Autonomous multi-session RGB–thermal mapping of historical multi-storey buildings for conservation monitoring*

A. Adán, V. Pérez and E. Adán

Abstract— **This paper presents a ground mobile robot equipped with RGB and thermal cameras for autonomous multi-session mapping of multi-storey buildings. The system generates dual RGB–thermal 3D models that enable temporally consistent monitoring of indoor environments. A multi-session acquisition and registration strategy is introduced to ensure spatial consistency across sessions while preserving alignment between visual and thermal data. The platform has been validated in real heritage buildings, producing repeatable thermal–geometric reconstructions under comparable conditions. The proposed approach enables non-invasive inspection, long-term monitoring, and integration into heritage digital twins.**

I. INTRODUCTION

Autonomous 3D scanning for heritage buildings has become a central topic in robotics and UAV platforms [1]. However, most existing approaches focus on geometric reconstruction, neglecting thermal information that can enrich building understanding [2].

Thermal sensing provides additional information about material properties, structural pathologies, energy losses, and hidden defects that are not directly observable in the visible spectrum. In the context of building inspection and monitoring in the three-dimensional world by robots or UAV systems, a few works dealing with the integration of thermal and colour data within geometric 3D models can be found [3], [4], [5], [6]. These proposals enable dual-modality representations that can be leveraged by EAC professionals. However, few robotic systems address consistent RGB–thermal modelling across multiple sessions and time periods [7].

Multi-session mapping is particularly relevant for highly changing indoor environments or multi-storey buildings, where revisits are required to detect changes, monitor degradation processes, or assess structural and energetic performance over time. Ensuring spatial consistency and RGB–thermal alignment across sessions remains a challenging problem addressed in this work.

We present a ground mobile robotic platform equipped with a long-range laser scanner, three RGB cameras and two thermal cameras for autonomous multi-session indoor modelling, called MoPAD3 (Mobile Platform for Autonomous Digitization). The proposed system generates temporally consistent dual RGB–thermal 3D models of multi-storey buildings through a multimodal perception and registration framework. The robot has been deployed in real multi-level buildings, demonstrating repeatable data acquisition and consistent thermal–geometric reconstruction across sessions.

The main contribution of this extended abstract is threefold: (i) the design and integration of a multi-camera RGB–thermal sensing architecture onboard a mobile robot for indoor mapping, obtaining omnidirectional thermal point clouds; (ii) a multi-session reconstruction strategy that enables persistent dual-modality 3D modelling of complex indoor environments; (iii) the proposed system has been successfully deployed in multi-storey buildings, a scenario that remains largely underexplored in multimodal robotic mapping.

II. SYSTEM OVERVIEW

MoPAD3 is a multimodal perception system that extends previous MoPAD versions with multi-floor and multi-session capabilities and is oriented towards the thermal digitisation of heritage buildings. It consists of the following components:

- Robotic base. MoPAD3 is built on a TurtleBot 2 platform incorporating a compact and low-cost Kobuki nonholonomic mobile base. The platform supports payloads of up to 5 kg and operates within a ROS-based architecture.
- Mid-range 3D laser scanner. A Leica BLK360 scanner provides range measurements from 0.6 m to 60 m, with a field of view of 360° × 300° (horizontal × vertical).
- RGB imaging system. Three integrated RGB cameras (2592 × 1944 pixels each) provide a field of view of 60° × 45° (vertical × horizontal) per camera. The cameras rotate synchronously with the scanner, capturing 10 × 3 images during a full rotation. This configuration yields approximately 150 megapixels per scan and achieves a combined FoV of 360° × 300°.
- Thermal imaging system. Two thermal cameras (160 × 120 pixels) with a field of view of 71° × 56° (vertical × horizontal) are externally mounted on the scanner body. The radiometric characteristics include a thermal sensitivity of 0.05 °C and an accuracy of ±2%. During rotation, each camera captures 10 overlapping thermal images, producing an almost omnidirectional thermal coverage, except for a lower blind cone of approximately 40° beneath the robot.
- Autonomy features. The platform incorporates autonomous self-charging and a switch actuator that

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powers the scanner on and off between sessions, reducing energy consumption.

The system is implemented within a ROS framework. The laser scanner and thermal cameras are controlled via their respective SDKs, allowing customised configuration of acquisition parameters. System communication and data transfer are interconnected via Wi-Fi through two dedicated networks: (i) the scanner network, which connects the scanner to the robot, and (ii) the MoPAD3 network, which links the robot to the switch actuator and the remote control server.

From a single acquisition position, MoPAD3 is capable of generating an omnidirectional RGB–thermal point cloud of the visible environment, except for the approximately 40° blind cone located beneath the platform. RGB and thermal images are registered to the BLK360 point cloud through an extrinsic calibration previously presented in [7]. Briefly, the RGB and thermal cameras are geometrically calibrated with respect to the scanner reference system, allowing the mapping of colour and temperature information onto the corresponding 3D points. As the cameras rotate together with the scanner, the relative transformation between sensors remains fixed, enabling consistent alignment for all acquisition angles.

III. MULTI-SESSION MAPPING FRAMEWORK

A. *Single storey cases*

Autonomous multi-session RGB–thermal mapping, together with the multi-storey deployment capability, constitute the main novel features of the MoPAD3 system. The stages of a multi-session campaign in the single-floor case are summarised below:

(1) Obstacle map acquisition. The methodology begins with an offline phase in which the robot generates a map of the environment. This map is reused in subsequent sessions within the same scenario.

(2) Parameter configuration. The user defines the multi-session parameters, including: number of sessions, time interval between sessions, robot stop locations and orientations, and scanning parameters.

(3) Navigation and data acquisition. The robot autonomously navigates to each predefined stop location, where RGB and thermal data are acquired according to the predefined plan. The acquisition phase concludes when the platform docks at the charging station.

(4) Data transfer and storage. The acquired point clouds and thermal images are transmitted to a remote server. The data are then cleared from the robot's onboard memory and stored in a hierarchical database structured into the following levels: day, session, zone, and position.

(5) Session-level processing. A registration phase is performed for each session, integrating multiple positions per zone (e.g., room) and multiple zones per session. An initial odometry-based alignment is refined using the Iterative Closest Point (ICP) algorithm [8], yielding a unified RGB–thermal point cloud.

(6) Standby phase. The data acquisition system is deactivated until the next scheduled session, while the robot remains docked. Sessions are typically separated by one to six hours to allow thermal variations.

(7) Session repetition. Steps (3)–(6) are repeated until the final scheduled session is completed.

(8) Inter-session registration. Spatial consistency across sessions is enforced through an additional registration stage. The global point cloud of each session is aligned with respect to the first session, which is used as the reference model.

B. *Multi-storey cases*

MoPAD3 can be used to generate RGB–thermal models of a multi-storey building by repeating the previously described single-floor workflow, while introducing several constraints. These constraints arise from the fact that the data acquisition of a single floor may require one hour or more. Under such circumstances, continuing the acquisition on additional floors within the same session would not be consistent, as the thermal conditions may have changed significantly.

The objective is to obtain a thermal representation of the building within the shortest possible time span, resembling a "3D thermal snapshot" of the indoor environment. To approximate this condition, the following acquisition protocol is enforced:

- Data acquisition is carried out during a period of stable weather conditions, lasting as many consecutive days as the number of floors.

- Each floor is digitised on a different consecutive day within this period, and the acquisition process starts at the same time each day.

As a result, for a building with n floors, a set of n multi-session RGB–thermal models is obtained, one per floor, captured under comparable external environmental conditions over n consecutive days. When combined, these floor-level models approximate a consistent 3D thermal representation of the entire indoor building for a specific short period of time.

It should be noted that both single-floor and multi-storey acquisition campaigns can be repeated over extended time intervals, such as months or seasons. When thermal models are generated across multiple time periods, the resulting temporal information enables the analysis of building energy behaviour at different scales, ranging from short-term variations (e.g., daily cycles) to medium-term trends influenced by seasonal conditions. Such time-resolved thermal models could support energy efficiency and heritage conservation through continuous monitoring under comparable environmental conditions.

Preventive conservation strategies that facilitate the early detection of degradation phenomena (e.g., moisture accumulation or thermal anomalies) can also assist restoration professionals in setting structural interventions while preserving the architectural integrity of historic buildings.

IV. EXPERIMENTAL DEPLOYMENT

The proposed system has been validated in several real heritage environments. In this paper we present the results obtained in a representative case study: the interior of the Palacio de Cervelló, located in Valencia (Spain). The building constitutes a historical palace of significant architectural value and currently hosts museum spaces and representative rooms open to the public (see Figure 1).

Two floors of the building were digitised using the proposed multi-session RGB–thermal mapping robot. The ground floor includes the palace museum, comprising five rooms, while the first floor contains six principal rooms corresponding to the main historical chambers. The total surveyed indoor floor area was approximately 300 m² per floor, covering exhibition spaces, corridors, and interconnecting zones.

A total of three sessions were conducted over two consecutive days under stable weather conditions at times 10:00, 12:00 and 14:00. The acquisition process followed the previously described quasi-synchronous protocol, ensuring comparable environmental conditions across sessions. Each floor was digitised independently, maintaining consistent start times to reduce thermal variability due to daily fluctuations. From each predefined stop location, the system generated omnidirectional RGB–thermal point clouds. Table I shows information about the data acquisition campaign carried out on different days. The acquisition required no physical intervention in the building structure, respecting conservation constraints typical of protected heritage environments.

TABLE I. THERMAL POINTS CLOUDS OF THE CASE STUDY

Session	**Day**	**Time**	**Floor**	**Scan Positions**	**Aver. TPC size (mill)**	**Aver. Point Density (n/cm^2)**
1	1st	10:00	#0	5	5.845	0.703
1	2nd	10:00	#1	11	9.901	0.725
2	1st	12:00	#0	5	5.830	0.718
2	2nd	12:00	#1	11	9.906	0.805
3	1st	14:00	#0	5	5.841	0.812
3	2nd	14:00	#1	11	9.903	0.765

The final RGB–thermal models exhibit a reconstruction density of approximately 0.8 points/cm² and around 15 million points per session. Figure 2 illustrates the results for each floor at different stages of the building thermal model generation process. Figure 2(a) shows the positioning of each room on Floor 0 within the robot's obstacle map, based on odometry. Figure 2(b) evidences the precise registration between consecutive scans, colour-coded for improved visualisation. A quantitative evaluation of the registration process was carried out. Specifically, the Root Mean Square Error (RMSE) obtained during the ICP registration stage was analysed. The inter-session registration process yielded RMSE values below 2 cm, with ICP convergence typically achieved in fewer than 50 iterations. These results indicate consistent spatial alignment across sessions. Figure 2(c) presents the thermal model of Floor 0 for the first session at 10:00, using a standard thermal colour palette.

The final thermal models of the building are shown in Figure 3. Temperature variations are clearly observable as time progresses throughout the morning. A heritage-oriented analysis of the multi-session RGB–thermal models enables the identification of temperature gradients in exterior-facing walls, the detection of localised thermal anomalies potentially related to moisture or material heterogeneity, and comparative thermal analysis across different areas.

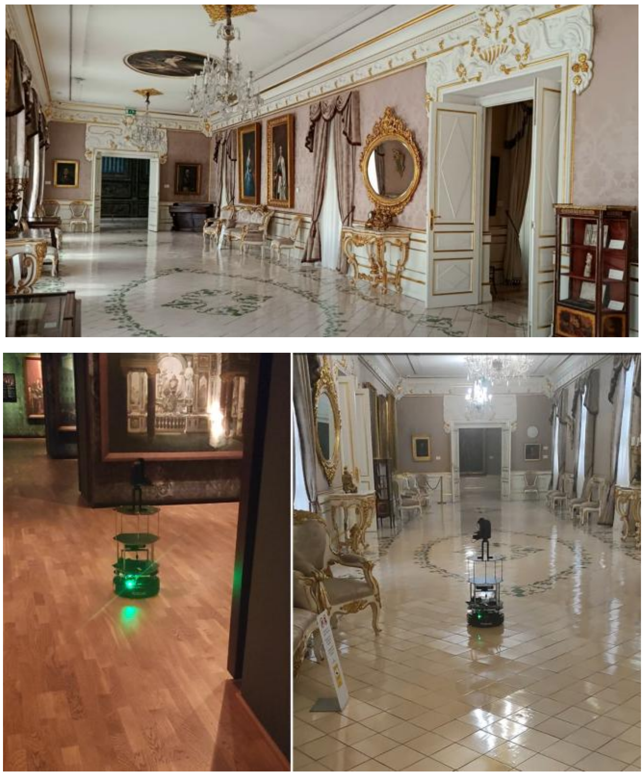
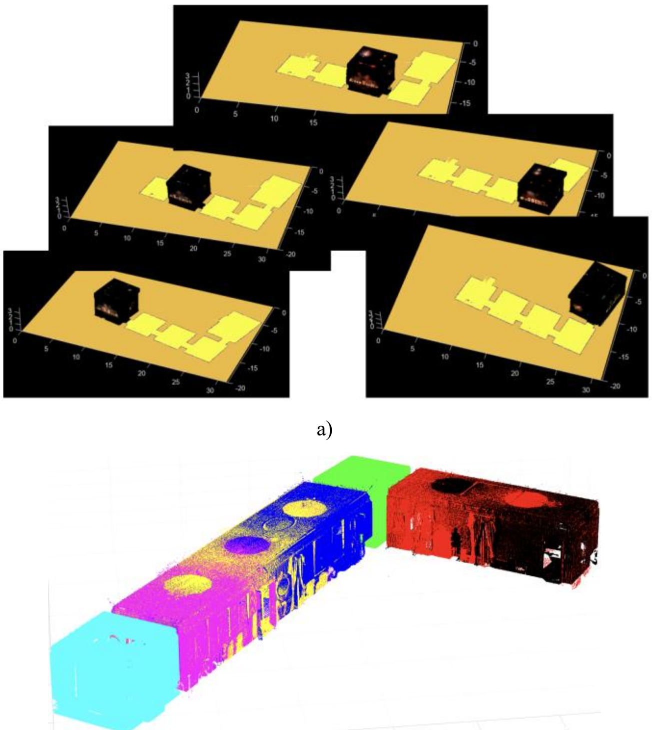
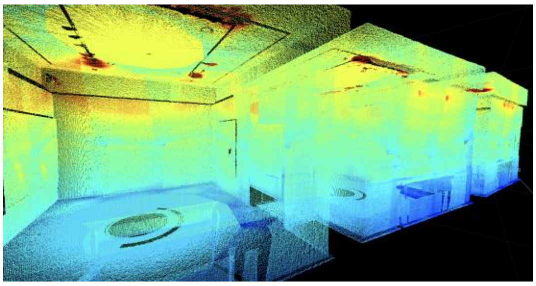


Figure 1. Cervelló's palace and MoPAD3 navigating and taking thermal scans inside Floor#0 and Floor#1



a)

b)



c)

Figure 2. Construction of the thermal model of the case study. a) Aligning the room models of Floor #0 into the robot obstacle map (in yellow). b) Details of the registration result of the first seven scans in Floor#1. c) Thermal model of Floor#0.

Overall, the case study demonstrates the feasibility of autonomous multi-session RGB–thermal mapping in a real multi-storey historic building. The resulting models provide a geometrically and thermally consistent basis for long-term monitoring and future integration into HBIM-based heritage digital twins.

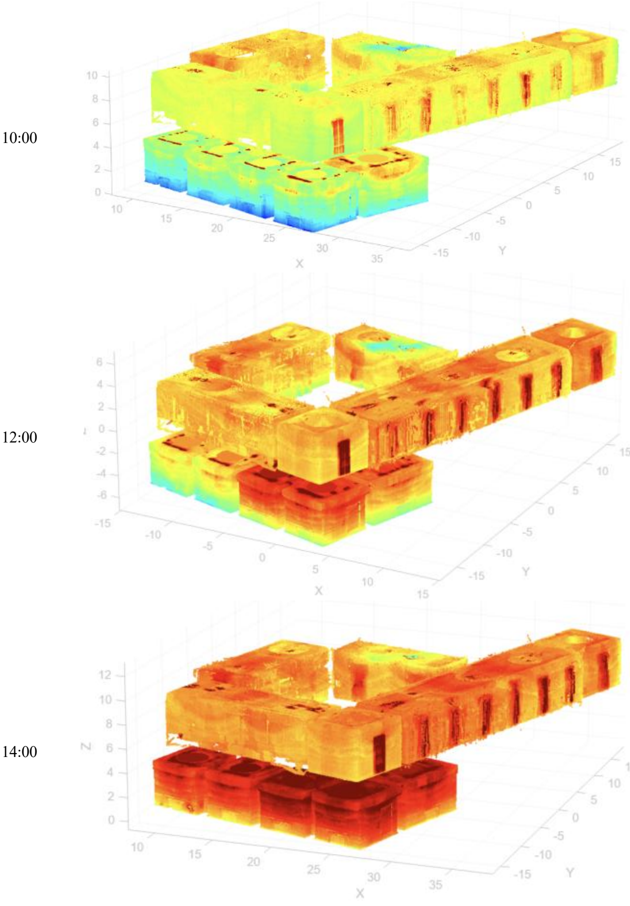


Figure 3. Multi-session models for Floor#0 and Floor#1 at times 10h, 12h and 14h

V. CONCLUSIONS

This work has presented a ground mobile robotic platform for autonomous multi-session RGB–thermal mapping of indoor environments, including multi-storey buildings. The proposed system enables the generation of temporally consistent dual-modality 3D models through a coordinated multimodal perception and inter-session registration framework.

In the context of heritage buildings, the presented approach provides a practical solution for long-term thermal monitoring. By repeating acquisition campaigns under controlled and comparable environmental conditions, the system enables consistent temporal analysis. Looking ahead, such time-resolved thermal representations could support preventive conservation strategies, facilitate the early detection of degradation phenomena (e.g., moisture accumulation or thermal anomalies), and assist restoration professionals in selecting or adapting materials and structural interventions while preserving the architectural integrity of historic buildings.

Finally, the resulting RGB–thermal point clouds constitute a valuable basis for the generation or enrichment of HBIM and heritage digital twin models. The integration of geometric and thermal information within consistent 3D representations enables semantically structured analysis of building elements, bridging robotic perception and digital heritage documentation. In this sense, the proposed system contributes to the convergence of mobile robotics, multimodal mapping, and e-Heritage applications.

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REFERENCES

[1] F. J. Castilla, A. Ramón, A. Adán, A. Trenado, and D. Fuentes, “3D Sensor-Fusion for the Documentation of Rural Heritage Buildings,” Remote Sensing 2021, Vol. 13, vol. 13, no. 7, Mar. 2021, doi: 10.3390/rs13071337.

[2] P. Kim, J. Chen, and Y. K. Cho, “SLAM-driven robotic mapping and registration of 3D point clouds,” Automation in Construction, vol. 89, no. May, pp. 38–48, May 2018, doi: 10.1016/j.autcon.2018.01.009.

[3] S. Rho, S. M. Park, J. Pyo, M. Lee, M. Jin, y S.-C. Yu, “LiDAR-Stereo Thermal Sensor Fusion for Indoor Disaster Environment”, IEEE Sensors Journal, vol. 23, n.o 7, pp. 7816-7827, abr. 2023, doi: 10.1109/JSEN.2023.3245619.

[4] J. Zhu, Y. Xu, L. Hoegner, y U. Stilla, “Generation of Thermal Point Clouds From Uncalibrated Thermal Infrared Image Sequences and Mobile Laser Scans”, IEEE Transactions on Instrumentation and Measurement, vol. 72, pp. 1-16, 2023, doi: 10.1109/TIM.2023.3284942.

[5] K. B. Tran, A. Carballo, y K. Takeda, “360 LiDAR + 360 RGB + 360 Thermal: Multimodal Targetless Calibration”, en 2024 IEEE Intelligent Vehicles Symposium (IV), jun. 2024, pp. 279-284. doi: 10.1109/IV55156.2024.10588438.

[6] F. C. Collins, F. Noichl, M. Slepicka, G. Cones, y A. Borrmann, “360-Degree Tri- Modal Scanning: Engineering a Modular Multi-Sensor Platform for Semantic Enrichment of BIM Models”, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. X-1-2024, pp. 41-48, may 2024, doi: 10.5194/isprs-annals-X-1-2024-41-2024.

[7] A. Adán, A. López-Rey, and A. Ramón, “Robot for thermal monitoring of buildings,” Automation in Construction, vol. 154, p. 105009, Oct. 2023, doi: 10.1016/J.AUTCON.2023.105009.

[8] P. J. Besl and N. D. McKay, “A Method for Registration of 3-D Shapes,” IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 14, no. 2, pp. 239–256, Feb. 1992, doi: 10.1109/34.121791.