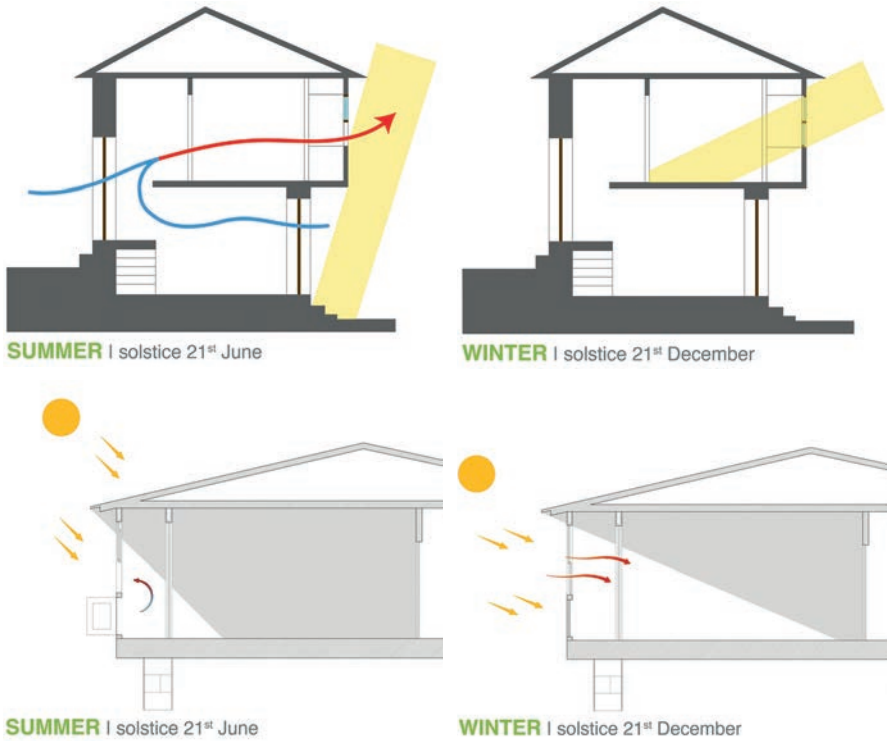


Figure 2. Schematic section of the glazed balcony operation. Top: Case study in Granja do Tedo, Tabuaço; Down: Case study in Salzedas, Tarouca.

The impact of balconies on thermal comfort

In the Beira Alta region, specifically in the Douro area, to understand the influence of balconies on thermal comfort conditions, several case studies were monitored (Figure 1), located in the municipalities of Tabuaço and Tarouca. The two cases presented in this article are representative of the region's vernacular architecture, with construction elements relatively well preserved and close to their original form. In both cases, the glazed balconies, built with wooden structures, are oriented toward the southern quadrant. In the case of the building in Salzedas, Tarouca, particular attention is drawn to the two levels of openings in the glazed balcony: wooden shutters on the lower

section and sash windows on the upper section, designed to maximise ventilation conditions during the summer.

In the studied locations, average winter temperatures range between 7.5–10°C, and summer temperatures between 22.5–25°C (AEMET 2011). Winter is the harshest season, with average maximum temperatures below 15°C, average minimums around 5°C, and 20–40 days with minimum temperatures $\leq 0^\circ\text{C}$ (AEMET 2011). Annual solar radiation totals approximately 2,300 hours. As such, the passive strategies employed focus mainly on maximizing solar gains and reducing heat losses during the winter months.

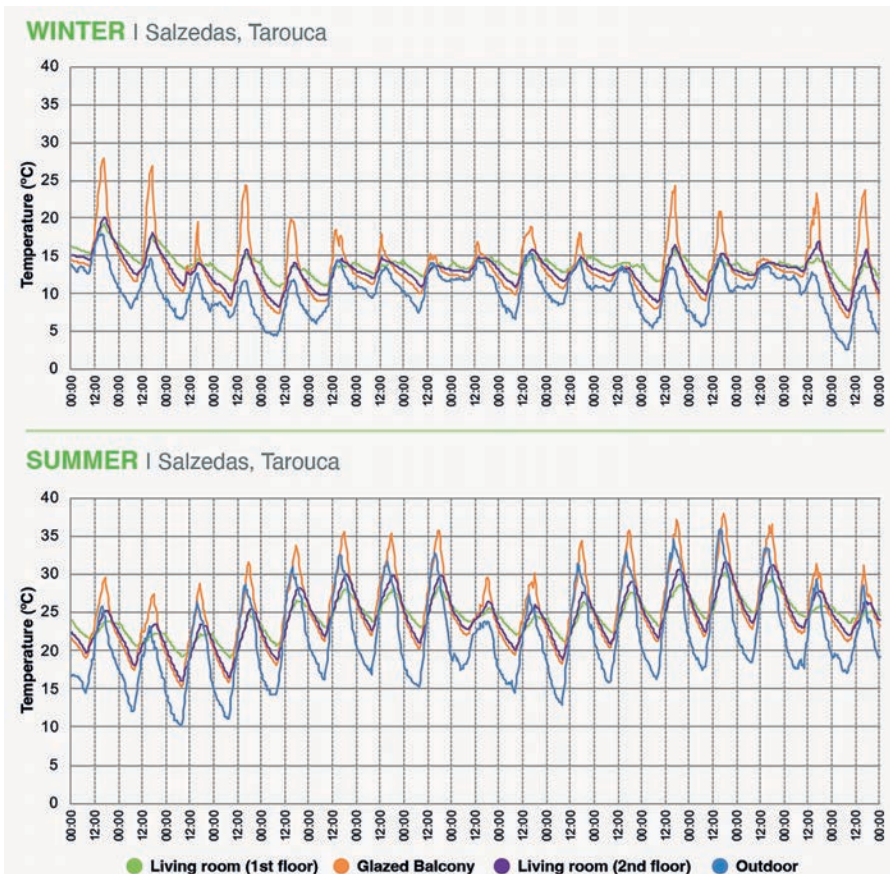


Figure 3. Air temperature profiles in the Salzedas building (excerpts from winter and summer monitoring)

In the monitoring conducted—and using the building in Salzedas as an example (performance data for the building in Granja do Tedo is available as open access in (Fernandes et al. 2020)) — it was observed that, in winter, interior temperatures in the balcony on sunny days reached peaks of around 25°C, even up to 28°C, with an average approximately 10°C higher than the outdoor temperature (Fig. 3). During this season, comparing the temperature profiles of different spaces, the heat gains in the balcony are shown to be significant. However, due to a lack of ventilation control and insufficient insulation of the envelope, nighttime heat losses are considerable. In summer, the balcony frequently exceeded 30–35°C, close to outdoor values, while the two living rooms recorded lower temperatures, around 25°C (Fig. 3). The lack of summer ventilation in the balcony to dissipate heat resulted in daily occurrences of overheating.

In the thermal comfort assessment, using an adaptive comfort model—adjusted to the Portuguese context and most appropriate for naturally ventilated buildings—the winter results show that the spaces adjacent to the balconies experience conditions near the lower limit of the comfort zone (Fig. 4). However, the heat gains from the balcony help reduce heating needs and, depending on the day, it is possible to reach indoor temperatures above 18°C using only passive means (Fig. 3). In summer, the operative temperature in these spaces is at the

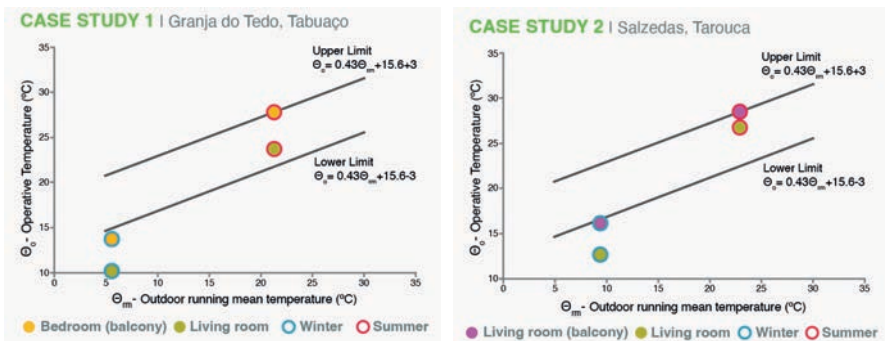


Figure 4. Adaptive comfort chart: comfort temperature (operative temperature) in the case studies on representative winter and summer days

upper limit of the comfort zone. In both case studies, the rooms located on the lower floors, which do not benefit from the glazed balconies, recorded lower operative temperature values compared to the spaces adjacent to the balconies. Occupant actions—particularly promoting ventilation in summer—would have positively contributed to improving thermal comfort conditions in the spaces next to the balconies.

The analysis of the results showed that they do not reflect an optimised performance of the balconies' functioning and potential. Constant convective heat exchange between the balcony and the adjacent space—without occupant intervention to close (in winter) or open (in summer) the windows to reduce or promote heat loss, respectively—prevented the balconies from operating at their full potential. In this context, although comfort conditions were within acceptable limits in summer and close to the lower limit in winter, it is worth highlighting that occupant action would have positively contributed to improving both performance and thermal comfort conditions.

Building energy simulation to assess the performance of glazed balconies

Building energy simulation is a powerful tool to test the effectiveness of passive strategies since it is impossible to monitor all buildings. In this section are presented the results of the energy simulation under dynamic conditions of building models based on the Granja do Tedo's case study (Fernandes 2020). The purpose of simulating this case study was to compare the effectiveness of glazed balconies on energy performance of buildings located in a cold winter climate.

To simplify the process of simulation and analysis, were defined a set of conditions that were kept stable or unchanged between the simulation of the several scenarios. In Table 1 are described the conditions and input information considered. Although simplified, the building models mimic the characteristics of the original building (construction systems; operation; etc.). Nonetheless, to carry out and simplify the comparative analysis, for some parameters were considered values based on standards and/or national legislation. The comparative analysis of the

different scenarios is based on the annual energy demand for heating/cooling (kWh/m²).

The aim is to compare the annual energy demand for different scenarios. The base model for comparison is the case study building, but in the simulation was introduced a semi-exposed wall (*tabique*) between the balcony and the indoor rooms (as existed in the building before the refurbishment), connected by two doors (Fig. 5). In the scenarios defined only the southwest façade was modified, being all

Table 1. Building energy simulation conditions, input information and comparison purpose

Weather data (EPW) [131]	Bragança
Climate zone [132]	
Winter: I1-I3	I2-V3
Summer: V1-V3	Heating Degree Day: 1764 °C
Note: 1. Mild; 2. Medium; 3. Harsh	Summer mean outdoor temperature: 22,7 °C
Internal heat gains [132]	4 W/m ²
Air change rate	Minimum 0,6 ach
Heating/Cooling temperature setpoint	18-25°C
Operation Schedules	
Internal gains	On 24/7
Windows opening	Balcony: Summer – Open 7 a.m. to 7 p.m. All other days: Closed. Other windows: Summer – Open 7 to 9 a.m. All other days: Closed.
Window shading	Balcony: Summer – On 9 a.m. to 7 p.m.; Off 7 p.m. to 10 p.m. All other days: Off 9 a.m. to 7 p.m.; On 7 p.m to 7 a.m. Other windows: All days Off 7 a.m. to 7 p.m.;
Doors opening	Entrance door Summer: Open 7 to 9 a.m.; All other days: Closed.
HVAC (18-25 °C)	On 24/7
Mechanical ventilation (to assure the minimum 0.6 ach)	On 24/7

the other conditions unchanged. The scenarios defined for simulation and comparison in this case are the following (Fig. 5):

- i) Case study building with glazed balcony (semi-exposed wall in *tabique* dividing the sunspace from bedroom and bathroom, and connected by two windows);
- ii) Building with balcony, external wall in *tabique* facing SW in first floor with two windows.
- iii) Building with all external walls in granite and two small windows in the SW façade.



Figure 5. Models of the three scenarios considered in simulations. (left) glazed balcony; (center) balcony; (right) no balcony, small windows.

The results of the simulations reveal that the building with the glazed balcony has the lowest annual energy demand for heating/cooling and the best performance in both conditions. The other two scenarios have a higher energy demand and are very similar, where the scenario with small windows is the worst on heating due to having less direct solar gains.

In the analysis of the three scenarios for the annual energy demand for heating/cooling it is clear that the sunspace effect of the glazed balcony has a positive effect. Focusing the analysis only on the energy demand for the bedroom contiguous to the glazed balcony, the scenario with the glazed balcony has the best performance both for heating and cooling (Fig. 6). Regarding heating, the bedroom in the scenario with the glazed balcony needs less $\approx 25\%$ than the scenario with balcony and less 35% than the scenario with small windows (Figure 6). Regarding cooling, it also has the best performance.

As a sunspace, on winter sunny days the glazed balcony can reach considerable higher temperatures than the ones recorded outdoors (Fig. 7). In the two winter weeks with the lowest minimum temperatures, it is possible to verify that on sunny days the maximum temperature inside the glazed balcony is frequently $\approx 15^{\circ}\text{C}$ higher than outdoors,

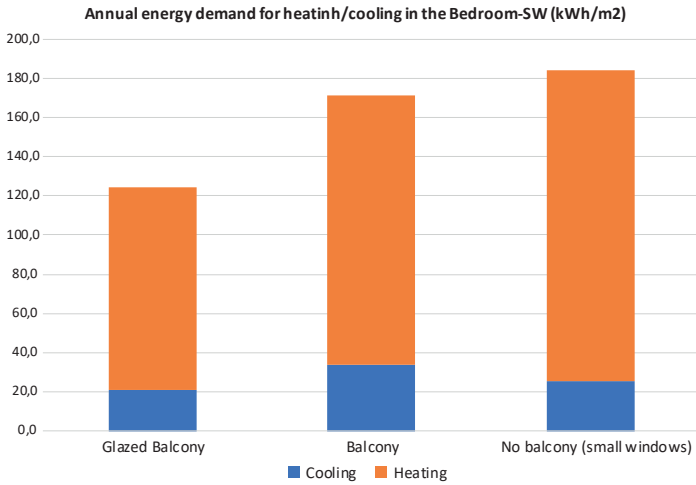


Figure 6. Annual energy demand for heating and cooling in the Bedroom-SW

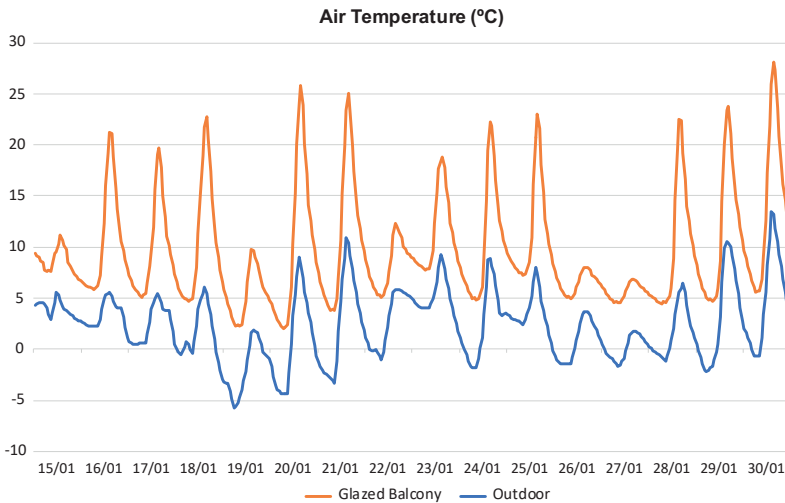


Figure 7. Air temperature in the glazed balcony and bedroom in the coldest winter weeks

with temperature peaks surpassing the 25°C in some days (Fig. 7). By comparing the days with the highest temperature peaks inside the glazed balcony with the solar radiation on those days, it is possible to verify that exists a direct relation between the days with higher solar radiation and the days with higher peaks.

Although the glazed balcony has been conceived to work as a sunspace during winter, during summer by opening windows to promote ventilation and by working also as shading element, this strategy shows to be effective in both seasons.

Concluding remarks

The results demonstrate the potential contribution of glazed balconies in reducing heating energy needs, with significant heat gains on sunny days, reaching temperature peaks around 10°C higher than those recorded outdoors. However, thermal comfort conditions in the studied buildings are compromised by insufficient thermal insulation of the envelope and/or the lack of occupant actions to control convective heat exchanges. Optimising both factors would improve the results. Nevertheless, it is essential to evaluate the annual energy balance of this type of building in order to test solutions that enhance performance while complying with legal requirements and simultaneously respecting and preserving traditional passive techniques. By applying such passive strategies, it becomes possible to meet the goals set out in the EPBD, contributing to energy efficiency levels aligned with nZEB standards, and consequently reducing both carbon emissions and energy poverty among households.

The lack of awareness regarding the advantages of this passive strategy—alongside the rejection and devaluation of traditional techniques, their improper application using inappropriate materials or orientations, or even their destruction—harms both the thermal comfort of buildings and the architectural essence of this construction typology. Despite being an iconic element of northern vernacular architecture, glazed balconies lack recognition and appreciation,

leading to their gradual neglect or demolition. To counteract this trend, efforts must be made to preserve and promote the advantages of these balconies, particularly regarding thermal comfort and energy efficiency. Furthermore, as evidenced by previous studies, advocating for their incorporation into new constructions is essential for reinforcing this beneficial architectural feature.

As shown in a recent work (Toroxel et al. 2024), well executed and oriented balconies can cut energy demands by 47% and extend indoor comfort by nearly 900 hours annually compared to buildings without them. The integration of local traditional techniques with modern design—combining current technological potential—can be one of the viable pathways toward achieving high-performance energy-efficient buildings.

Acknowledgments

This work was partly financed by FCT / MCTES through national funds (PIDDAC) under the R&D Unit Institute for Sustainability and Innovation in Structural Engineering (ISISE), under reference UIDB / 04029/2020 (doi.org/10.54499/UIDB/04029/2020), and under the Associate Laboratory Advanced Production and Intelligent Systems ARISE under reference LA/P/0112/2020. The authors also thank Mr. José Pombo and Mr. Carlos Pinto and their families for helping with this research.

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Recommendations of retrofitting solutions for the vernacular built heritage of Montesinho Natural Park

15



Eduarda Luso¹, Débora Ferreira¹, Jorge Vaz¹, Sílvia Fernandes¹

Introduction

The Montesinho Natural Park (MNP) is known for its ecological diversity, being the habitat of emblematic species such as the Iberian wolf, the deer, and several birds of prey. For the protection of endangered species and the sustainable management of natural resources, the park has been the stage for several environmental conservation projects.

Regarding the preservation and enhancement of the vernacular heritage, there are many projects to rehabilitate MNP's houses respecting the original materials and techniques, such as the use of granite, schist and slate. Local inhabitants are encouraged to restore and preserve their homes following conservation guidelines. However, this effort faces a significant challenge, as the artisans who hold the ancestral wisdom of the execution of slate roofs and the laying of stone with lime mortars are disappearing, making it increasingly difficult to find skilled labour for the execution, maintenance or rehabilitation of these buildings.

The retrofitting of vernacular architecture in Montesinho Natural Park must prioritize the preservation of traditional construction techniques while enhancing structural integrity and durability. Considering only the maintenance of the facade and the general appearance of the external building, which is the particular object of this article, it is necessary to

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intervene in roofing, masonry walls, joint mortars and/or plastering. In fact, one of the key aspects of preservation interventions is the roof, typically made of slate, which should be carefully maintained and, when necessary, repaired using locally sourced materials. To improve energy efficiency and weather resistance, discreet waterproofing layers can be added beneath the slate, along with natural insulation materials such as cork, ensuring better thermal performance without compromising breathability. In this context, with the support of the INHAVIT project – Sustainable Approaches for the Rehabilitation and Revitalization of the Built Cultural Heritage in the Montesinho Natural Park, funded by the Fundação Ciência e Tecnologia (FCT), whose aim is to assess and characterize the built rural environment of the MNP, both at the level of buildings and villages, it was possible to create a Slate Roof Covering Execution Manual (Vaz et al. 2025), that will be briefly summarized.

Also, stone masonry walls, another defining element of the region's architecture, often requires reinforcement to prevent structural degradation. This article refers to some recommendations for preserving built heritage, suggested by ICOMOS (ICOMOS 2004) and suitable for old stone masonry.

Finally, regarding mortars, the recommendations for mixtures and ratios are based on studies carried out within the scope of the INHAVIT Project, where it was possible to carry out both mechanical tests in the laboratory and “in-situ” on real mortars.

The Slate Roofs

Technical aspects of the construction of slate roofs

Ceramic tile roofs, typically using barrel clay roof tiles, are common in the villages of the Trás-os-Montes region, particularly in MNP. However, slate roofing represents a distinctive feature of these villages and constitutes an important cultural and architectural heritage that deserves preservation. Traditionally, slate roofs are supported by wooden beams or truss structures, which rest directly on stone masonry walls

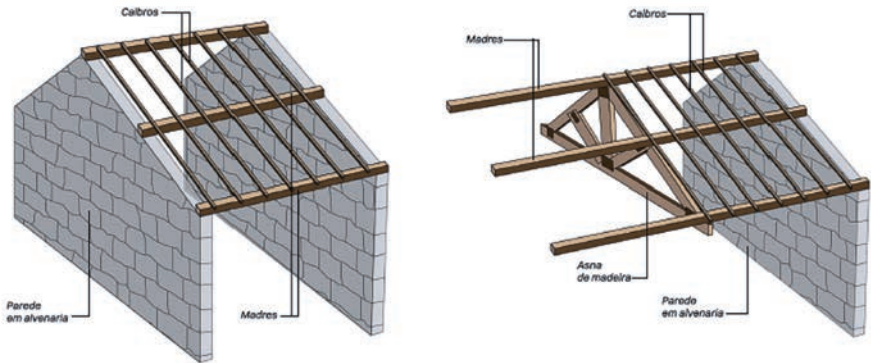


Figure 1. Timber wood structures (Vaz et al. 2025)

in simpler cases or are reinforced by more complex structural systems for larger dimensions or varied roof shapes (Figure 1).

The state of these roofs and their supporting structures can vary significantly; some may not require extensive intervention as they are not in a state of serious deterioration. In these situations, only minor adjustments to the positions of the slate slabs or localized reinforcement of the wooden structure are necessary. Deterioration of the timber structure, such as deformations, warping, or fractures, can have consequences in terms of load distribution and introduce horizontal loads into the supporting masonry walls, potentially causing further anomalies such as deformation or buckling of the masonry. In these cases, it is essential to promptly repair the entire timber structure, with the aim of, on the one hand, halting the degradation of the materials and, on the other, enhancing or improving their performance. Inspection and diagnosis of the structure are therefore essential (Vaz et al. 2013).

Repair strategies can be distinguished into two levels of intervention depth (directly related to the state of conservation itself): Minor Repair (MiR) and Major Repair (MaR), taking into account the data provided in the study and diagnosis (Vaz et al. 2013). Minor repairs include small-scale repair work to the wooden structure in damaged areas due to cracks, biological attack, and gaps, possibly requiring localised reinforcement using traditional techniques (Figure 2). They also include

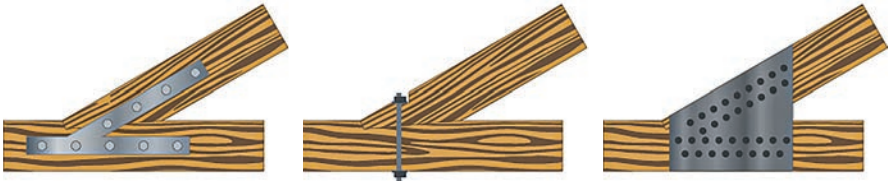


Figure 2. Localised reinforcement using traditional techniques

disinfection through the application of toxic products by injection, fumigation and brushing.

Major repairs include all the work required to repair and reinforce wood, but must be carried out by a specialized team. This is the case of repairing parts of the rotten or deteriorated wooden structure by replacing them with a prosthesis, or repairing deteriorated supports using glued prosthesis by cutting and removing the degraded section of wood, drilling holes to introduce polyester, steel or fibre rods (Figure 3) (Vaz et al. 2013).

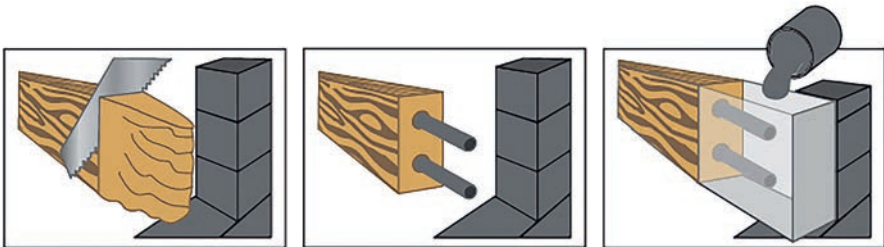


Figure 3. Example of reinforcement with a prosthesis [3]

In rehabilitation, the installation of thermal insulation, when not already installed, must be carried out at the time of construction of the shale roof, applying it next to the inclined mat when the space immediately below is habitable, respecting the execution details and dimensions defined in the thermal behaviour project.

The reconstruction of ceramic roofs lacks a standard execution procedure, as several construction companies have adopted different approaches. However, the rebuilding of slate roofs constitutes a very

different technique and the knowledge of its execution is restricted to a small number of craftsmen and the “know-how” is at risk.

The “Slate Roof Covering Execution Manual”

Currently, traditional slate roofing techniques are at risk due to a shortage of specialized artisans, underscoring the importance of preserving and disseminating this expertise. To address this need, a manual (Vaz et al. 2025), “Manual de Execução do Revestimento de Coberturas em Lousa” has been created detailing traditional techniques used in slate roof construction, including guidelines for correct thermal insulation installation where necessary. Particular attention is paid to the “rustic roof” technique, which uses irregular slate slabs resulting from natural fissuring, providing a unique, rustic, and authentic appearance to traditional buildings (Figure 4).

This Manual presents a detailed record, through images, schemes, sketches and descriptive text of the traditional slate roof construction technique, ensuring the safeguarding of this ancestral knowledge, which is now held by a reduced number of artisans.

Part of these typical houses have been adapted for rural tourism, allowing visitors to experience the traditional way of life without compromising the original architecture. The villages of Rio de Onor, Montesinho and Guadramil are examples of intervened villages that maintain a traditional way of life, with typical architecture in stone and slate.



Figure 4. Slate Roof Covering Execution Manual (Vaz et al. 2025)

The present work aims to contribute to the investigation and dissemination of the ancestral technique of construction of slate roofs and the use of lime mortars, widely used in most of the houses of the MNP.

Stone Masonry Walls

Consolidation and Retrofit of Stone Masonry Walls

Ancient stone masonry structures, while highly durable, may require consolidation and reinforcement due to weathering, seismic activity, structural settlement, or material degradation.

Before any intervention, a specialised technician's inspection of the masonry structure, like visual or experimental inspections for cracks, displacements, material deterioration and pronounced deformation, is fundamental.

Following ICOMOS recommendations (ICOMOS 2004) minimally intrusive and reversible interventions should preferably be chosen to consolidate and/or reinforce these elements. This can be achieved through techniques such as *Repointing of Mortar Joints or Grouting* with lime-based mixtures, which stabilize the walls while maintaining compatibility with the original materials. Additionally, stainless steel ties or other minimally invasive reinforcement methods can improve stability without altering the traditional appearance. A reinforced structural project will be needed for more complex interventions (external or embedded reinforcements or stone replacement and stitching).

Repointing mortar joints, where deteriorated mortar is carefully removed and replaced with a compatible mix, using traditional tools (Figure 5 and 6) and lime-based mortars, is the first option to consider (Mack 1998; Speweick 2004). Lime-based or hydraulic lime mortars are preferred because they allow flexibility, moisture exchange, and compatible strength while maintaining permeability (Table 1). Furthermore, the colour and texture must match to ensure both aesthetic and structural integrity. The choice of mortar can follow the recommendations proposed for plastering and laying mortars.

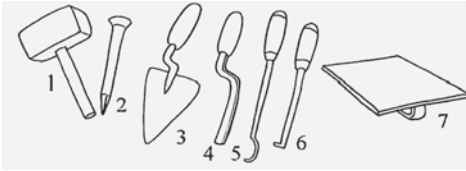


Figure 5. Tools used for joints repointing

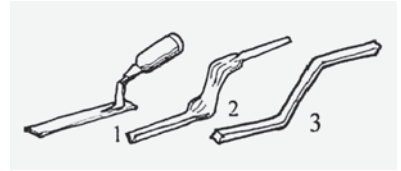


Figure 6. Tools used for tightening mortar

Table 1. Main Properties of Mortar for Repointing Joints (Luso & Lourenço 2017)

Mortar for Repointing Joints	Mechanical Properties at 90 days [MPa]			Bond Strength at 90 days [MPa]
	Tensile Strength	Compressive Strength	Modulus of Elasticity	
	0,4-0,8	0,6-3	3000-6000	0,1-0,5

Grouting involves injecting fluid materials (grouts) into the masonry to fill voids and restore cohesion (Figure 7). Grouting is a well-known, ancient technique which can be durable and mechanically efficient, whilst preserving the historic value. The selection of a grout for repairs is based on the physical and chemical properties of the existing masonry. Compatibility between the existing and the injection material is a major factor in the success of the intervention (Luso & Lourenço 2017).

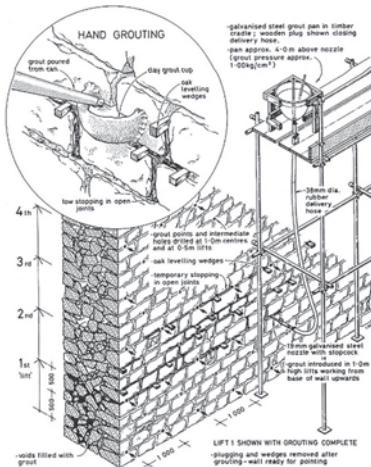


Figure 7. Hand and gravity grouting scheme (Ashurst & Ashurst 1990) and an example of injection

Lime-based grouts are recommended for this kind of intervention to maintain breathability and compatibility with original materials (Luso & Lourenço 2017). Commercially available grouts are also a good option (Luso & Lourenço 2016).

Joint and Rendering Mortars

The use of traditional mortars is crucial in maintaining the authenticity and resilience of these buildings. Lime-based mortars, rather than cement-based alternatives, should be applied to ensure breathability, flexibility and durability. In areas particularly exposed to moisture, hydraulic lime mortars offer additional resistance, preventing issues such as cracking or salt crystallization.

Based on the results obtained in samples of mortars tested chemically and mechanically, the joint and rendering mortars have more or less the same composition using lime, sand, clay, straw and plant roots. It is believed that the addition of shale powder in some compositions was common, although it gives a darker tone to the mortar (Figure 8).



Figure 8. Aspects of some mortars and based materials such as clay, non-sliceous sand and shale powder

The recommendations for partial (filling gaps) or total replacement of plastering or laying mortars should comply, as far as possible, with the following steps:

1. Preparation of one or more compositions of good-quality aerial lime mortar (putty lime) with a long maturation time (Figure 9) and local aggregates. Alternatively, hydraulic lime is also a good choice;

2. Conducting tests to verify the minimum requirements. If necessary, make corrections to the tested formulation (Table 2);
3. Making experimental panels on site (Figure 10) with different brush strokes, for fine adjustment of texture and colour;
4. Again, if necessary, making corrections to the tested formulation.



Figure 9. Putty lime with 5 years and 1 month of maturation (Margalha et al. 2011)

Table 2. Recommended mechanical and physical characteristics for render mortars (Luso & Lourenço 2017)

Render Mortars	Mechanical Properties at 90 days [MPa]		Capillarity Coefficient [kg/m ² .min ^{1/2}]	Bond Strength at 90 days [MPa]
	Tensile Strength	Compressive Strength		
		0,2-0,7	0,4-2,5	1,0-1,5



Figure 10. Example of mortar experimental panel for repointing or plaster/joint mortar

The composition of these mortars is normally given by the volumetric ratio between the components, so that for aerial lime mortars, the traditional ratios vary between 1:1 and 1:5 (aerial lime: sand) in volume. The mixing water is the minimum necessary for workability and adequate consistency, especially in the case of plasters. The mixing time of lime mortars is fundamental, and the longer the time, the better the quality and durability of the mortar. Table 3 shows some characteristics of traditional mortars found in the literature (Veiga et al. 2001).

Table 3. Replacement mortars – Characteristics of possible compositions (Veiga et al. 2001)

Composition: volumetric proportions <i>binder : aggregate</i>	Compressive Strength [MPa]	Dynamic Elastic Modulus [MPa]	Capillarity coefficient at 24 h [kg/m ² .min ^{1/2}]
<i>lime : sand</i> (1:3)	0,2-0,8	2300 – 4100	1,1 – 1,6
<i>lime : pozolan : sand</i> (1:2 to 1:3)	0,5-2,3	2500 – 4500	1,3 – 2,3
<i>lime : hydraulic lime : sand</i> (1:2 to 1:3)	0,4-1,0	1600 – 5600	1,2 – 1,9
<i>hydraulic lime : sand</i> (1:2 to 1:3)	0,6-3,1	1100 – 7500	1,0 – 2,4
<i>lime : cement : sand</i> (1:3)	0,8-5,1	3000 – 6500	1,0 – 2,0

Alternatively, a commercially available pre-mixed mortar with known characteristics can be used, as long as it meets the minimum requirements and is aesthetically compatible. This option ultimately reduces the selection process to a single step, the preparation of a pre-mixed mortar with well-known and suitable characteristics, in multi-layer applications, if necessary.

Conclusions

The recommendations suggested here in this article are somewhat generalist, requiring prior analysis and inspection of the building by specialized technicians.

It is increasingly common to see that users, owners and even contractors opt directly to repair anomalies, ignoring the causes that originated them. This fact is repeated countless times, either due to the lack of knowledge of those involved or to the intention of saving time, often entering a vicious cycle where the anomalies are merely “camouflaged”, only to reappear later – the so-called “Repathologies”.

The lack of gathering available information with the systematization of the main anomalies that affect these buildings makes this situation increasingly worse, increasing the level of degradation of the buildings. The methodology followed to prepare a correct and objective diagnosis of the building must be developed according to a set of logical chaining procedures, in an attempt to converge towards obtaining the best solution to be adopted.

With the support of the INHAVIT Project, it was possible to establish a building standard and select intervention techniques for their rehabilitation, consolidation and reinforcement, presented here in this article.

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This publication aims to show the results of the **INHAVIT – Sustainability-led approaches for the rehabilitation and revitalization of the cultural built heritage of Montesinho Natural Park** Research Project, funded by the Portuguese Foundation for Science and Technology (FCT). The project was part of the International Research Programme created by FCT to promote R&D activities of an interdisciplinary and multidisciplinary nature in the Montesinho Natural Park. The reference of the project is MTS/BRB/0086/2020 and the DOI: <https://doi.org/10.54499/MTS/BRB/0086/2020>.

The work carried out is the result of the close collaboration between three Portuguese universities: University of Minho (UM), Institute for Sustainability and Innovation (ISISE), Department of Civil Engineering, Guimarães (project leader); the University of Aveiro (UA), Civil Engineering Research and Innovation for Sustainability (CERIS), Department of Civil Engineering, Aveiro; and the Polytechnic Institute of Bragança (IPB), Department of Civil Constructions, Bragança.

The research team would like to acknowledge the international consultants that have participated in the project: the Italian National Research Council (CNR), Institute of Heritage Science, from Italy; the University of Burgos, Department of Mathematics and Computation, Research Group in Energy Engineering (iENERGIA), from Spain; and the company Gratia Hydro, specialized in the design and construction of

small hydroelectric power stations, from the Netherlands. The research team would also like to acknowledge the city hall of Bragança and the parishes (juntas de freguesia) of França and Rio-de-Onor/Alveleda, for their active interest and collaboration in the project. Finally, the research team acknowledges Márcia Moreno, Maria Correia, Paulo Mafra, Rafael Sobrinho Correia, Hugo Pires, Mariana Correia, Raimundo Mendes da Silva, Juan María Hidalgo-Betanzos and Jorge Fernandes for their contributions to the present publication.



Graphic Design: Sersilito

Photographs in between chapters: Juan Camilo Arias Tapiero

Publisher: Sersilito, Empresa Gráfica Lda.
Travessa Sá e Melo, 209 – Gueifães
4470-116 Maia, Portugal

Legal Deposit: 552225/25

ISBN: 978-989-35653-6-0

Edition: Braga, 2025

Project: INHAVIT (Sustainability-led approaches for the rehabilitation and revitalization of the cultural built heritage of Montesinho Natural Park)

Project Reference: MTS/BRB/0086/2020

Funding entity: Fundação para a Ciência e a Tecnologia (FCT)

Institutions and research team:



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