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GIS-based inventory for safeguarding and promoting Portuguese glazed tiles cultural heritage

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Abstract

Innovative, non-invasive, digital, and cost-effective instruments for systematic inventory, monitoring and promotion are a valuable resource for managing tangible and intangible cultural heritage. Due to its powerful and effective inventory and analysis potential, which allows supporting central and local entities responsible for cultural heritage management, Geographic Information Systems (GIS) have proven to be an appropriate information technology for developing these kinds of instruments. Given the above, this work aims to introduce a GIS-based instrument to support inventorying, safeguarding, tourism, and cultural promotion of the traditional Portuguese glazed tile ('azulejo', in Portuguese) to raise general awareness of the importance of this unique Portuguese heritage. To the best of the authors' knowledge, there is no other instrument available with inventory and safeguarding management functions that is accessible and affordable, developed to be used at a municipal level and that contributes to the enrichment of the cultural and tourist information. Information from 70 tile works located in the Portuguese city of Covilhã was used to test the proposed GIS tool, resulting in a georeferenced alphanumeric, graphical, image and drawing inventory and in three pedestrian routes for touristic and cultural heritage promotion. The results were validated by both the research team and the municipality of Covilhã, foreseeing its expansion and daily use in the management of the heritage of the traditional Portuguese glazed tile. The proposed instrument can be replicated in other locations and easily implemented and managed by municipalities or institutions dealing with the protection of cultural heritage.

Keywords Cultural heritage, Traditional Portuguese glazed tile (*azulejo*), Geographical information system (GIS), Inventory, Safeguarding and cultural promotion

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Introduction

Framework and objectives

In recent years, cultural heritage has played an influential role in shared identities and spatial and environmental development. According to the United Nations Educational, Scientific, and Cultural Organization (UNESCO) [1],"cultural heritage includes artefacts, monuments, a group of buildings and sites, museums that have a diversity of values including symbolic, historical, artistic, aesthetic, ethnological or anthropological, scientific, and social significance. It includes tangible heritage (movable, immobile, and underwater) and intangible cultural heritage (ICH) embedded into cultural and natural heritage artefacts, sites, or monuments'. From another point of view, the Portuguese Parliament defines cultural heritage as 'a group of resources inherited from the past which people identify as a reflection and expression of their evolving values, beliefs, knowledge, and traditions. It includes all aspects of the environment resulting from the interaction between people and places through time' [2].

Furthermore, historical perspectives are essential for making well-informed choices regarding environmental challenges, such as spatial planning, sustainable development or climate adaptation. This increased awareness emphasizes the importance of cultural heritage for present-day challenges and presents a new set of conditions and standards, which requires the development of new methodologies [3]. The definition of cultural heritage has proven to be dynamic, and it has increasingly broadened, moving away from being object-oriented to the preservation of whole landscapes and includes material, intangible and virtual heritage contexts [3]. Consequently, the set of demands associated with heritage has equally shifted, and there is an increasing need for heritage to become more contextualized, integrated, and accessible through the digitalization of historical data, namely with the development of information and communications technology (ICT) based methodologies applied to cultural goods [3–8].

The scope of the present work focuses on the immovable component of tangible cultural heritage [9], specifically on what is designated as 'architectural heritage' according to the Convention for the Protection of the Architectural Heritage of Europe (1985) [10]. Architectural heritage encompasses [10] monuments (all buildings and structures of conspicuous historical, archaeological, artistic, scientific, social or technical interest, including their fixtures and fittings), groups of buildings (homogeneous groups of urban or rural buildings remarkable for their historical, archaeological, artistic, scientific, social or technical interest which are sufficiently coherent to form topographically definable units) and archaeological sites (the combined works of man and nature, being areas which are partially built upon and sufficiently distinctive and homogeneous to be topographically definable and of notable historical, archaeological, artistic, scientific, social or technical interest).

Architectural heritage faces many problems and challenges, such as modifications caused by environmental degradation, erosion, misuse, abandonment, and collapse caused by natural disasters, excessive human intervention in the preservation, development and restoration processes, such as inappropriate replacement of materials and colors, and loot for commercial purposes [5, 11]. These problems led to the loss of historical and cultural information and the reduction of the heritage's historical value. To address these problems and form community and shared identities, besides conservation, there is a need for architectural heritage to become contextualized and its information accessible to several stakeholders, such as politicians, national and municipal managers, police authorities, population, tourists, and researchers [3, 12].

For organizations and authorities responsible for safeguarding heritage places, inventories are essential information resources for making informed decisions and applying heritage-related laws and policies, thus helping to preserve heritage places for future generations and improving management and tourism promotion [13, 14]. Inventories provide information about heritage places, their location and their condition. To be an effective decision support tool, the information contained within inventories must be organized and kept up-to-date to reflect changes in time. Data collection activities and remote sensing data analysis, such as satellite imagery, can achieve this. Furthermore, publicly accessible inventories encourage citizens to add knowledge to the existing records and promote public input on heritage places not included in official inventories. Data collection and analysis is an important component of the inventory process and can be incorporated to fill in gaps and update information [15].

Several digital technologies can be adopted to gather a significant amount of data quickly and effectively. Simou et al. [5] state that new digital technologies are emerging every day, from digital scanning to information management systems, which have excelled in documenting monuments and historic sites. Among the different digital technologies applied to architectural heritage data collection activities (isolated or combined), it is possible to highlight the use of 3D Lidar [11, 16, 17], Unmanned Aerial Vehicles (UAV) [8, 16, 17], Digital Terrain Modelling (DMT) [8], Close Range Photogrammetry (CRP) [6, 8, 16, 18, 19], Smart Sensing [20, 21], 3D modelling [6, 7, 16–18, 22, 23], Laser Scan (LS) [16–18, 23] and Artificial Intelligence (AI) [24]. For architectural heritage data visualization, several authors also mention the use of Virtual Reality (VR) [6, 16, 25, 26] and Augmented Reality (AR) [16, 26, 27]. However, using these technologies can result in a significant amount of data, which can easily be overwhelming and challenging to manage if not correctly and hierarchically categorized.

According to Santos et al. [12], digital heritage inventories face several challenges: data from different sources, fast technological advancements that can easily outdate the systems and procedures, the need for continuous managing, updating and saving of inventory records over time, software and hardware implementation, updating and maintenance costs, the need for deduplication due to the existence of separate inventory systems that address very similar needs and the creation of compatible inventory systems for broader information integration (at national, European or world level). The literature review revealed a reduced number of publications on implemented Cultural Heritage Inventory Systems (CHIS). A web platform mentioned in several articles is the Arches open-source software platform from the Getty Conservation Institute (GCI) [28–31]. The platform is purpose-built for the international cultural heritage field, and it is designed to record all types of immovable heritage, including archaeological sites, buildings and other historic structures, landscapes, and heritage ensembles or districts. In addition to its wide field of applications, Arches is primarily intended for software developers who need to build flexible web applications. Still, it can be challenging for those who do not have specific training for its development.

Small municipalities with scarce technical staff resources need more tailored ICT and decision support tools to address the management of architectural heritage preservation and promotion. The effective implementation of preventive conservation and effective promotion approaches demand standardized and robust tools able to integrate the data coming from multiple sources and perform several types of analysis, as well as ensure the proper information exchange between expert and non-expert users. This has been done with Geographic Information Systems (GIS) and Building Information Modelling (BIM) and, lately, by integrating both. These approaches employ geospatial databases that can store various alphanumeric, raster and vector information (all of them properly georeferenced), perform multi-criteria and spatiotemporal analysis, and generate thematic maps [32]. Several authors refer to GIS and BIM applied to architectural heritage as Heritage GIS (HGIS) [3, 33–36] and Historical BIM (HBIM) [23, 27, 33, 37–41]. HGIS is generally applied for inventorying, carrying out spatial analyses and defining policies and strategies for heritage preservation at the city or territorial level. HBIM, based on the creation of 3D models with information available to all stakeholders involved in the preservation process, is more suited to managing interventions at the building level [37, 42].

Considering the potential that these tools have shown for the preservation of different kinds of cultural heritage, the present study was undertaken to develop a specific architectural heritage inventory system (AHIS) for traditional Portuguese glazed tiles, whose safeguarding studies, as far as the authors could verify, are very scarce. Given the specificities of HBIM systems, the authors made the conscious choice to start the study by defining an HGIS, which can integrate, in future stages, HBIM systems focused on selected historic buildings. This was achieved by establishing the basis of a controlled-cost GIS-based system to allow the collection, inventory and analysis of glazed tile covering information to be used at the municipal level. The proposed system intends to fill an identified gap, namely the need for AHIS suited for local entities (most systems are developed at a national level). The systems' framework flexibility allows its application to other locations, its adaptation to other types of heritage information, and its integration into national systems.

This paper is organized into four sections. The framework and scope of the work and a literature review on the cultural heritage of the Portuguese glazed tile are presented in the introduction. The proposed approach to support inventory, safeguarding and the promotion of the heritage of glazed tiles is described in the Method section. The Case study and discussion section is dedicated to the analysis of the glazed tile heritage in Covilhã using the developed GIS-based tool. Public valuation and awareness through touristic information, maps and tours are also evaluated. Finally, the main findings, limitations and future work directions are in the Conclusions.

Portuguese glazed tile cultural heritage

Tiles are one of the signature characteristics of almost every period in the Portuguese History of Architecture and Decorative Arts. It has been used in Architecture as decoration or as an intrinsic part of the building's layout and, more recently, for building comfort purposes [43]. The traditional glazed tile in Portugal is called '*azulejo*' and is rightly considered one of the country's most distinctive forms of art. According to Matos et al. [44], the '*azulejo* is a secular element of material culture: present with special relevance in the country's cultural landscape and presenting itself as an identity marker'. The same authors state that no other tile-producing country has used and disseminated this form of expression as globally as the Portuguese.

In the Iberian Peninsula, the art of glazed tiles is believed to have been introduced in the thirteenth century by the Arabs [45], who used it to decorate their palaces and religious buildings [46]. Traditional Portuguese glazed tiles developed during the reigns of D. João II and D. Manuel (fifteenth and sixteenth centuries) when a Moorish revivalism emerged due to the continuous orders of glazed tiles from Spanish ceramic factories mostly located in Seville [47, 48]. Glazed tiles were extensively used in palaces and churches throughout the sixteenth century, later limited to religious buildings during the Spanish occupation of Portugal (1580–1640) and the subsequent Restoration wars (1640–1668). During the reign of D. João V (1706–1750), the glazed tile was extensively used as a highly ornamental, less expensive and more durable decorative element. The glazed tile was present not only on religious buildings and palaces but also on housings owned by the bourgeoisie, finding its place in the interior areas and private gardens.

In the late seventeenth century, figured compositions were being developed and sometimes covered wall surfaces completely. The figurative panels acquired large-scale popularity. Cobalt blue was highly favored, thus triggering the development of specific ceramic paintings and a Portuguese cultural heritage trademark [47]. The Baroque style in the eighteenth century is another milestone in the development of decorative glazed tiles. During this century, '*azulejo*' motifs were influenced by the '*Talha*' (gilt and carved wood) and reproduced its themes. In this regard, Meco [47] states that there is a '(…) tendency towards entire wall surfaces being covered by *azulejos*, creating a characteristically baroque, spectacular impact'.

After Lisbon's 1775 earthquake, from the necessity to rebuild the city under a difficult economic situation, glazed tiles found a new practical and utilitarian concept as an aesthetic complement to the reconstruction which perdured during the following centuries [47]. Following the end of the eighteenth century, the decrease in the systematic use of glazed tile was aggravated by the French invasions (1807–1814), which led to the end of the artisanal production of tiles. Nevertheless, glazed tile recovered an essential role as a decorative accessory in renting accommodations during the Portuguese Liberal regime (1834). Building facades were a field of ornamental experimentation with tile-covered frontispieces and main entrances of housing and shops [47, 49].

The production of glazed tile started with the Industrial Revolution in Portugal. Pattern-glazed tiles were mass-produced in several ceramic factories that began operating in the second half of the nineteenth century [46], being Oporto and Lisbon the origins of most of the production. Pronounced reliefs were characteristic from the North of the country (Oporto), with volume and light/shadow contrast, while the southern production (Lisbon) maintained the smooth patterns of the lasting memory, thus transposing it from interior spaces to an exterior application on facades.

Until the twentieth century, these glazed tiles were applied to building facades nationwide, thus leading to a new urban landscape [47]. During the twentieth century, tile exuberance and intensity of color appeared in architectural friezes, compositions, Art Nouveau panels and, later, in Art Deco buildings. Simultaneously, a nationalist tendency emerged for 'postcard-suggesting' panels representing daily life scenes. From 1940 onwards, architectural solutions using glazed tiles in the '*Estado Novo*' style were superseded by stone panels as a surface covering (usually marble) [47]. In the 1950s, architects and modern plastic artists, mainly from Brazil, influenced and encouraged the reuse of glazed tile in architecture, both in housing and public buildings [47].

Over the centuries, tile has been exposed to several influences and inspirations, which changed it profoundly. According to Meco [47], tile absorbed the structural present in architecture itself, as well as the notion of spatiality and the intertwining of plans and surfaces. The traditional Portuguese glazed tiles were always interconnected to build heritage and have played a role in transforming architecture.

When it comes to the study of the cultural heritage of the Portuguese glazed tile, two figures stand out: Joaquim de Vasconcelos (1849–1936), the first to sustainably value Portuguese tiles by highlighting them in the context of ceramics, promoting inventory, researching, and publishing on the subject, and João Miguel dos Santos Simões (1907–1972), who substantiated the autonomy of the glazed tile compared to ceramics [50].

Considering the long and rich Portuguese glazed tile heritage, its safeguarding and the promotion of a sense of cultural awareness are national concerns.

Tile cultural heritage safeguarding and promotion

Artistic glazed tiles have been present in Portuguese daily life for centuries. However, most of the time, common citizens and institutions do not value them. Consequently, this cultural heritage is threatened by needless glazed tile removal, demolitions of glazed tile-covered buildings, vandalism, neglect and lack of conservation. In addition, due to age and use, and despite their perceived durability and low maintenance requirements, the need to preserve traditional glazed tiles is urgent and requires expert knowledge. Huge heritage losses are currently happening due to unscrupulous restoration or inappropriate earlier repair and maintenance interventions. Other problems have also recently arisen due to the increased perception of their value for art experts, historians, and antique dealers, which had led to damage caused by amateurs trying to remove them, theft of tiles from unprotected or neglected historic sites, and incurred visual damage when poorly matched new tiles are added to an older scheme [12].

In Portugal, the awareness of the heritage's value of glazed tiles started in 2007 with the project '*SOS Azulejo*', created to contribute to a global approach and a strategic line for Portuguese cultural policies [51]. The Portuguese Criminal Police Museum mentored it, and its target consisted of the effective protection of Portuguese historical and artistic glazed tiles. This public institution became aware that artistic glazed tiles increasing value was getting more tempting for art and antiques burglary and trafficking. In fact, the lack of information makes returning tiles to their original location challenging even when recovered.

For this reason, developing digital inventory systems to mitigate these problems is urgent and can be addressed using GIS. As shown in "Framework and objectives" section and previous author's works [4, 52], the wide use of GIS in different areas of architectural heritage preservation, especially through inventories, has been developed in recent years. Nonetheless, the inventory of tile heritage is scarce, and the subject is mainly studied in some Mediterranean countries such as Portugal, Spain and Italy. In Portugal, the inventory of traditional glazed tiles started in the last decade, but its integration into other heritage inventories has yet to be addressed.

It is also important to mention that traditional Portuguese tiles are considered 'integrated heritage' because they can only be fully appreciated when contextualized with the surrounding architecture for which they were originally conceived, thus determining how they should be documented [53, 54]. Traditionally, international heritage documentation norms only refer to tangible heritage as movable or immovable. This concept needs to be adapted to be applied to 'integrated heritage' and consider the main difference between a digital glazed tile heritage inventory and other heritage documentation.

In line with this concept, in 2011, the Portuguese association '*SOS Azulejo*' proposed a vital measure to be included in new regulations: the prohibition of demolishing buildings covered with glazed tiles and/or removing glazed tiles from their facades. This means that historic buildings and artistic glazed tiles are regarded and protected as a whole, not only in exceptional architectural value cases. This measure became mandatory in all Portuguese cities with the Portuguese Law nr. 79/2017 [55], and it represents a major advance in the global protection of the heritage of the Portuguese historic glazed tiles. However, compliance with this law implies the existence of technical teams, protocols, and an integrated national heritage inventory system, which does not exist yet.

In the absence of an extensive and digital tile heritage inventory system, the authors chose, as the baseline for the proposed integrated system to consider a current guide for glazed tiles inventories, an existing inventory standard, and two Portuguese digital heritage inventory systems [56–59] (Guide for the inventory of *azulejos* found in situ, Inventory standards: Ceramics, Az Infinitum—*Azulejo* indexation and referencing system, and SIPA—Architectural heritage information system). This option allowed the integration of the available data from the two digital inventory systems and the considered existing glazed tile inventory standards and guides. Integrating newly collected information in future inventory system updates is straightforward.

Method

Currently, the task of promotion and valorization of Portuguese glazed tile heritage is assigned to local authorities. The final goal of the proposed methodology is to provide a digital instrument and a means to support inventorying, safeguarding and the maintenance of this heritage and to allow awareness and protection through tourism and cultural promotion throughout the territory.

The design work structure is based on feedback loops that allow dynamic data acquisition and update, thus providing near real-time information for decision-making and an evolving tool that can adapt to specific needs and changing requirements for specific situations.

The methodology is also based on GIS for data structure, queries, graphical user interface and reports. Figure 1 presents the work structure adopted for the proposed GIS instrument.

The methodology developed considers two phases. During phase one, an Initial Study on exterior glazed tiles on buildings with interesting heritage features, wall panels and toponymical plates is performed. During this survey, it is possible to identify common characteristics of tiles works and correlate the information with known references. Notwithstanding, during the first phase, a standard Inventory Form adapted to the Portuguese glazed tile and heritage reality is developed to simplify

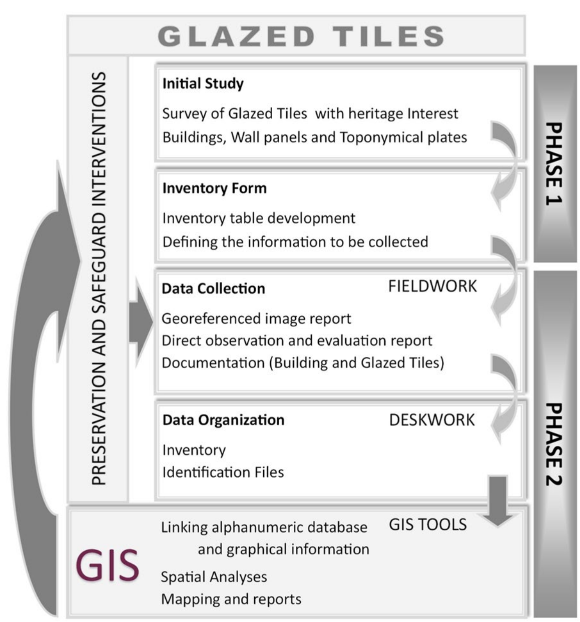

Fig. 1 Work structure of the proposed instrument for glazed tile inventory, safeguarding and promotion

the collection of further information or new tiles sites. This will be valuable later during the second phase of the methodology, thus allowing for high-reliability data collection even if skilled professionals are not readily available for fieldwork.

During the second phase, a broad field survey using the previously developed form is undertaken (first stage) by collecting georeferenced image data of the external tile coverings, panels and toponymical plates, building and location information, as well as the information received from other sources as archives, municipalities, references and building owners. The second stage of the second phase is the Data stage, which involves structuring the field-collected data inventory and distributing the information through the relevant files and geodatabases. Data is filtered and checked for duplicates, incorrections and other inconsistencies. Data quality is assured through cross-validation against references and reports. The information is aggregated on a GIS-unified project in the third stage. Metadata is prepared to summarize basic information about data and allow users to understand the collected information. Tools are developed for querying, editing and inputting future data (GIS). It is also now possible to perform geospatial analysis using tiles' heritage information and position data. The analysis will depend on each application's goals and will allow adding value to the collected information by dissemination for tourism or future studies.

The mere availability and dissemination of information are expected to be a significant aid for safeguarding the heritage and increasing awareness of its value. It will also help with future preservation efforts through reports, online web mapping services, and others.

The second phase is designed to be a loop system, where information from the database is checked against the actual locations by sampling procedures and updated as requalification is performed on the tiles' heritage. New data is also introduced into the system as it is reported using mobile-based developed forms. The latest data allows for a continuous update on spatial analysis, mapping products, touristic value, and future app applications.

Table 1, adapted from several authors [4, 58–61], highlights some pertinent information to consider in developing the tile inventory form (second stage of phase 1). This form gathers not only building and glazed tiles information but also information on references, studies and accessibility, which are essential for public sighting and tourism. This way, historical, artistical and touristic information is aggregated to take advantage of the analytical capabilities of GIS to produce updated and dynamic touristic products, such as thematic routes, accessibility constrain routes, and historical period routes, that will attract visitors and provide immersive, high-quality, valuable and consistent experiences.

Case study

Characterization of the study area

The analyzed case study is the municipality of Covilhã, located in mainland Portugal's central region on Estrela Mountain's southeast slope. The municipality covers a territory of 555 km^2 and has a population of approximately 46,500 inhabitants, with 72% residing in the city's urban perimeter [62].

At the end of the nineteenth century and the beginning of the 20th, the industrialization process in the municipality of Covilhã registered a significant evolution. The city's main economic activity, the wool industry, boosted the emergence of industrial, religious, public, and residential buildings of high architectural interest. Many of these buildings were inspired by the architectural Art Nouveau style, with frequent use of glazed tiles elements applied in facades, moldings, or decorative elements. Most of these buildings emerged during the 2nd and 3rd decades of the twentieth century. Figure 2 shows some of the most emblematic examples of buildings coated or decorated with glazed tiles that can be found in the city.

In addition to this type of tile use, several examples of toponymical plates and old and new wall panels of artistic and decorative interest can also be found in the city's historic center and urban perimeter. Figure 3 shows examples of a toponymical plate (a) and two wall panels, one older (n.d.) (b) and one more recent (2001) (c). Element (c) is a decorative panel alluding to the golden age of the wool industry, and (b) an information panel with the city's tourism marketing and promotion purposes.

Analysis

To validate the GIS-based tool on inventory, retrieve, visualization and management capabilities, a trial dataset on 70 glazed tile works located in the urban perimeter of Covilhã was performed. It included collection, organization, treatment and analysis of data. To test the promotion capabilities of the instrument, an accessibility study was conducted using the pedestrian infrastructure network. No data on glazed tiles were found in the Az Infinitum system for the analyzed geographical area. However, it was possible to retrieve information about 12 buildings with traditional glazed tile covering or decorative elements from the SIPA database. For the remaining registered buildings, toponymical plates and wall panels, the inventory data was

Table 1 Inventory: building and glazed tile data

Building data	Glazed tile data
Building location: country, region, district, municipality, parish, street and house number, Lon WGS84, Lat WGS84, X ETRS89, Y ETRS89, Z elevation SIPA[a]: designation, identification number, link to SIPA data Building identification: if it does not exist, an ID must be assigned Protection and conditioning: world heritage, built heritage, benefits from a protection zone, in the process of classification, in study, non-existent Public interest, national monument, municipal interest Construction period: main construction period Architect or constructor Property type: public, private Ownership: ownership information Case number at municipal services: number ID Typology: residence, industrial, commercial, religious, panel or other Occupation: property occupation Architectural style: dominant, secondary Other decorative elements than tiles: if existing General building condition (exterior): good, reasonable, bad, doom Interventions chronology: if existing. Main moments of design, application, conservation, remodeling, restoration, and management Bibliography, drawings and documents: source, link Pictures: images	Tile location: facade, inside the building Tile identification: ID number Construction period: main construction periods Local context: brief description of the glazed tile object surroundings in its geophysical, historical, and socio-cultural aspects Classification 1: coating, ceramic panel, toponymical plate or other Classification 2: facade, patio, external staircase, balcony, wall, wall panel, small religious panel, caption Classification 3: pattern, repeat composition, figurative, ornamental, or loose figure Iconography: religion, biblical, magic, mysticism, nature, human being—humanity, society—civilization—culture, history, ancient history, literature, classical mythology, abstract ideas and concepts, abstract—non-figurative art Monochrome or polychromatic: monochrome, polychromatic Objective and succinct tile description: From general to particular: building, space, glazed tile, and section Material (ceramic product): faience, stone dust, stoneware, porcelain, terracotta Tile decoration technique: information on tile manufacture, divided into conformation, decoration and application Composition dimensions: height x width (meters) Tile dimensions: height x width (centimeters) Tile condition: good, reasonable, bad Authorship: company, artist, painter or other Authorship nationality: country Interventions chronology: if existing. Main moments of design, application, conservation, remodeling, restoration, and management Bibliography, drawings and documents: source, link Pictures: images
Accessibility by public transport: yes (public transport information), no Tourist interest: yes, no Observations: supplementary records Survey entity: entity name Survey date: year/month/day	

[a] Portuguese information system for architectural heritage

(a) (b) (c)

Fig. 2 **a** Residential building *'Palacete do Jardim'*, by architect Ernesto Korrodi (1915); **b** Industrial building *'Empresa Transformadora de Lãs'*, currently the Faculty of Engineering of the University of Beira Interior, by architect Ernest Korrodi, covered with Aleluia factory tiles (1920); **c** Religious building 'Church of *Santa Maria Maior*' (1886), covered with tiles from the Aleluia factory in 1943

Fig. 3 **a** Street toponymical plate 'Rva de D. Cristovão de Castro'; **b** Decorative wall tile panel with tourist marketing and promotion purposes (n.d.); **c** Decorative wall tile panel alluding to the wool/textile industry (2001)

filled in using direct observation, collection of georeferenced images on site and consulting physical and digital documentation files (in libraries, municipal archives and publications, online documentation, among others). Figure 4 presents an overview of the distribution and location of the three types of elements (toponymical plates, wall panels and buildings) registered in the developed GIS tool and an example of the element information query window.

The database followed the INSPIRE directive style to allow the sharing and dissemination of the collected information for other projects. All non-automatic fields were completed manually, with a description of the gathered information and its encoding. An extract of the database (12 glazed tile works) can be consulted at Zenodo [63].

The pedestrian network was used to test the analysis of cultural and tourist routes for promotional use. The 2021 Covilhã network treated by Nogueira et al. and Lucena et al. [64–67] in a GIS environment was employed to obtain optimized faster and more comfortable routes. The paths' longitudinal slope and its influence on pedestrian speed, determined based on Tobler's Hiking function [68], allowed to obtain travel times that were considered in the Network Analyst tool of the ArcGis® program [69–71] to get the most suitable routes for a set of elements to visit.

Three optimized pedestrian routes analyses were performed considering time as impedance. The departure and arrival point of the proposed routes is the Town Square, next to Covilhã's City Hall. The town square was selected as the departure and arrival point because it is located next to the city's most historic district, where a significant concentration of tile heritage elements, car parking facilities and one of its tourist offices can be found.

The 1st route proposed (3.2 km long) considers the visit of 13 toponymical tile plates and can be walked in about 70 min. In addition to pedestrian circulation time, the analysis also considers a 2-min visitor stop at each toponymical plate. The route's thematic map, presented in Fig. 5, shows the optimized sequence of the visit obtained

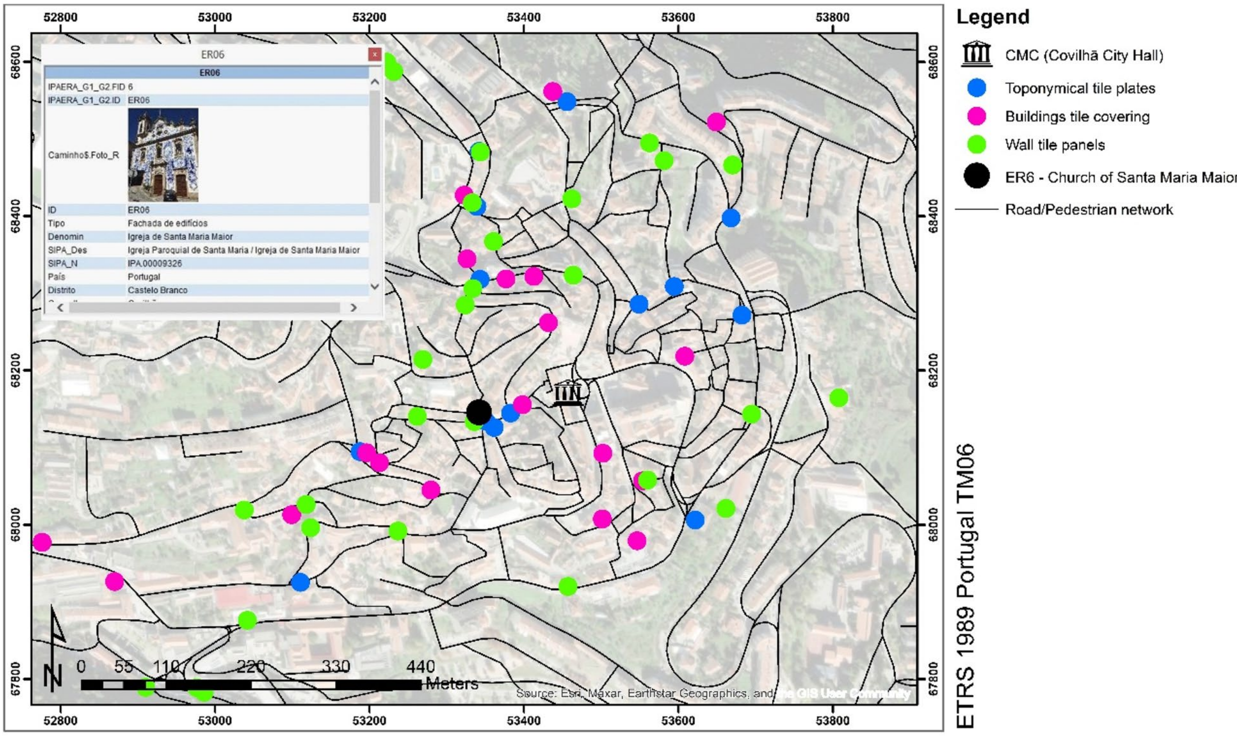

Fig. 4 Spatial distribution of glazed tile elements considered in the case study

for the toponymical plates. The 2nd route suggested has a length of 2.6 km and a walking time of approximately 60 min to visit 13 wall tile panels. A 2-min stop at each wall panel and a selection of wall panels based on a 300 m buffer, centered on Covilhã's City Hall building entrance, were considered in the analysis. Figure 6 shows the route's thematic map with the wall panels' visiting order. The last route tested allows visiting 12 buildings with tile covering or decorative elements along a 3.9 km circuit that can be covered on foot in about 2 h. A 5-min visitor stop at each element, and 12 buildings registered in the SIPA system were considered in the analysis. Figure 7 shows the route's thematic map with the buildings visiting order.

The results achieved with the data collection, organization, analysis and visualization allowed the validation of the suitability of the proposed approach. Considering the quantity and quality of the information stored in the glazed tile database and the flexibility of the used GIS analysis tools, the inventory can be expanded in the future, and routes can be easily adapted to different scenarios regarding the number and type of elements to be visited, architectural style, visit time, stop time at each location, changes in pedestrian circulation parameters, among other relevant aspects. The tool can also be used for management purposes and other accessibility studies, such as evacuation/emergency routes or large-volume transportation paths.

Conclusions

Architectural heritage plays an influential role in the spatial and environmental development of cities and historic landscapes, thus promoting a shared identity for their citizens and reflecting and expressing a nation's evolving values, beliefs, knowledge, and traditions through time.

The present work aimed to define a framework for using GIS to safeguard and promote a specific Portuguese architectural heritage trademark—the traditional glazed tiles. Implementing the proposed glazed tile GIS-based inventory provides all stakeholders with a system for safeguarding and preserving the glazed tiles and using the existing and collected data for promotional purposes (touristic), aiming to raise general awareness of the importance of this unique Portuguese cultural heritage.

Although directed towards the needs of municipalities or local cultural heritage management entities, the proposed system complies with the existing national standards to enable its integration into broader systems, such

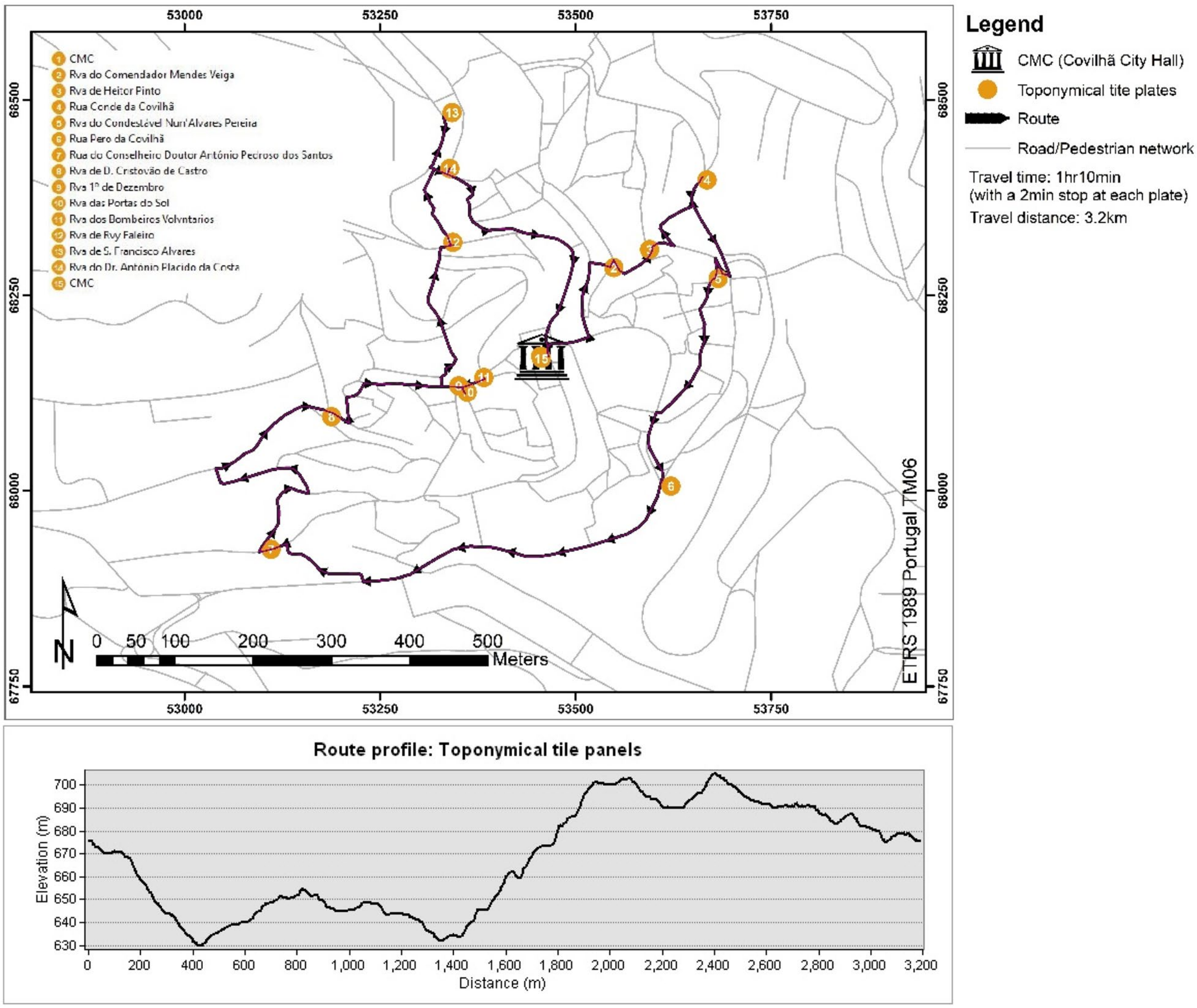

Fig. 5 Thematic map: toponymical glazed tile plates route

as the existing Portuguese '*azulejo*' and architectural heritage inventory systems. To address this issue, the authors adopted as the baseline an existing guide for glazed tiles inventories, an existing inventory standard, and the integration of the available data of two Portuguese digital heritage inventory systems. The instrument allows the integration and coordination of different types of information (descriptions, location, dates, pictures, hyperlinks, maps, among others) and databases (either existing or future ones), with analysis and visualization capabilities of glazed tiles location and information in dynamic maps.

The proposed approach was applied to a case study of 70 glazed tile works in the municipality of Covilhã (Portugal). The system can be expanded to include more works and comprise inventory, inquisition, visualization, analysis and management capabilities of the glazed tile works and the streets and pedestrian infrastructure network. The considered pedestrian network and GIS tools allowed to obtain some examples of optimized and comfortable touristic routes that can be used for promotion purposes. The case study proved the system's feasibility, allowing the integration of glazed tiles, buildings and transport network data from several sources in one single centralized inventory instrument. The results were validated by the municipality of Covilhã, thus foreseeing the expansion and daily use of the instrument in the management of the municipal glazed tile heritage. However, due to its specificity, the integration into international heritage inventory systems is expected to be more complex.

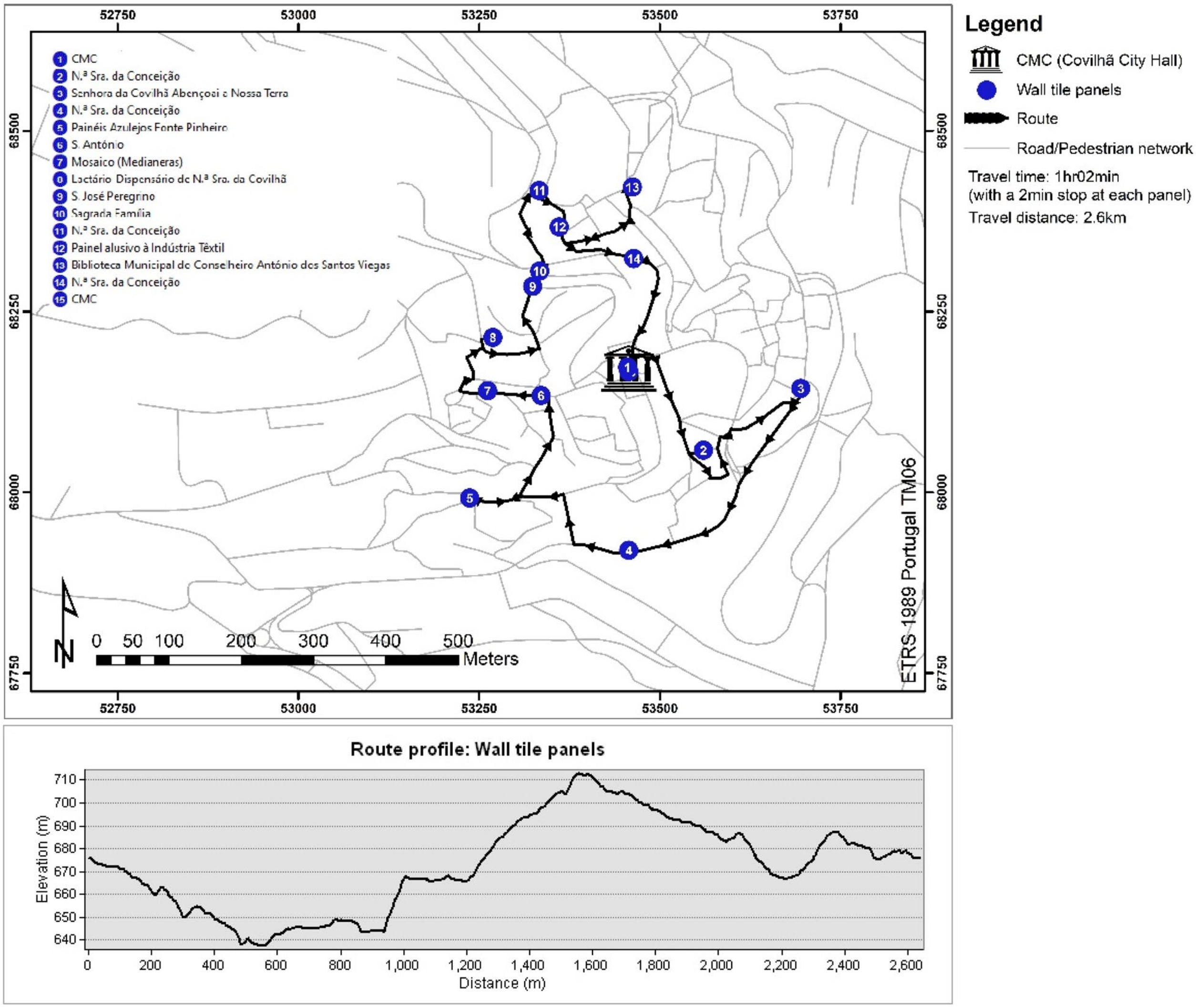

Fig. 6 Thematic map: wall glazed tile panels route

From the undertaken work, it is possible to conclude that using a GIS-based solution provides managers with an instrument that easily allows recording, visualizing, querying and spatial analysis with reasonable efforts and costs. By incorporating all these components, the proposed instrument enables the implementation of the entire process, from data acquisition to data analysis and dissemination, as well as its replication in other locations. Although its development was explicitly aimed at glazed tile heritage, it can also be adapted for other purposes related to architectural heritage, such as intervention timelines, degradation models or other features inventories (windows, doors, among others).

The availability and dissemination of information will significantly aid in safeguarding the heritage and increasing awareness of its value. It will also help in future preservation efforts through reports, online web mapping services and apps for touristic purposes. Future developments include integrating HBIM systems, adding new ICT technologies outcomes to the system (3D modelling, AR, AI, and others) and incorporating Volunteered Geographic Information (VGI) to involve the local population and tourists. This last development should be carefully evaluated since it makes data validation more complex for municipalities with scarce resources.

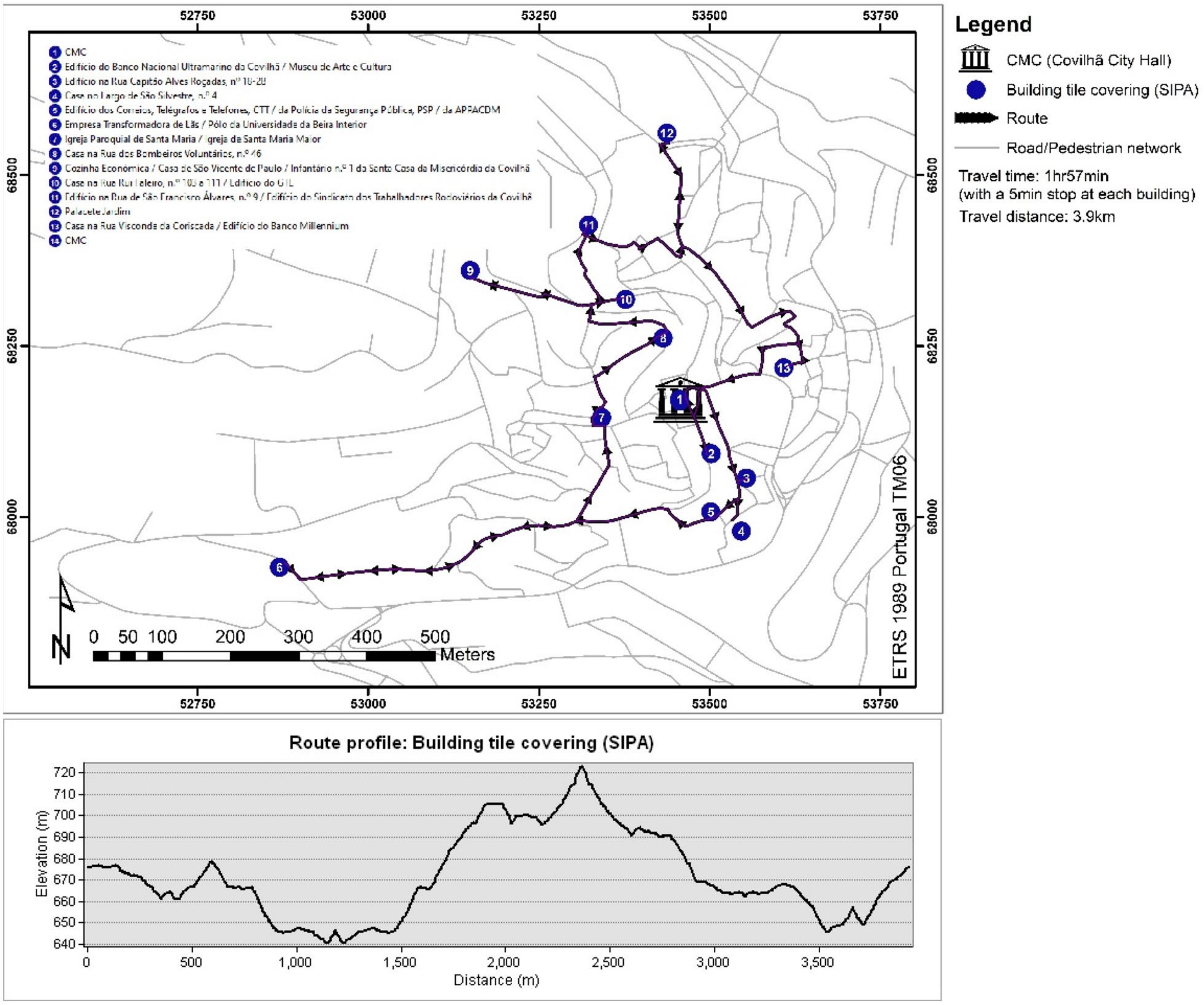

Fig. 7 Thematic map: buildings with glazed tile covering route

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Author contributions
Conceptualization, BS, JG, PGA and AMN; methodology, BS, JG, PGA and AMN; validation, BS and JG; formal analysis, BS, JG and PGA; investigation, BS, JG, PGA and AMN; writing—original draft preparation, BS, JG, PGA and AMN; writing—review and editing, BS, JG and PGA. All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials
The datasets generated and analyzed during the current study, owned by the authors and their affiliations, are not publicly available. However, they can be made available by the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare no competing interests.

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