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Optimization of 360-based photogrammetric pipeline for narrow and dark indoor surveys

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ABSTRACT

Photogrammetry has been commonly used for surveying architectural structures over the past two decades; however, this technique faces limitations, particularly in complex, narrow, or dark spaces due to optical constraints. Recently, advanced technologies such as 360° cameras have started to influence established photogrammetric protocols. Capturing an entire scene in a single spherical shot offers significant value for the rapid and efficient surveying of indoor spaces, although new methodologies are needed for data management, storage, and computational optimization. This paper introduces **SQUILLIDAE** (Spherical acQuisition Instrument for Low-Light and InDOor nArrow spacEs), a cost-efficient and versatile multi-camera system designed to enhance photogrammetric techniques derived from spherical imagery. It details our approach from initial investigations to final design choices and includes a comparative analysis of results, as well as several perspectives for future technical improvements.

THE SQUILLIDAE

A **multi-camera rig** was chosen to enable simultaneous image capture from multiple positions, thereby enhancing coverage and reducing acquisition time. Since the laboratory already possesses an Insta360 One R, we decided to continue within the Insta360 ecosystem for both hardware and software. This choice allows for synchronized captures across multiple Insta360 cameras using the Insta360 Action Remote. The setup for this experiment includes **two Insta360 One R** cameras positioned at the edges of the rig, with an **Insta360 X3** camera centrally mounted at an elevated position.

Four LED panels (Manfrotto Lykos Daylight and Bi-Color, each producing approximately 1500 lux) can be oriented to illuminate the scene. **Preliminary tests** were conducted in a controlled laboratory environment to assess the setup under various configurations before in-situ deployment. **Two capture configurations** were evaluated: the first with two ultra-wide-angle (UGA) modules and a single omnidirectional camera, and the second using three 360° cameras. The full panoramic configuration is expected to enhance the reconstruction of complex spaces. Ultimately, the latter method was chosen for further investigation due to its robustness and accuracy.

The **main parameters influencing reconstruction accuracy** were the baseline distance between cameras and the movement of the rig. However, the most significant accuracy gain was achieved by varying the orientation of the cameras, adjusting the primary focal axis of the optical system, revalidating the pyramidal protocol. This is most probably explained by optical quality it-self correlated to extreme fish-eye radial distortion and the projection system combined with stitching artifacts (Fig.2).

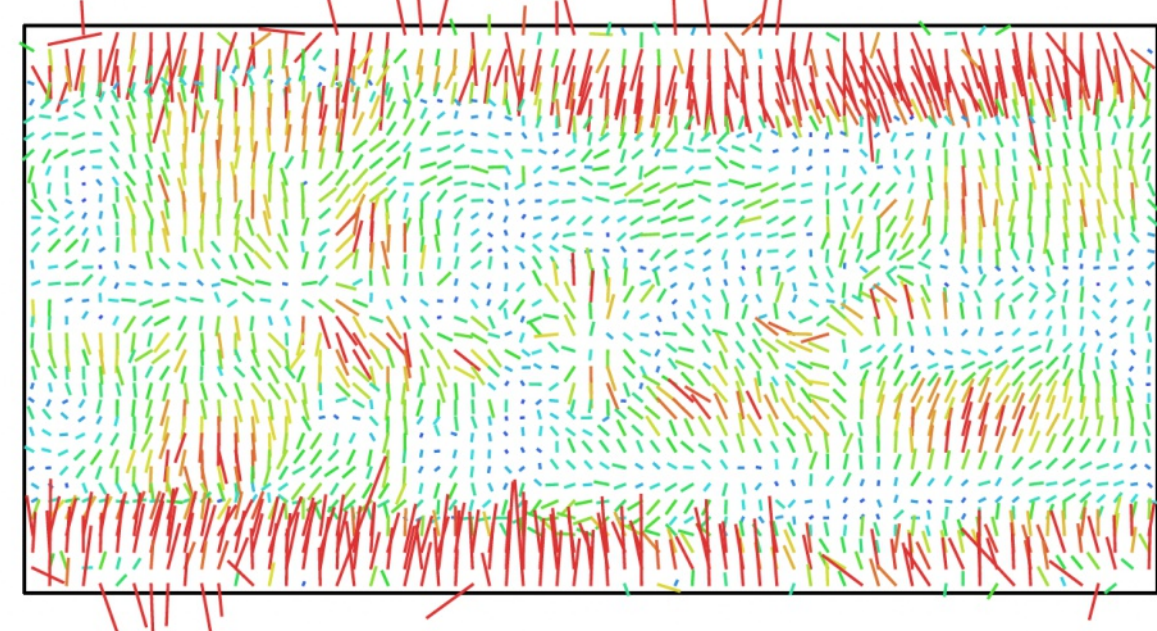


Figure 2. Example of image residuals for Insta360 OneR on the cells, revealing the effect of zenith and nadir distortion.

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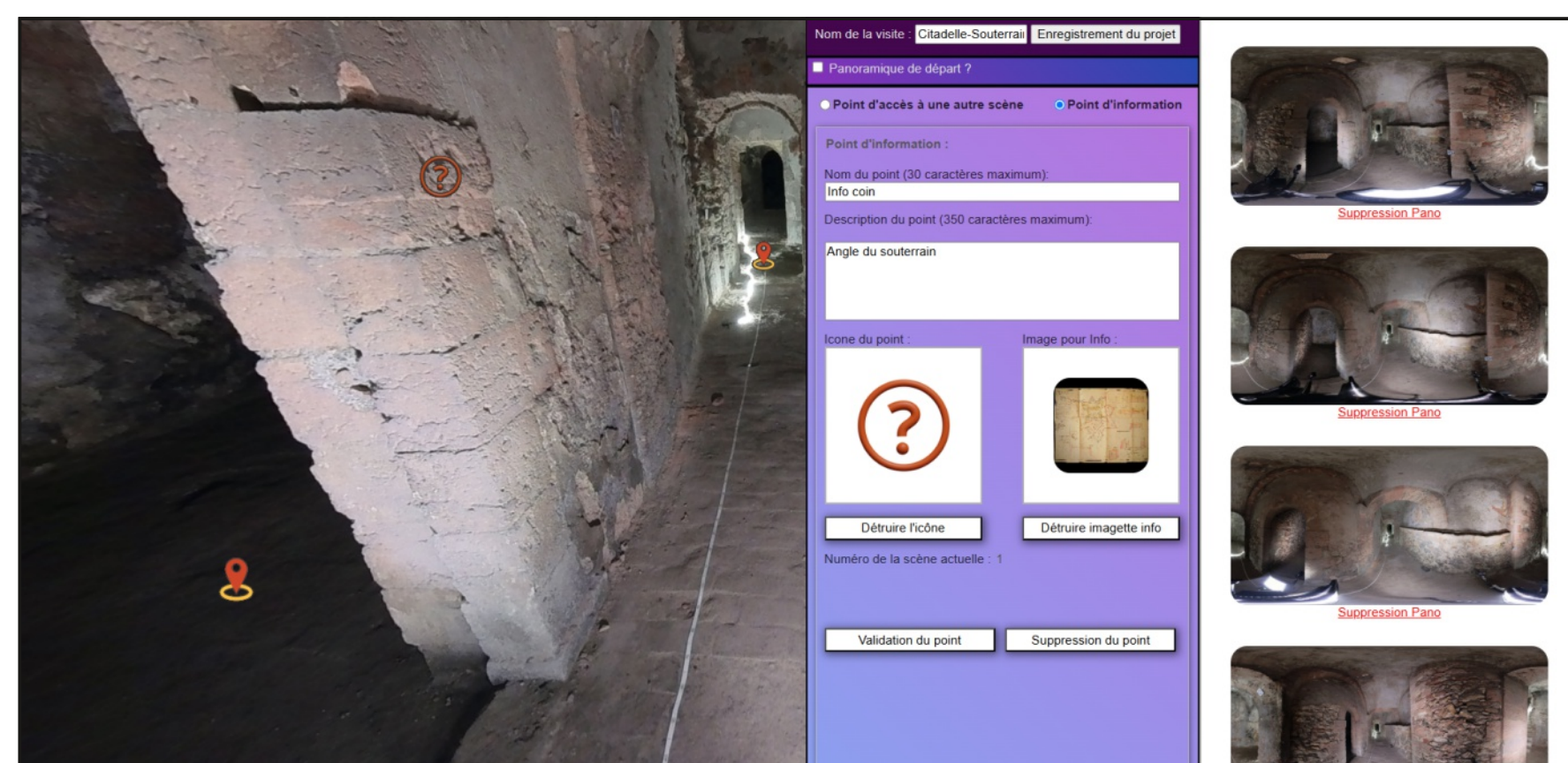


Figure 6. MYRTE interface for the creation of Virtual Tours



Figure 1. The Squillidae system with full 360° set-up

CASE STUDY

The first deployment of the prototype took place in Marseille, at Fort Saint Nicolas, a Historic Monument. Three areas within the Citadel were identified as particularly challenging due to documentation and accessibility issues, including former cells and two underground pathways. A laser scan using the Leica BLK360 G2 was conducted prior to the photogrammetric survey to serve as a geometric reference.

The in-lab protocol and setup were deployed in two complex architectural spaces. **The cells** consist of a small corridor leading to several pairs of small rooms, each covered with prisoner graffiti and carvings. **The tunnels** presented even greater challenges for surveying, as they encompassed both narrow corridors and rooms of varying sizes. The variation in illumination between the two architectural spaces remained a significant challenge despite the use of LED panels (Fig.3). The terrestrial laser scanning (TLS) survey took several hours, generating approximately 3 GB of data. CCTag markers were used for scaling, with a Leica S910 digital distometer employed to validate the measurements. A total of three hours were required to capture 415 panoramas within the cells. **The focal axis of each spherical camera was oriented to focus on the floor, ceiling, or opposing walls.**



Figure 3. The squillidae system inside the corridors

RESULTS

The goal was to reconstruct these complex scenes using Meshroom, but limitations of the current version prevented successful completion. The remainder of the testing and validation process was carried out using Agisoft Metashape and the 15 CCTAG markers were manually pointed and referenced with their local coordinates from the laser source. For the scale and objectives of the survey, an uncertainty of less than 5 cm is considered suitable. The dense matching process was completed in two hours at medium density. The generated point cloud consists of approximately 28 million points, and after cleaning, it contains around 20 million points. The laser-based and image-based point clouds were compared with CloudCompare **Cloud-to-Cloud (C2C)** comparison after an ICP bundle. The results showed that **fewer than 7%** of the 3D coordinates for the cells pointcloud are above the 5 cm threshold. For the tunnels, **less than 2%** of the points are more than 5 cm from the reference (Fig.4).

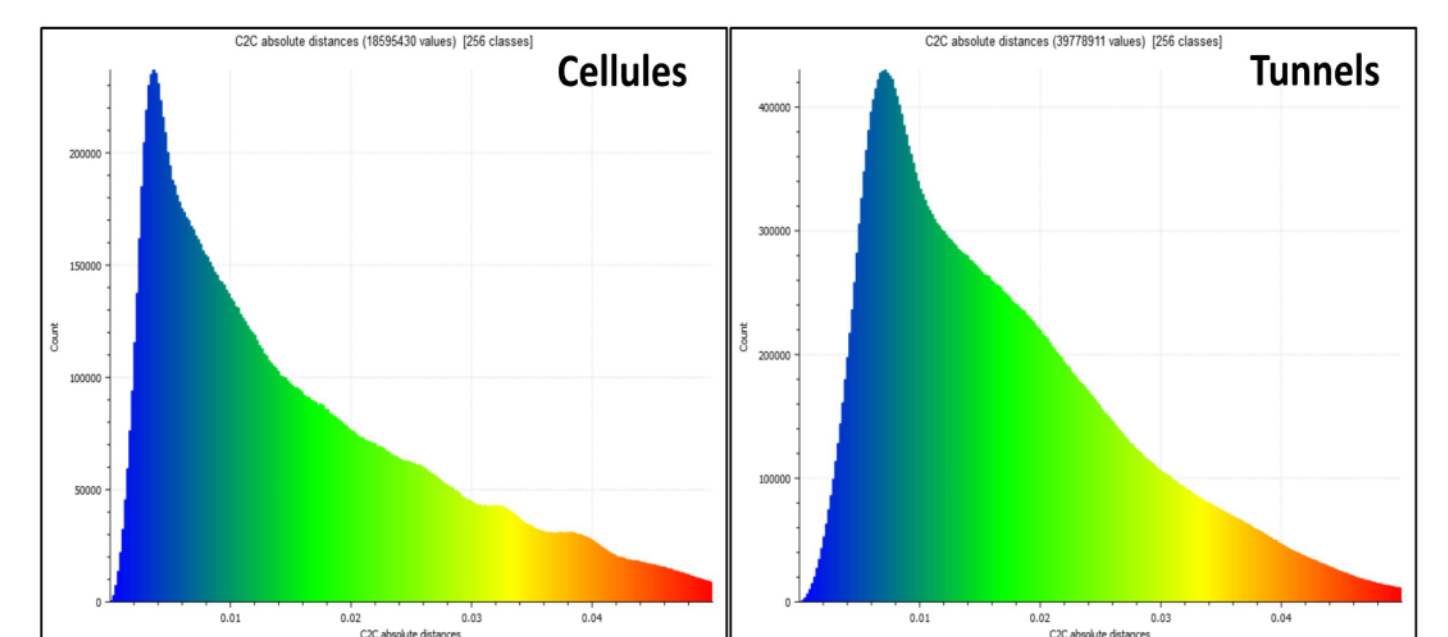


Figure 4. Cloud-to-Cloud comparison results for cells (left) and corridors (right)

FUTURE WORKS : VR EXPERIMENT - MYRTE PROTOTYPE

The capture achieved by the SQUILLIDAE system is aimed at developing a **multipurpose survey, enabling the creation of Virtual Tours in addition to photogrammetric coverage**. The system is planned to integrate with a software prototype developed in our lab, MYRTE, designed to create enriched virtual tours for cultural heritage applications.

To extend the functionalities of MYRTE, a multi-layer version is under development to combine 2D and 3D exploration through point cloud integration and camera positioning. Refining the prototype and updating the MYRTE source code is necessary before the combined system can reach its full potential. An updated version of the SQUILLIDAE system has been also tested, using three 72 MP cameras to enhance image-based reconstruction and support virtual tours. Another experiment explored integrating ambisonic capture for multisensory VR tours.

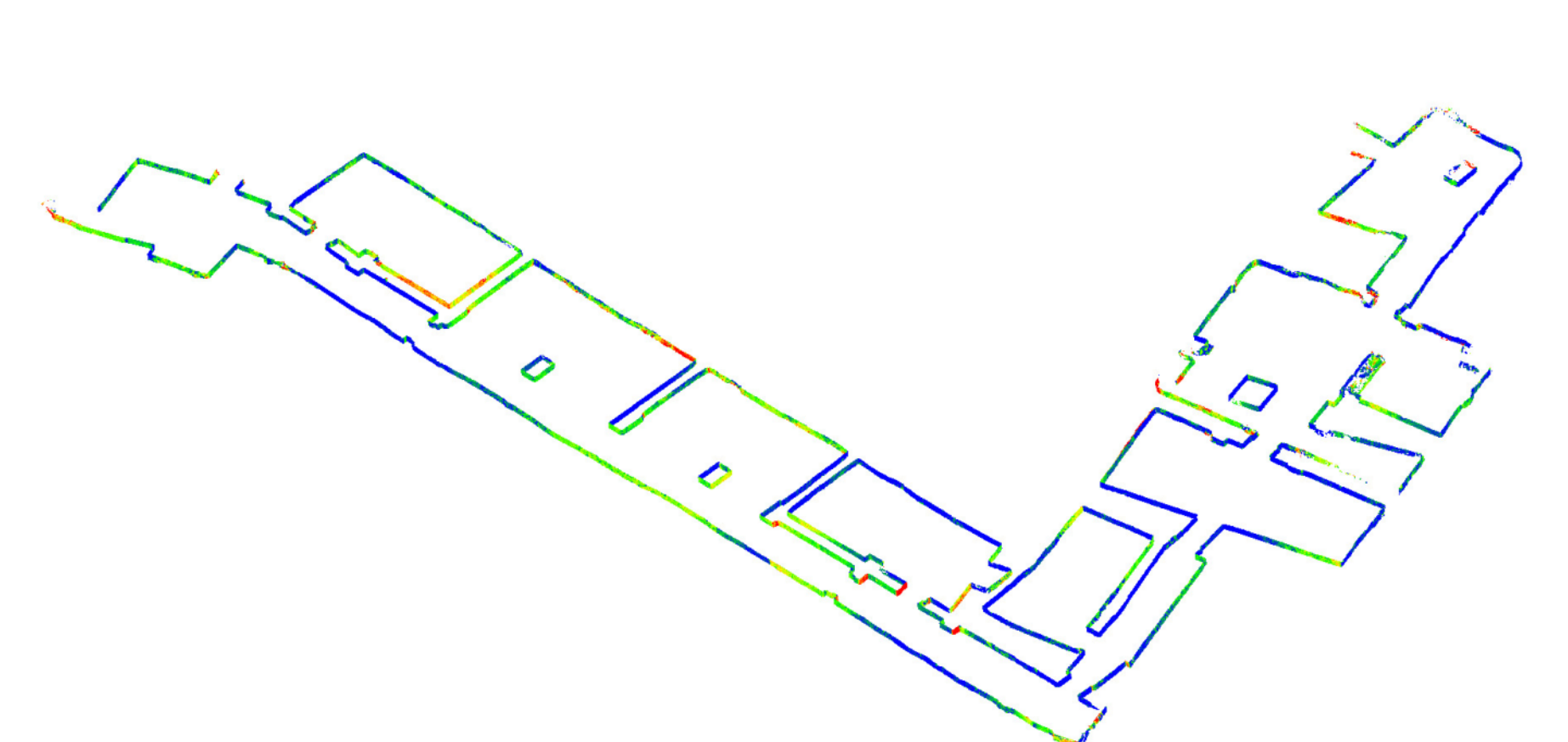
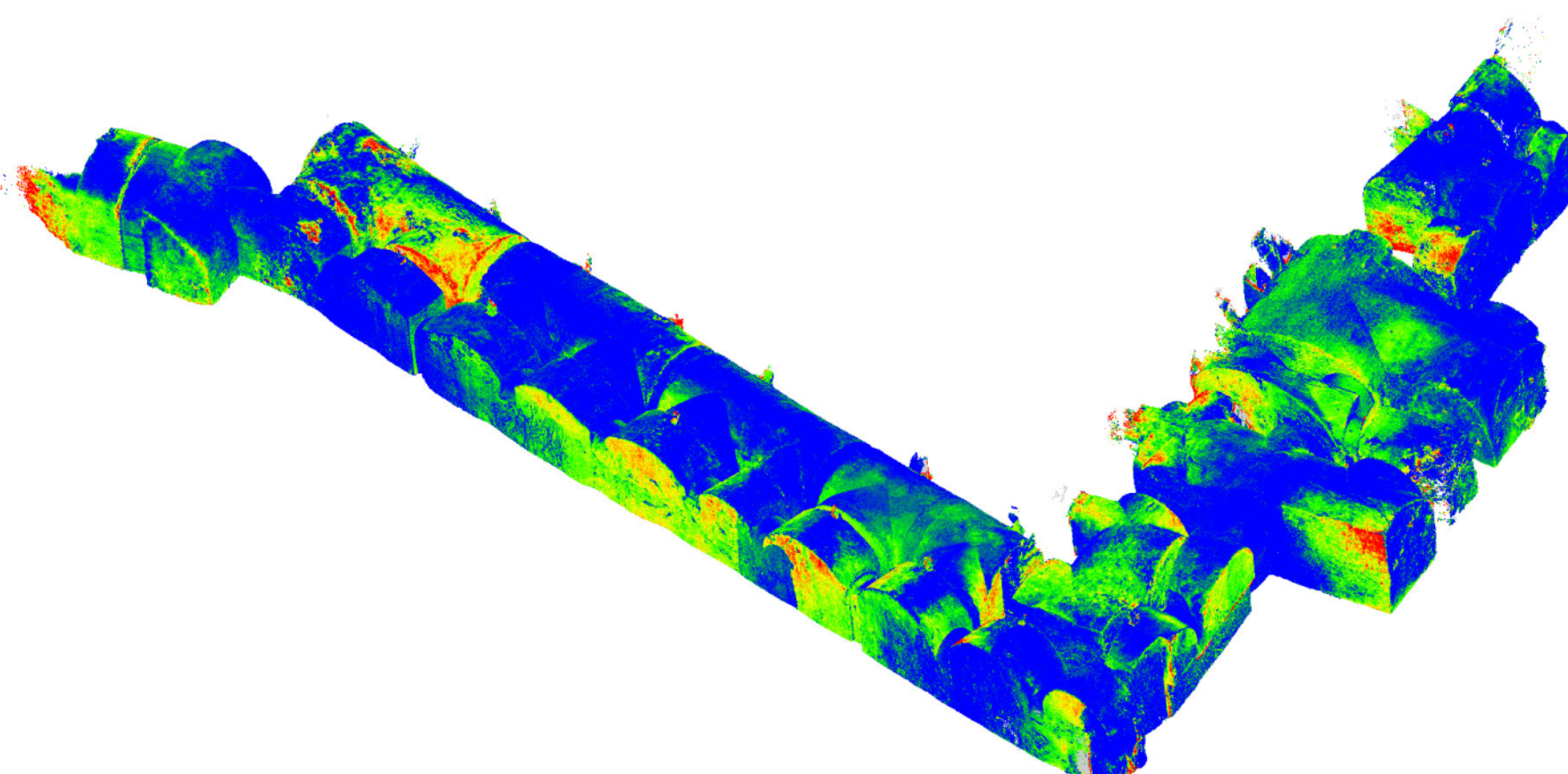


Figure 5. Corridors - Axonometric view of : image-based pointcloud (left) ; C2C discrepancy between 0 and 5 cm range (middle) ; plan from profile section (right)

CONCLUSIONS AND DISCUSSIONS

The combined acquisition protocol and instrumental setup demonstrated **significant potential for fast and efficient surveying**. The results from the prototype show that its geometric reconstruction quality is comparable to that of an entry-level laser scanner at a fraction of the cost. The SQUILLIDAE setup offers flexibility, superior color rendering, and enhanced homologous point detection, resulting in acceptably accurate 2D/3D representations when **the target accuracy is below 5 cm** (Fig.5).

Future experiments will focus on highly challenging spaces, such as revolving staircases, narrow underground areas, and complex environments like wooden frameworks or metal structures. A promising direction lies in integrating AI technologies for hybrid reconstruction and visualization, envisioned at the intersection of Neural Radiance Fields (NeRF) and extended-reality virtual tours enriched with annotations and storytelling.

REFERENCES & ACKNOWLEDGEMENT



This poster has been reduced by an LLM (ChatGPT version 4) and verified by the authors.