Documentation and rapid assessment of the health status of historic centers by the use of 360-degree videos and G.I.S.

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Abstract

The present work explores a methodology that makes use of low-cost technologies for generating panoramic videos in historic settings (characterized by very narrow streets) for the rapid identification of buildings that have injuries or damages induced by seismic events. The methodology was tested in the historic center of Popoli Terme (Italy). Importing the videos generated by a 360-degree camera into the Geographic information System (GIS) environment enables surveying and assessing the condition of the buildings with the assistance of a seismic expert. The proposed methodology can also be applied during emergency scenarios where rapid and complete documentation of damaged assets assumes a key role.

Keywords

Building engineering, 360-degree video, historic centers, building health status

1. Introduction

In recent times, there has been an increasing interest in the application of 360-degree panoramic visualizations in various fields. This can be attributed to their cost-effectiveness, enhanced realism and elevated level of immersion [1]. The 360-degree video, also known as immersive video or spherical video, is a technology that captures a complete view of a scene at the same time. It allows viewers to virtually explore their surroundings by panning around the entire environment. A 360-degree camera could feature a lens positioned on the top to capture a complete view of its surroundings. Alternatively, some 360-degree cameras are equipped with lenses on two sides to capture a panoramic view from top to bottom and

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left to right, which are later stitched together to create a seamless image [2]. Building knowledge and its subsequent analysis [3-4], especially in post-earthquake contexts, have taken on an increasingly important role; the difficulty of access and the slowness of data processing have led to the development of systems capable of producing information that is as rapid and precise as possible [5-8]. Croce et al. [9] acquired videos recorded in the historic center of Castelluccio di Norcia, one of the municipalities affected by seismic events occurred in Central Italy in 2016; the authors produced 3D models of the village that allow for the comparison between the configurations of Castelluccio pre and post the seismic event of the 30 October 2016. Zhang et al. [10] highlighted the crucial role of extracting post-earthquake building damage information for loss assessment; to address this challenge, they proposed a novel approach using low-altitude remote sensing via unmanned aerial vehicles (UAVs). Their method leverages a combination of ultramicro oblique UAV imagery and infrared thermal imaging technology to achieve automatic detection of structural damage in external walls. The method incorporates four key components: (1) 3D live-action modeling and analysis of building structures using ultramicro oblique images, (2) extraction of damage information from buildings, (3) detection of cracks in walls using infrared thermal imaging, and (4) integration of these detection systems for comprehensive data gathering on earthquake-damaged buildings. Cataldo et al. [11] explore the potential of a low-cost, advanced video-based technique for the assessment of structural damage due to seismic events, utilizing a low-cost, high-speed video camera for the motion magnification processing of footage of a two-story reinforced-concrete frame building subjected to shaking table tests. Feng et al. [12] emphasize the importance of 360-degree videos not only as instruments to create evacuation scenarios using Virtual Realities (VR) experiments. The 360-degree cameras were used for capturing an aerial view of the overall movement of the students, with the aim of evaluating their behavior and reproducing it in the simulation. The importance of the 360-degree video in the documentation of historic centers and Cultural Heritage (CH) sites was addressed by Alsadik [13]; in this latter paper, the author describes the documentation of three Iraqi historical sites using crowdsource drone videos. In this direction, Pepe at al. [14] realize not only a documentation but also a 3D reconstruction of a historical site. The described literature studies lack the definition of a systematic workflow for the full exploitation of 360-degree videos for the identification of the health status of CH buildings and historic centers. Therefore, this paper tries to overcome this limitation by exploring the potential of the spherical video for the documentation and rapid assessment of the state of conservation of age-old buildings. The study is part of the research project GENESIS "Seismic risk management for the touristic valorisation of the historical centres of Southern Italy", financed by the Italian Ministry of Education, University and Research (MIUR). The article is structured as follows: Section 2 provides an overview of the significance of 360-degree videos for historic city centers; Section 3 outlines the methods and tools employed, including video acquisition and integration with GIS software; Section 4 details the case study of Popoli Terme, describing the data collection and analysis processes; finally, Section 5 discusses the evaluation of building health status, highlighting key findings and limitations, and Section 6 concludes with potential applications and future research directions.

2. 360-degree Videos for Historic City Centers

The CH and historic city centers of Italy hold immense importance, both nationally and globally. These sites are not only treasures of architectural and artistic excellence but also repositories of the rich history and diverse cultural traditions that have shaped Italian identity over centuries. They attract millions of tourists each year, significantly contributing to the country's economy. Preserving these cultural assets ensures that future generations can continue to learn from and appreciate Italy's historical legacy. The knowledge process of built CH, given its extent and heterogeneity, has become a major challenge for researchers in recent years. These important topics are the focus of the GENESIS project (Figure 1), whose goal is to create a dynamic and interdisciplinary platform for the management of seismic risk that can be updated over time and space. The data collected are obtained from multi-scale surveys (depending on the level of detail to be achieved) of several case-study historic centers. Different types of surveys are carried out, ranging from historical, instrumental and monitoring systems. The collected data enable the evaluation of the seismic vulnerability and risk of historic centers, as well as the effectiveness of viable retrofitting strategies. This aims to provide a territorial assessment of the health status and enhance tourism in the historic areas.

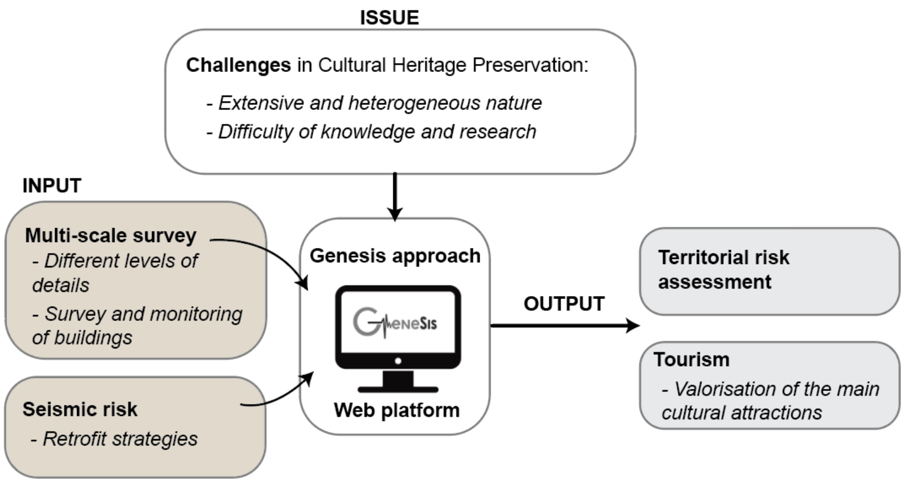


Figure 1: Conceptual map of the main activities of the GENESIS project.

Using new technologies to enhance or acquire the knowledge level of buildings at various scales is becoming increasingly important. The "Genesis approach" leverages these technologies not only in the tourism sector [15-17] but in the buildings assessment [18-19].

The technology of 360-degree videos can be extremely useful for enhancing and supporting inspections and optimizing maintenance planning in urban areas, particularly from a seismic and structural perspective. These videos provide an immersive view of the environment, enabling experts to conduct comprehensive remote analyses without being physically present, which is particularly valuable in emergencies or for hard-to-reach buildings. The detailed documentation captured by these videos is crucial for identifying building damage, such as crack patterns, and can be archived as future comparison to monitor the evolution of structural issues over time. Additionally, these tools can detect moisture in structures, enabling early diagnosis of problems like water infiltration or leaks. In historic centers, 360-degree videos facilitate more efficient maintenance planning by allowing personnel to assess current building conditions and prioritize areas for intervention, thus optimizing resources and work times.

3. Methods and tools

A comprehensive understanding of building structures for structural and seismic analysis can be efficiently supported by integrating 360-degree videos with Geographic Information System (GIS) software. Considering this, the proposed method includes the following steps:

1. Implementation of a system to generate videos;
2. Selection of the case-study;
3. Acquisition of videos;
4. Importing videos into GIS software and reconstruction of acquired pathways;
5. Characterization of the built environment;
6. Evaluation of the building health status.

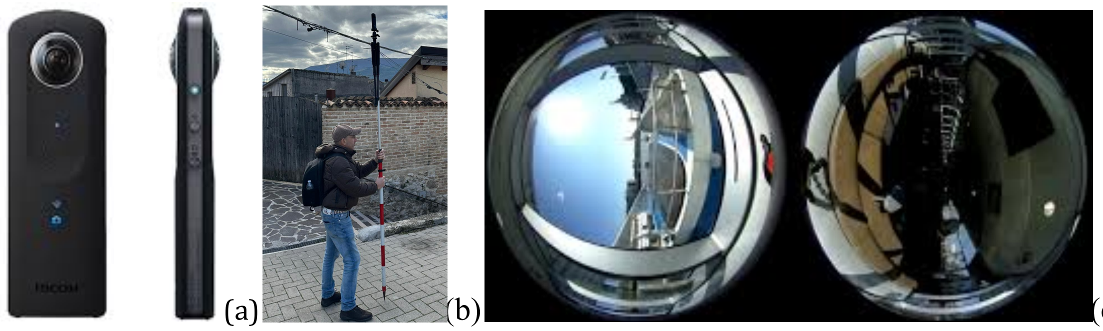
The first step involves setting up the system with a camera capable of capturing 360-degree video. To acquire information at different heights and floors, the camera can be mounted on a pole or Unmanned Aerial Vehicle (UAV). The system may include specialized software or hardware that controls the camera's orientation and ensures it records a complete spherical view at a predefined altitude. Before the acquisition stage, it is necessary to set the camera resolution, i.e., the number of pixels that make up the video image, expressed as the width and height of the video in pixels. In general, higher video resolution means a sharper and more detailed image, but higher resolution video files also require more storage space and bandwidth for playback. Some common video resolutions are:

- SD (Standard Definition): 480p (720x480);
- HD (High Definition): 720p (1280x720), 1080p (1920x1080);
- Full HD (FHD): 1080p (1920x1080);
- 2K: 1440p (2560x1440);
- 4K (Ultra HD): 2160p (3840x2160);
- 8K (Ultra HD): 4320p (7680x4320).

Once the videos are captured, they can be managed in the appropriate format (frame rate, bitrate, codec) to be imported into GIS software. In this environment, users can integrate the immersive 360-degree experience with other geospatial data layers, such as maps, terrain models, or infrastructure information. Finally, the videos are used to acquire information on material type, structural damage, structural type, and number of floors, supporting a rapid vulnerability assessment. This information is useful for planning consolidation interventions and resource allocation.

3.1. Implementation of a system to generate videos

The video dataset was successfully acquired using the Ricoh Theta Z1 sensor. This sensor captures images at a resolution of 23 MP (6720 × 3360 pixels) with a high-performance and accurate image-stitching algorithm (Figure 2a). For video recording, it can record at a resolution of 4K (3840 × 1920 pixels) at 29.97 fps [20]. To acquire information in the historic center at a suitable height and obtain data on the upper parts of buildings, the sensor was mounted on a pole, as shown in Figure 2b. This setup allowed videos to be acquired at a height of 3.5 meters. The two cameras with fisheye lenses enable the capture of two single images (Figure 2c).



(a) (b) (c)

Figure 2: System of acquisition: 360-degree camera (a), camera mounted on the pole (b) and type of the images generated by Ricoh Theta Z1 sensors (c).

Before the acquisition phase, the video resolution to be adopted must be selected. The Ricoh Theta Z1 primarily supports two resolutions for 360-degree video: 4K (3840 x 1920) at 30 fps and 2K (1920 x 960) at 30 fps. Therefore, it was essential to make a judicious choice that balances video quality and memory space. Videos in 4K deliver exceptionally high quality, ideal for viewing on VR devices and large screens. However, these files are considerably larger and consume more memory space. On the other hand, 2K videos offer decent quality, adequate for most web applications and medium-sized screens, with considerably smaller file sizes. Table 1 summarizes the file sizes generated by the Ricoh Theta Z1 sensor at each allowable resolution. Taking into consideration the characteristics of the camera and the ability to capture as much information as possible in a single work session, several tests were conducted to evaluate the differences between the two resolutions. After reviewing the outcomes, the 2K format was selected based on the results obtained.

Table 1
File Sizes by Resolution for Ricoh Theta Z1.

Resolution	Medium Bitrate	Approximate size (1 minute)	Approximate size (1 hour)
4K	56 Mbps	~420 MB	~25 GB
2K	16 Mbps	~120 MB	~7 GB

3.2. Case study

Popoli Terme, a small town of approximately 4,700 inhabitants in Italy's Abruzzi region, is a significant testament to Italian cultural heritage. Selected as a pilot case study due to its historical significance and strategic geographical position, the town is located in a seismically active area intersected by a major fault system. This was highlighted in 2009 when an earthquake in nearby L'Aquila (AQ) caused substantial damage to Popoli Terme, underscoring the need for comprehensive seismic risk assessment.

The study focuses on the historic center, comprising around 500 buildings from the 13th and 14th centuries. This area provides an exceptional opportunity to study medieval urban planning, construction techniques, and the resilience of historical structures to seismic events. While virtual tours like Google Street View (GSV) offer immersive navigation, they face limitations in historic centers with narrow, winding streets and stepped pathways. Consequently, GSV's coverage in Popoli Terme is incomplete, missing the intricate network of alleys and hidden corners. To address the limitations of conventional mapping methods, a novel approach was employed. A two-day inspection using 360-degree video technology was conducted to comprehensively map all streets within the historic center. This method provided a more thorough and complete survey of the road system. A comparative analysis, shown in Figure 3, highlights the improved completeness of the survey achieved with 360-degree video mapping compared to GSV. This innovative approach provides a comprehensive visual record of the town and valuable data for urban planners, conservationists, and emergency responders. It is essential for assessing building conditions, identifying hazards, and planning conservation efforts. Additionally, it offers critical support for emergency response and damage assessment in the event of future seismic activity [12].

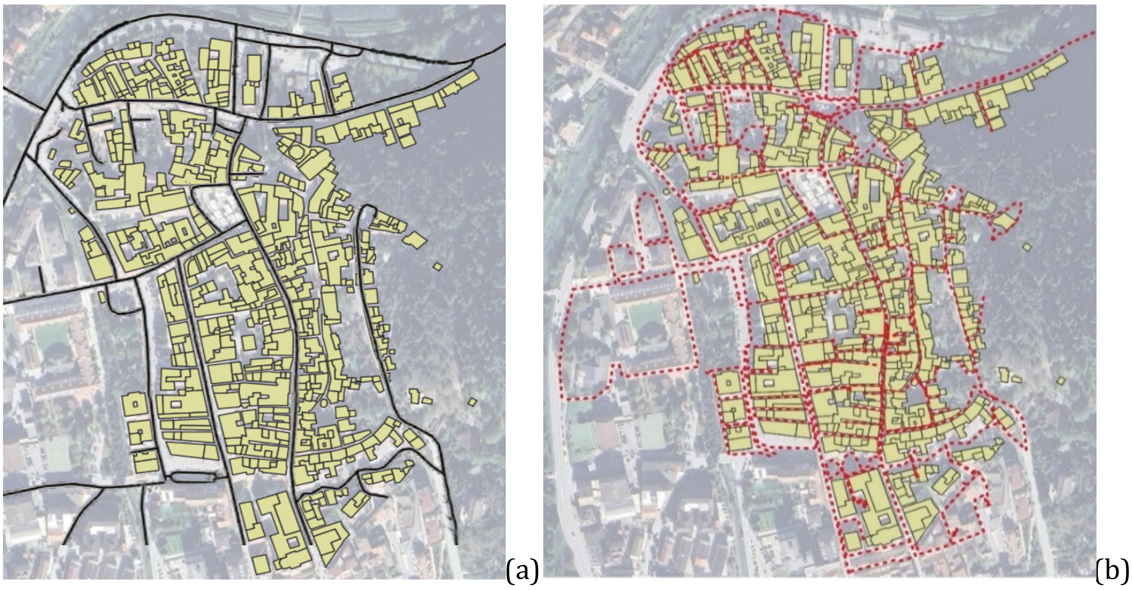


Figure 3: Comparison of GSV (a) and 360-degree videos (b) surveys carried out for the historic center of Popoli Terme.

3.3. Acquisition of videos

The generation of the videos can be carried out using suitable apps developed by Ricoh, one for acquisition and another for post-processing. In particular, the data was acquired using the RICOH THETA App, which is compatible with both iOS and Android devices. The videos were subsequently imported into RICOH THETA Stitcher, a desktop application specifically designed for stitching and processing 360-degree images captured by THETA cameras (available for both Windows and Mac operating systems). In this environment, high-quality, seamless 360-degree images can be produced with minimal distortion and artifacts. Additionally, the stitched images can be refined using advanced editing tools to adjust exposure, white balance, and color correction.

3.4. Importing videos into GIS software and reconstruction of acquired pathways

Video management requires the contextualization of locations. To achieve this, a shapefile that reconstructs the areas and their attributes (such as the date of acquisition and the link to the 360-degree video) needs to be created. This allows users to easily geolocate the videos. For the specific case study, ArcMap software, part of Esri's ArcGIS suite, was used [21]. Figure 4 shows a screenshot illustrating several paths captured by the operator using the 360-degree camera, along with the attributes of the shapefile of the type "polyline". Additionally, to enhance the graphical interpretation of paths, a point-type shapefile marking the beginning of each path was introduced. This file, utilizing a spatial join tool, includes a field labeled with the path's name. This feature simplifies and streamlines interaction with the paths in the historic center.

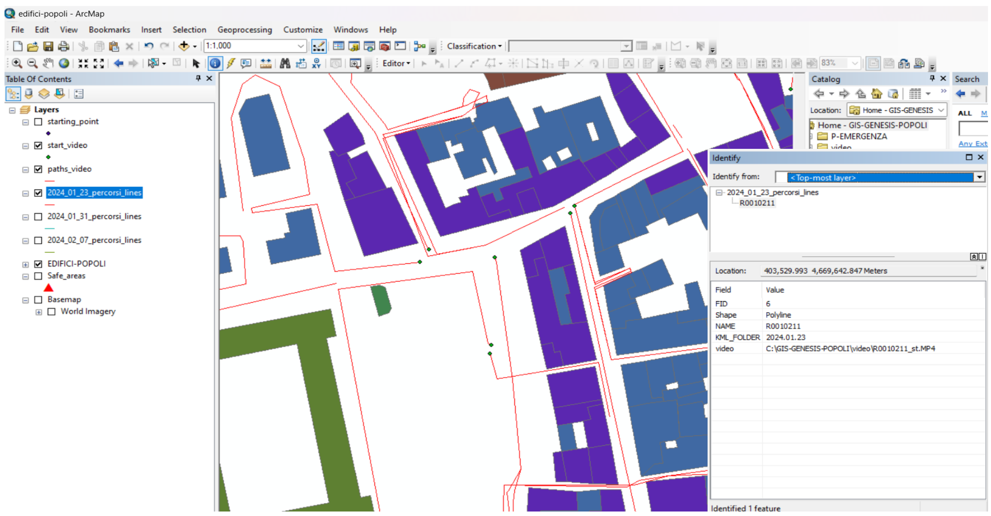


Figure 4: Screenshot in ArcMap software about the management of the paths.

3.5. Characterization of the built environment

The 360-degree camera inspections allowed for a quick and preliminary analysis of the buildings in the historic center of Popoli Terme. These analyses are an important starting point for studying the historic center because they serve two main purposes: 1) To study the urban environment of the historic center as a whole; 2) To examine the geometric and constructive features of each building individually. After a preliminary mapping of all buildings in the historic center, the urban environment, including the road network, street widths, and slopes, was defined based on the surveyed routes. This information is crucial for planning evacuation strategies during seismic events, as it helps identify the safest and quickest routes. 360-degree videos have revealed the height and structural material of each building in the historic center as well as the masonry type in the presence of unplastered walls (Figure 5). Specifically, most of the buildings range from 3-4 stories high (approximately 8-11 meters, Figure 5a) and are made of masonry (95%). This finding is somewhat predictable given the age of the area analyzed. Only a small portion of the buildings (5%) are made of reinforced concrete, resulting from renovations carried out in the 1980s (Figure 5b).

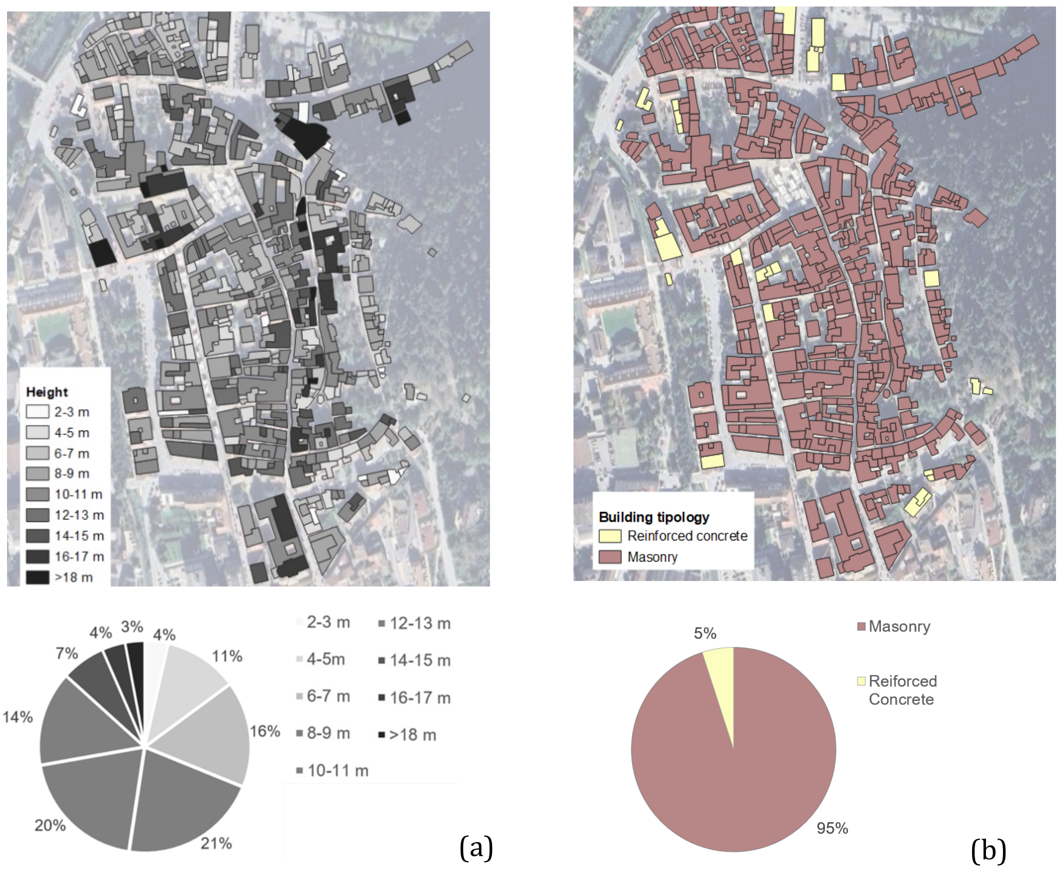


Figure 5: Characterization of the buildings of the historic center in terms of height (a) and building type (b).

3.6. Evaluation of the building health status

The use of 360-degree video technology allows for a comprehensive evaluation of structures, focusing on three critical aspects: conservation status, moisture issues, and crack patterns. By capturing panoramic imagery, experts can remotely assess the condition of facades and architectural details. This technology enables a thorough examination of surface degradation and material weathering, without the need for physical access to every part of the building. The ability to zoom in on specific areas and view them from multiple angles enhances the accuracy of condition assessments. The choice of video resolution is critical for the ability to detect fine structural details such as cracks. The use of 2K format, while beneficial for data management and storage, can represent a significant limitation in detecting very fine cracks. The 2K resolution provides adequate definition for most applications but may not be sufficient to identify cracks smaller than a few millimeters wide, especially under unfavorable lighting conditions. Additionally, the distance between the camera and the object under analysis plays a crucial role: greater distances can further reduce the ability to detect minor details. Therefore, it is essential to integrate video data with physical inspections or other high-resolution imaging techniques to achieve a more accurate assessment of structural condition. In the case study of Popoli Terme, the northeastern part of the historic center appears more degraded in terms of maintenance compared to other areas. As shown in Figure 6, the alleys present staircases with missing parts and significant moisture issues (Figure 6a). This area of the historic center suffered the most damage in the 2009 earthquake. Many buildings here were deemed unusable, with collapses and widespread damage evident (Figure 6b). The lack of maintenance is reflected in the near-total absence of local interventions or improvements over the years.


(a)

(b)

Figure 6: View of the alleys in the historic center in poor maintenance condition (a) and cracking pattern with collapse (b) of buildings in Popoli Terme (PE).

All these data are of fundamental importance for the rapid vulnerability analyses that are generally used in literature when working on a territorial scale, including in historic centers. From the parameters and characteristics extrapolated with these technologies, critical issues and potentials of the analyzed areas are identified, obtaining results in terms of vulnerability [22].

4. Conclusions

This study explored a methodology based on low-cost technologies to generate 360-degree videos in historic centers characterized by very narrow streets in order to detect buildings with damage or seismic-induced failure mechanisms. The methodology was tested in the historic center of Popoli Terme (PE, Italy). By importing the videos generated by the Ricoh Theta camera into the Geographic Information System (G.I.S.) environment, and thanks to the help of a seismic expert, it was possible to document the conditions of all the buildings located within the historic area in a rapid and efficient way.

The main outcomes of this study are summarized hereafter:

- The proposed method makes it possible to guide stakeholders towards optimal resource planning and promises to enhance urban resilience while respecting the town's historic character. This approach exemplifies a modern, data-driven strategy for urban planning and disaster preparedness in historic towns.
- The comprehensive data collected through the surveys carried out on the historic center of Popoli Terme (PE) will be integrated into the GENESIS platform. By centralizing diverse information about buildings, infrastructure, and urban layout, the GENESIS platform enables a holistic understanding of the town's weaknesses and strengths. This integrated assessment is particularly vital for Popoli Terme (PE), a town characterized by a high seismic hazard.
- The 360-degree video technology supports the seismic vulnerability analysis of the urban centers, enabling (a) critical decisions on building retrofits, (b) emergency planning and (c) resource allocation, balancing preservation needs with safety imperatives. This method not only aids in protecting Popoli Terme's residents and CH but also sets a replicable model for other historic towns facing similar challenges.
- This methodology is applicable in emergency scenarios, where rapid and comprehensive documentation of damaged assets assumes a crucial role. UAV-mounted 360-degree video is a solution for reaching and documenting hard-to-access locations for a rapid evaluation of the conditions of buildings.
- 360-degree videos offer many benefits, including the ability to be remotely accessed by drones that can fly over areas that are remote or dangerous due to structural damages or residual hazards. These videos provide a comprehensive panoramic view of the environment and buildings, allowing for detailed and accurate assessments of conditions after emergencies. Furthermore, drones' capability to monitor an area continuously over time enables early detection of changes in building conditions or the environment. This approach not only provides real-time information to field operators, supporting rapid and informed decisions during rescue and recovery operations, but also reduces the risk to involved personnel by avoiding exposures to physical or environmental hazards.

Future research should focus on using AI-based algorithms to detect building damage from 360-degree videos. The integration of ground platforms or drones equipped with 360-degree video cameras and AI can identify issues like cracks and corrosion early, facilitating timely maintenance. However, challenges such as ensuring sufficient video resolution, managing lighting variability, and training AI models on large, diverse datasets also need to be addressed.

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