ARTIFICIAL INTELLIGENCE APPLIED TO CULTURAL HERITAGE AND SUSTAINABILITY: A PORTUGUESE CASE STUDY

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_ Janaina Cardoso de Mello

PhD, Full Professor, Universidade Federal de Sergipe, Brazil, janainamello.ufs@gmail.com

_ Gabriel Ko Freitag e Silva

CNPq PIBIC Researcher, Universidade Federal de Sergipe, Brazil, gabrielkoofreitag@gmail.com

_ Gyamarco Pereira Nascimento Secci

CNPq PIBITI Researcher, Universidade Federal de Sergipe, Brazil, gyamarco@gmail.com

ABSTRACT

The application of Artificial Intelligence (AI) in Portuguese cultural heritage has proved to be a promising solution for the preservation and dissemination of culture, as well as for the dissemination of cultural tourism in the country. The relationship of environmental and economic sustainability permeates the conservation of spaces and lives in their interrelationship and history. This study intends to present the development of the initial results of the SIAP project - Artificial Intelligence System for the detection and alert of risks to Heritage, whose objective seeks to use artificial intelligence tools in data processing for greater effectiveness of heritage supervision services and optimization of intervention strategies, through remote sensing and monitoring of historic structures. The technology involved the use of MT-InSAR (satellite) and LiDAR (Light Detection and Ranging) data collection campaigns. Thus, the anomalies identified from the action of time on the built structures that make up the Portuguese historic monuments fed the AI learning cycle and will thus be correlated with the remaining sources of information. With this data, decisions regarding building restoration processes will be able to opt for non-aggressive management of the surrounding ecosystem, as well as for the socioeconomic inclusion of the community in the project to value cultural assets and the people who store their memories and traditions. The project results from the partnership of Measure Simplex #113_ Diz IA to Cultural Heritage with the Ministry of Culture of Portugal.

KEYWORDS _ *Artificial Intelligence (AI), Cultural Heritage, Sustainability, SIAP project, Socioeconomic Inclusion*

INTRODUCTION

The SIAP (Artificial Intelligence System for Detection and Alert of Heritage Risks) is a project in Portugal that utilizes Artificial Intelligence (AI) tools to monitor and identify potential threats and risks to the country's cultural heritage. The objective of SIAP is to process data collected through remote sensing and monitoring of historic structures, using satellite and LiDAR technology, to detect anomalies and provide alerts regarding possible damage or deterioration in historical monuments and buildings. By harnessing AI, SIAP aims to optimize heritage supervision services, enabling more efficient and timely intervention in the preservation and conservation of Portugal's cultural heritage.

With the application of MT-InSAR (Multitemporal Interferometric Synthetic Aperture Radar), a satellite-based technique, it is possible to monitor deformations and displacements on the Earth's surface over time. By analyzing synthetic aperture radar data, MT-InSAR can identify subtle topographic variations and detect anomalies in historical structures such as monuments and buildings. This technology provides valuable information for understanding environmental changes and enables the adoption of appropriate preservation measures.

LiDAR, which stands for Light Detection and Ranging, is a remote sensing technology that uses laser pulses to measure the distance between the sensor and surrounding objects. This technique is widely employed to obtain precise data on the topography and three-dimensional shape of objects and structures. In the context of cultural heritage, LiDAR is utilized for acquiring detailed data on historical buildings, sculptures, and cultural landscapes. These three-dimensional pieces of information are crucial for documentation and preservation of architectural and historical elements, as well as for analyzing changes over time and developing appropriate conservation strategies.

Considering the opportunity to keep up with the advancements in the application of digital technologies, specifically AI, in the safeguarding of cultural heritage, the objective of this research is as follows: 1. Identify management strategies; 2. Investigate the skills and competencies required for their implementation; 3. Understand their multidisciplinary handling; 4. Explore possibilities for replication in other geographical spaces, such as Brazilian heritage sites in Sergipe, for example.

The methodology of the exploratory research followed qualitative and descriptive principles to achieve a detailed analysis of the problem situation regarding risks to tangible cultural heritage caused by natural disasters, armed conflicts, or neglect in local administration. The aim was to find ways to measure and mitigate such damages, establishing elements that promote preventive conservation or restoration processes, with digitized records that also serve research and heritage education for future generations.

In this way, the digital accesses of the SIAP project were studied, along with the bibliographic references related to its experience, as well as other works dealing with interventions using AI, satellite mapping, and 3D modelling in the dialogue between researchers and digital technology developers, construction area experts, and public administration.

THE PRESERVATION OF HISTORIC ARCHITECTURAL HERITAGE BY SIAP

When working with the preservation of historic architectural heritage, the importance of imagery, textual, auditory, and colorimetry records is essential for the composition of documentation that provides support for conservation and restoration projects. The available tools allow researchers to acquire a significant amount (and quality) of data, manage them, and share them in real-time with a large audience, thanks to an increasingly widespread network infrastructure with fast and cost-effective connections (Gallozzi, Senatore & Strollo, 2019, p. 48).

As reported by Gallozzi et al. (2019, p. 48), architectural surveying involves a complex series of operations aimed at collecting, evaluating, and interpreting a large volume of data related to the morphology of a Cultural Heritage/Built Monument, as well as data about its construction, structure, materials, decoration, history, and more. From the organization of this data, graphic presentations are developed to identify all the characteristics and peculiarities of the Monument, which justifies the need for precise measurement.

The SIAP project - Artificial Intelligence System for Detection and Alert of Heritage Risks - was developed in response to the challenges of managing and maintaining diverse heritage assets, proposing the adoption of a reactive management system to a proactive one. Machine learning techniques were developed to process data acquired from various sources. The implementation of an early warning system will facilitate risk mitigation, increase safety, and reduce costs associated with the protection of Portuguese cultural material (Arêde et al., 2022b, pp. 995-996).

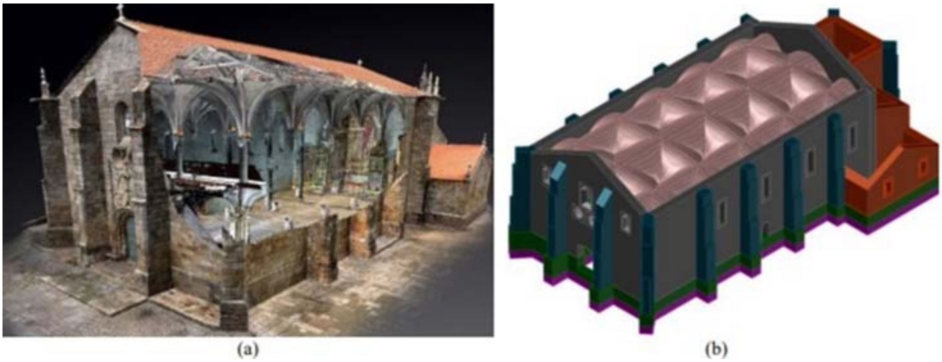

Figure 1: Models being developed: (a) realistic model [source: HPires];
(b) CAD model, geometry only (Arêde et al., 2022b, pp. 1001).

Before reaching the architectural stage, it is necessary to gather information about the building in files. This requires a multidisciplinary team with backgrounds in History, Linguistics, Archival Science, and Information Science. For extracting data from historical sources on 16th to 18th-century buildings, which are in deteriorated paper format, optical character recognition (OCR) techniques were applied. Prior to that, document binarization was performed to eliminate a significant portion of noise and enhance the quality of the extracted text. Through post-processing techniques, it is possible to greatly improve the quality of the information extracted from the documents, addressing gaps, errors, omissions, and ambiguities (Osório et al., 2022, p. 12-13).

RISK TO BUILT HERITAGE AND AI TECHNIQUES FOR MITIGATION

Since 2016, the Guide to Risk Management in Cultural Heritage, published by ICCROM and the Government of Canada, defines risk as "the chance of something happening that will have a negative impact on our objectives." As Pádua (2022, p. 17) stated, it is necessary to identify the causes and effects, understand the risk, and assess the potential performance of interventions in reducing vulnerability. For this purpose, risk management will be positioned at the core of an organizational system oriented towards the conservation of heritage.

The northeast region of Trás-os-Montes is the development area for the SIAP project, which aims to monitor the risks to built cultural heritage. The project focuses on three national monuments owned by the State: the Main Church of Torre de Moncorvo, the Main Church of Freixo de Espada à Cinta, and the Main Church of Vila Nova de Foz Côa. These three churches are rooted in a territory marked by the Vilariça fault, a tectonic fault with an extension of about 250 km that crosses this entire region (DRCN, 2021).

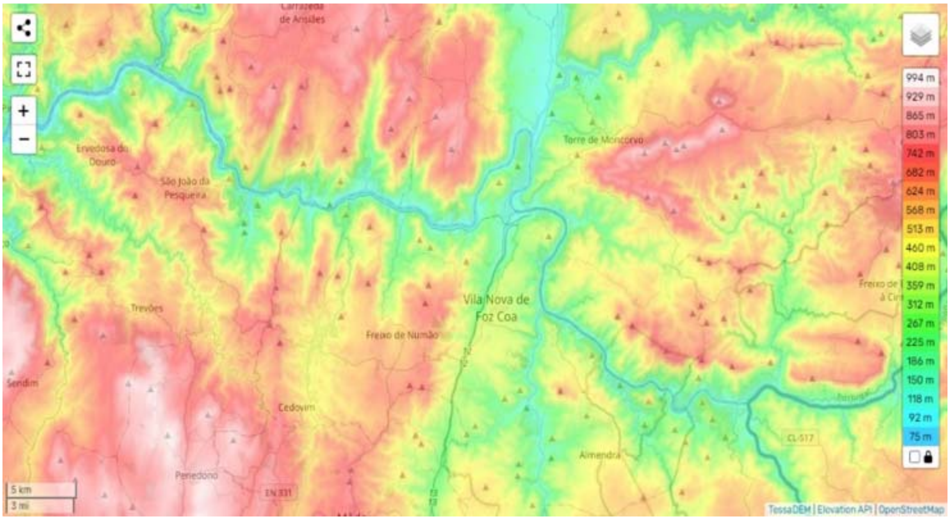

Figure 2: Topographic map of U.F Mós, Santo Amaro, and Vila Nova de Foz Côa, altitude, relief. Available: <https://pt-br.topographic-map.com/map-pb5fgt/U-F-M%C3%B3s-Santo-Amaro-e-Vila-Nova-Foz-C%C3%B4a/>

Vila Nova de Foz Côa presents rugged terrain throughout its region, resulting from active tectonics and pronounced differential erosion, related to the incision of the Douro River and its main left bank tributaries. With a minimum altitude of 99 m, maximum altitude of 847 m, and average altitude of 385 m, its location on the blocks of the tectonic fault demonstrates the complexity of preserving buildings in that area. It is also situated in the Central Iberian Zone, specifically in the former Shale-Graywacke Complex (Búrcio, 2004, p. 10-11).

Developed as a digital platform for data storage and processing for risk alert monitoring, SIAP is based on three pillars: a) monitoring, which involves data collection and analysis, as well as the respective alerts generated by the system; b) knowledge, which encompasses the creation of an intelligent digital archive that enhances the synthesis and research of documents (textual/images) about the monuments and enables interactive exploration of 3D models resulting from on-site surveys; and c) processes, which allows the alerts generated by the system to be integrated into the organization's procedures and addressed by the operational teams of DRCN, according to the most suitable action plans and methodologies (Rebelo, 2022, p. 18).

"Its innovative character led to its transformation into a Simplex Measure. Called AI for Cultural Heritage, it is Measure 113 of Simplex 2019, being the only one in the cultural government area that combines the axis of emerging technologies with improving efficiency in Public Administration" (DRCN, 2021).

To handle remote sensing technologies and data processing with AI, the following skills and competencies are necessary: 1. Knowledge of Remote Sensing: Understanding the principles and concepts of remote sensing, including different sensors, data acquisition techniques, and image interpretation; 2. Data Analysis: Proficiency in data analysis techniques, including preprocessing, image enhancement, feature extraction, and classification algorithms. Familiarity with software tools used for data analysis, such as Python libraries (e.g., NumPy, Pandas) and remote sensing software (e.g., ENVI, ArcGIS); 3. Machine Learning and AI: Familiarity with machine learning algorithms, such as supervised and unsupervised learning, deep learning, and neural networks. Knowledge of AI techniques for image analysis, object detection, and pattern recognition; 4. Programming Skills: Proficiency in programming languages commonly used in remote sensing and AI, such as Python, R, or MATLAB. Ability to write code for data processing, algorithm implementation, and model development; 5. Image Processing: Understanding image processing techniques, including filtering, image registration, image fusion, and image segmentation. Knowledge of digital image processing algorithms and tools; 6. Statistical Analysis: Ability to apply statistical methods to analyze and interpret remote sensing data. Knowledge of statistical concepts, hypothesis testing, regression analysis, and spatial statistics; 7. Domain Knowledge: Familiarity with the specific application domain of remote sensing and AI, such as agriculture, environmental monitoring, urban planning, or disaster management. Understanding the requirements, challenges, and potential applications of these technologies in the respective domain; 8. Critical Thinking and Problem Solving: Ability to analyze complex problems, identify suitable remote sensing and AI approaches, and propose effective solutions. Strong analytical skills and attention to detail; 9. Communication and Collaboration: Effective communication skills to convey complex technical concepts to non-experts and collaborate with multidisciplinary teams. Ability to work in a team environment and contribute to project planning and execution; 10. Continuous Learning: Willingness to stay updated with the latest advancements in remote sensing technologies, AI algorithms, and data processing techniques. Actively seeking opportunities for professional development and attending relevant workshops, conferences, and training programs.

Developing these skills and competencies will enable individuals to effectively use remote sensing technologies and AI for data processing, analysis, and decision-making in various applications.

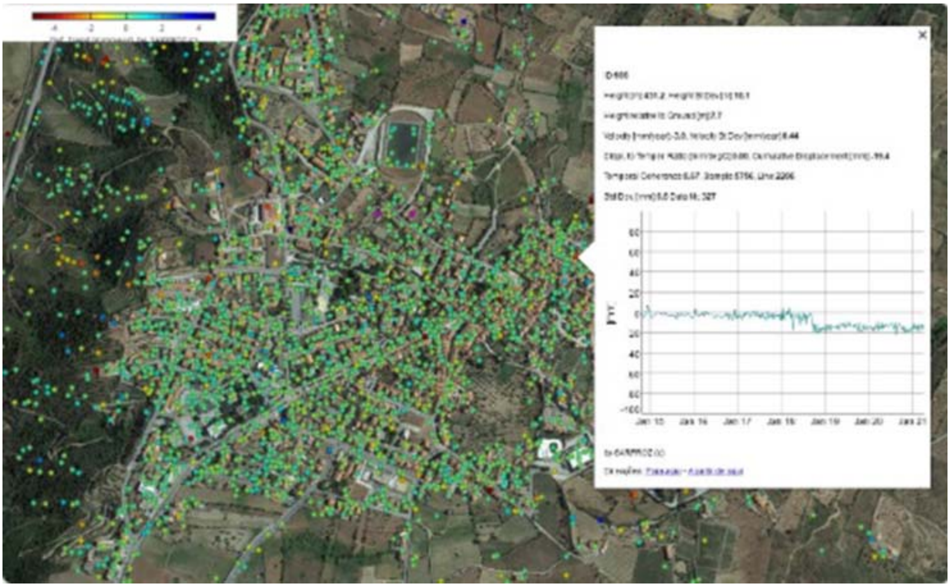

Figure 3: Methodology for monitoring and analysis of immovable assets (SIAP, 2023).

Among the digital technologies used, Synthetic Aperture Radar (SAR) sensors provide systematic data sets for mapping movements and deformations of the Earth’s crust. The collected data is processed using multitemporal InSAR analysis, using sensors from the C-band, ERS-1/2, Envisat, and Sentinel-1A/B, developed by the European Space Agency. This action allowed for a 20-year timeline to be covered, focusing the analysis on the main churches of Vila Nova de Foz Côa, Freixo de Espada à Cinta, and Torre de Moncorvo, processing an area of over 3,800 km2 located on the tectonic fault. While stability was recorded, upward and downward movements of 30 mm/year were also detected near the main church of Vila Nova de Foz Côa, as well as movement in its southern wall. This pattern did not repeat in the churches of Freixo de Espada à Cinta and Torre de Moncorvo, and surrounding areas (Sousa, 2022, p. 20). With the improvement of LiDAR systems, it is possible to fully record the morphology of the surface of materials that shape cultural heritage assets, with resolution, extent, and accuracy. As-Built surveys facilitate the characterization of the correspondence between the original asset and its virtual representation, allowing for the virtual analysis of structural, constructional, and material aspects of the real object. This enables the use of the Digital Twin concept in this relationship of similarity between the physical world and its virtual representation, combining the spatial and temporal dimensions of the systems and processes that occur within it (Pires et al., 2022, p. 22).

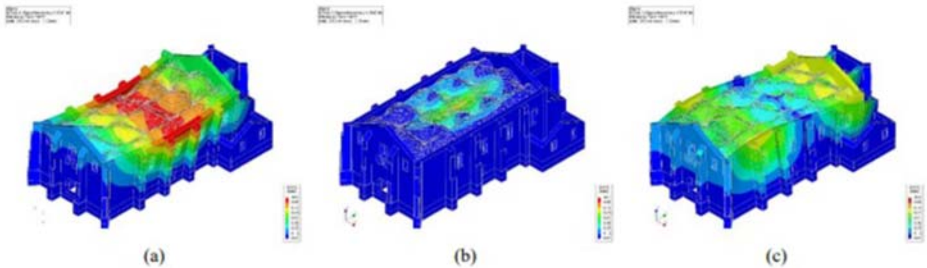

Figure 4: Modal shapes of the base model M0: (a) Mode 1- mostly transversal shape; (b) Mode 2 – local mode of the out-of-plane deformation of the vault and columns; (c) Mode 3 – anti-symmetrical transversal shape. (Arêde et. ali, 2022b, p. 1004).

By implementing the structural monitoring system in the Main Church of Freixo de Espada à Cinta and conducting numerical analyses with three-dimensional parameterization using LiDAR technology, sensors were installed in two areas of the church where relevant cracking occurs: one near the main façade to the West and the other near the wall adjacent to the triumphal arch on the North side. This allows for monitoring of crack openings, wall rotations, and vibrations within the structure. In the church, a total of nine crack gauges, three clinometers (measuring rotation in-plane and out-of-plane of the wall), and five accelerometers were installed. Additionally, four temperature and humidity sensors were added to study their influence on the results obtained from the other sensors. Through the reverse engineering process, a three-dimensional model was constructed using a point cloud obtained from laser scanning of the church. From the obtained three-dimensional model, a finite element model was developed, which was used for performing linear and nonlinear static numerical analyses, providing a better understanding of the current state of conservation (Arêde et al., 2022a, p. 23).

Houses and Townhouses Covered with Portuguese Tiles (Estância, SE, Brazil): Potential use of AI in the safeguarding of cultural heritage.

In Sergipe, the municipality of Estância is home to a Set of Houses and Townhouses with Facades Covered with Portuguese Tiles, which was listed as a state heritage site in 1997. Through this legal provision, local government bodies were expected to act in safeguarding this cultural heritage through monitoring, documentation, preventive conservation, and restoration efforts. During a technical visit conducted in 2021, it was observed that a portion of the buildings has reached an advanced state of deterioration of the tilework, with instances of vandalism, cement application, and fissures in the covering. As this material is exposed to the climatic conditions of high temperatures in Northeast Brazil, it requires careful maintenance and studies to identify its compositional aesthetics.

According to Brendle and Costa (2013, p.3), the city of Estância holds the largest collection of tiles in Sergipe, with specimens dating back to the 19th century and featuring a wide range of patterns. The tilework covers the facades of mixed-use townhouses, used for both commercial activities and housing, as well as some single-story houses. Estância is home to some rare tile patterns, such as the “star” tile with blue painting on a white background.

The properties that feature tiles recognized as state cultural heritage are located at the following addresses: Rua Capitão Salomão No. 67; Rua Pedro Soares No. 442 (or Cap. Salomão No. 84) - (property with significant alteration, including the mutilation of the portico with a metal railing and destruction of the interior of the ground floor); Rua Capitão Salomão No. 122; Rua Capitão Salomão No. 136; Rua Capitão Salomão No. 227; Rua Capitão Salomão No. 228; Rua Capitão Salomão No. 256; Rua Duque de Caxias No. 339; and Rua Capitão Salomão No. 162.

The use of LiDAR systems would be highly beneficial for the comprehensive registration of the morphology of the surfaces that shape the cultural heritage assets in Estância, particularly in relation to the tiles. This technology provides resolution, coverage, and accuracy, enabling a detailed representation of the tile materials.

Figure 5: Houses and Townhouses Covered with Portuguese Tiles, Estância, Sergipe, Brazil. (Photos: Janaina Mello, 2021).

If in Portugal, the protective discourse of preserving built heritage and its enjoyment by citizens under safe conditions is one of the main missions of DRCN. Therefore, preserving the physical structure of monuments constitutes one of its most challenging responsibilities (SIAP, 2023). In Estância, SE, Brazil, the Portuguese-origin tile heritage faces neglect, squandering, destruction, and oblivion, and even with the legal resource of listing as cultural heritage, the government turns a blind eye to the damages to the city's central buildings.

CONCLUSIONS

The SIAP (Information System for Cultural Heritage) has been widely used in Portugal for the management and monitoring of at-risk cultural heritage. Its innovative and integrated approach, combining remote sensing technologies, data processing, and artificial intelligence, has contributed to the efficient preservation and conservation of monuments and historic buildings. Considering the at-risk cultural heritage in Sergipe, Brazil, the implementation of SIAP could offer similar benefits. Using advanced technologies such as sensors and AI data analysis, it would be possible to carry out detailed monitoring of Sergipe's cultural heritage, identifying risks, preventing damages, and assisting in decision-making for its conservation. The application of SIAP in Sergipe could be an effective strategy to address the challenges faced by the local cultural heritage, promoting its safeguarding in an integrated and sustainable manner.

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