AN OPEN-SOURCE APPROACH FOR MULTI-SENSOR SCAN-TO-BIM WORKFLOWS

Juan José Gavilanes Bowen (1), Diogo F. R. Parracho (2), João Poças Martins (3)

(1) Department of Civil and Georesources Engineering, Faculty of Engineering, University of Porto, Porto, Portugal

(2) CONSTRUCT-GEQUALTEC, Faculty of Engineering, University of Porto, Porto, Portugal. 0000-0003-0413-6178

(3) CONSTRUCT-GEQUALTEC, Faculty of Engineering, University of Porto, Porto, Portugal. 0000-0001-9878-3792

Abstract
Open-source methodologies promote broader access to knowledge, tools, and technological development by supporting reproducible and community-driven advancements. By integrating digital surveying into these workflows, it is possible to reduce the existing dependency of the construction field on proprietary software solutions. For this purpose, this study aims to develop an open-source Scan-to-BIM approach, based on multi-sensor surveying.
Scan-to-BIM refers to the process of using captured spatial data to create accurate as-built/as-is BIM models, facilitating tasks such as renovation and maintenance throughout the infrastructure lifecycle. This study employs the open-source software Blender, paired with the Bonsai add-on, as the central platform for compiling data gathered from aerial and handheld surveys conducted at FEUP. The case study integrates three major sensing technologies to capture both exterior and interior data: UAV-based photogrammetry and thermography (which enabled an additional Image-to-BIM process), as well as LiDAR scanning via an iOS device.
The results prove that an affordable open-source Scan-to-BIM workflow is fully achievable, thus enabling smaller entities to access high-quality 3D documentation. Photogrammetry achieved millimetric-level accuracy relative to the real building, while the LiDAR surveys required little to no scale adjustment to match the results of both sensors, indicating the successful integration of multiple data sources within the open-source workflow. Finally, Blender, along with the Bonsai add-on, proved to be a versatile platform capable of efficiently managing complex Scan-to-BIM processes. Overall, the study demonstrates that open-source tools can support advanced BIM tasks; therefore, offering a practical and cost-effective alternative to proprietary software solutions.

1. Introduction

Digital 3D reconstruction currently represents an important point of interest within the civil engineering field, particularly in activities such as the preservation of existing conditions, which is critical for documenting historical or culturally important buildings, or as a reference for future restoration or renovation projects. Additionally, as-is models allow architects and engineers to design more accurately within the real constraints of a structure, simulate changes or additions before physical intervention, and promptly detect design conflicts or structural problems. Its applications can also extend to maintenance and facility management, where these models facilitate planning and management of maintenance activities, while monitoring the condition of building elements over time [1].

The principal contribution of this study is to develop a Scan-to-BIM workflow to process and integrate collected spatial data by employing the open-source software (OSS) Blender, with the Bonsai add-on. Enhancing the capability to integrate acquired datasets and to develop an easily scalable, replicable workflow. This software offers a vast and diverse range of applications, which streamlines the process of integrating the results of these technologies into a single environment [2], [3]. The use of UAVs also enables the exploration of areas that would otherwise be unsafe or impractical to survey using traditional techniques.

This methodology relies on advanced sensing technologies, which capture detailed spatial information about the built environment. This study aims to explore in depth three of the most prevalent technologies currently used: photogrammetry, LiDAR, and thermography. Their complementarity for building façade inspections is assessed to determine their strengths, particularly how photogrammetry can capture high-resolution color imagery that can be used to generate detailed and textured 3D models, how LiDAR provides highly accurate and dense 3D point clouds, even in low-light or complex environments, and how thermography detects temperature variations on surfaces, enabling the identification of hidden defects like insulation failures or moisture intrusion. The potential for combining the three technologies to improve the accuracy and comprehensiveness of inspections is examined as well, and their disadvantages are also covered [4], [5].

To support this theoretical framework, this work includes a case study focused on digitally recreating the B001-B003 rooms at the Faculty of Engineering of the University of Porto (FEUP), carrying out various surveys conducted with handheld LiDAR methods, and an UAV equipped with RGB and thermal cameras. It is a perfect example of how digital reconstruction can aid in facility management, retrofitting, or energy analysis, as it is a functional building. Its varied surfaces and materials make it a strong subject where thermography, LiDAR, and photogrammetry can show their strengths and limitations.

2. Related Work

A growing number of scientific studies are being published that highlight the development of using UAVs (Unmanned Aerial Vehicles) to create 3D models of buildings, through improved imaging technology, as well as deep learning and point cloud processing techniques [6], [7]. UAVs equipped with RGB cameras provide high-resolution, multi-view imaging data for developing detailed models of building façades with damage assessments, in addition to alleviating some of the challenges of physical accessibility encountered by manual surveys.

Early work emphasized damage detection in building façades through the analysis of point cloud gaps generated from aerial oblique imagery, demonstrating that structural damage can be identified by learning-based classification of geometric voids in 3D models [8]. Subsequent contributions integrated convolutional neural network features with three-dimensional descriptors to improve generalization across diverse urban contexts, further validating UAV-based data as a viable foundation for automated visual inspection workflows [6].

Parallel to photogrammetric reconstruction, light detection and ranging (LiDAR) has gained momentum for façade and streetscape documentation due to its high geometric accuracy, robustness in low-light environments, and capacity to produce dense terrestrial point clouds. Studies comparing airborne LiDAR with UAV-derived photogrammetry show that the latter can achieve comparable accuracy for volumetric and height estimation tasks, particularly in open built environments with limited vegetation interference [9], [10]. Complementary workflows leveraging both terrestrial laser scanning (TLS) and UAV imagery have also been proposed to address occlusions and improve coverage, with recent contributions exploring automated TLS scan planning informed by coarse photogrammetric models to reduce redundancy and acquisition time [11].

Other work highlights the potential for post-acquisition data fusion using Iterative Closest Point (ICP) algorithms to align TLS and photogrammetric point clouds for heritage conservation, visualization, and gaming engine environments [4], [12]. Thermal imaging has emerged as an additional sensing modality for UAV-based façade diagnostics, enabling non-contact assessment of building envelope behavior and energy performance. Existing studies focus on identifying insulation defects, moisture paths, and thermal bridging using temperature contrast analysis. Research demonstrates that infrared thermography can support large-scale urban energy auditing when calibrated and integrated with RGB imagery, although geometric accuracy and image registration remain key challenges [13].

Experimental work conducted in laboratories and in the field continues to show that emissivity, time of day, angle of view, and distance to the camera may all affect the acquisition of reliable data from thermal sensors [14], [15]. The most recent studies provide stronger evidence of the potential for combining thermal data and photogrammetry to support UAVs using BIM and Building Energy Modelling (BEM), and also demonstrate how UAVs with dual-sensor payloads could provide both geometric and thermal diagnostic information in a common spatial framework [16], [17].

Despite individual advances in photogrammetry, LiDAR, and thermography, the literature shows that most contributions analyze these sensing modalities in isolation or in limited pairs [18]. Multi-sensor UAV workflows that integrate all three technologies remain scarce, particularly with respect to façade-scale Scan-to-BIM pipelines. While existing studies validate the benefits of combining RGB and LiDAR or RGB and thermal imagery for reconstruction and energy auditing, very few address the fusion of heterogeneous datasets at the point cloud or mesh level, and almost none operationalize these integrations within open-source software environments.

Although photogrammetry provides high-resolution texture and dense surface geometry, LiDAR provides metrically accurate spatial structure, and thermal cameras can detect envelope defects that cannot be visually identified through the RGB spectrum, there is still a clear gap between photogrammetry, laser scanning, and thermal imaging technologies. This gap also coincides with more recent developments using open standards and open-source Building Information Modeling (BIM) workflows. There has been an increase in demand for open BIM

workflows with the advent of the IfcOpenShell ecosystem, which has allowed for vendor-neutral data sharing, IFC-native modelling, and greater interoperability between Architectural, Engineering, Construction and Operation (AECO) businesses and their associated workflows through the use of BIM technology [2], [19], [20].
Although open-source BIM programs are developing quickly, UAV images from multi-sensor data have not been quantitatively analyzed together and included in BIM (i.e., for open-source programs using Scan-to-BIM and Image-to-BIM processes) on a broad scale. Most existing applications depend on proprietary processing, dedicated hardware and closed-source post-processing, creating a barrier to replicating and accessing this type of data in research settings and for businesses with limited resources.

3. Methodology

This paper outlines a workflow for creating a Scan-to-BIM process using multiple sensors, including photogrammetry, LiDAR, and thermal imaging. This methodology is comprised of three key stages: (1) Data Collection through UAV and Handheld Systems; (2) Data Processing and Point Cloud Generation; and (3) Modeling and data structuring within an OpenBIM platform. Data collection was conducted using multiple sensors to capture geometric and thermal information from the case study building. UAV-based RGB imagery was collected along façade-aligned flight paths at oblique viewing angles to maximize texture completeness and minimize occlusions using a DJI Mavic 2 Enterprise Dual. The LiDAR scans were obtained using handheld methods to achieve geometric accuracy within the interior. Additionally, thermal imaging was collected with infrared cameras mounted both on UAV and handheld configurations. The data acquisition process is documented in Figure 1.

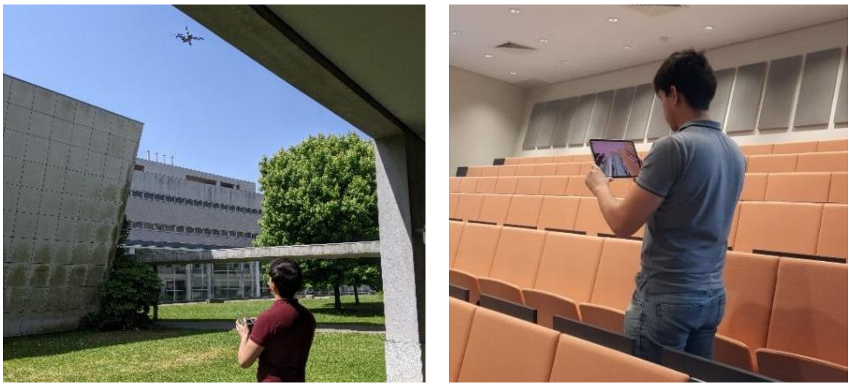

Figure 1: Data acquisition conducted by the author. On the left, the façade captured with a drone; on the right, the interior captured with an iOS device.

The structure of the methodology is illustrated in Figure 2:

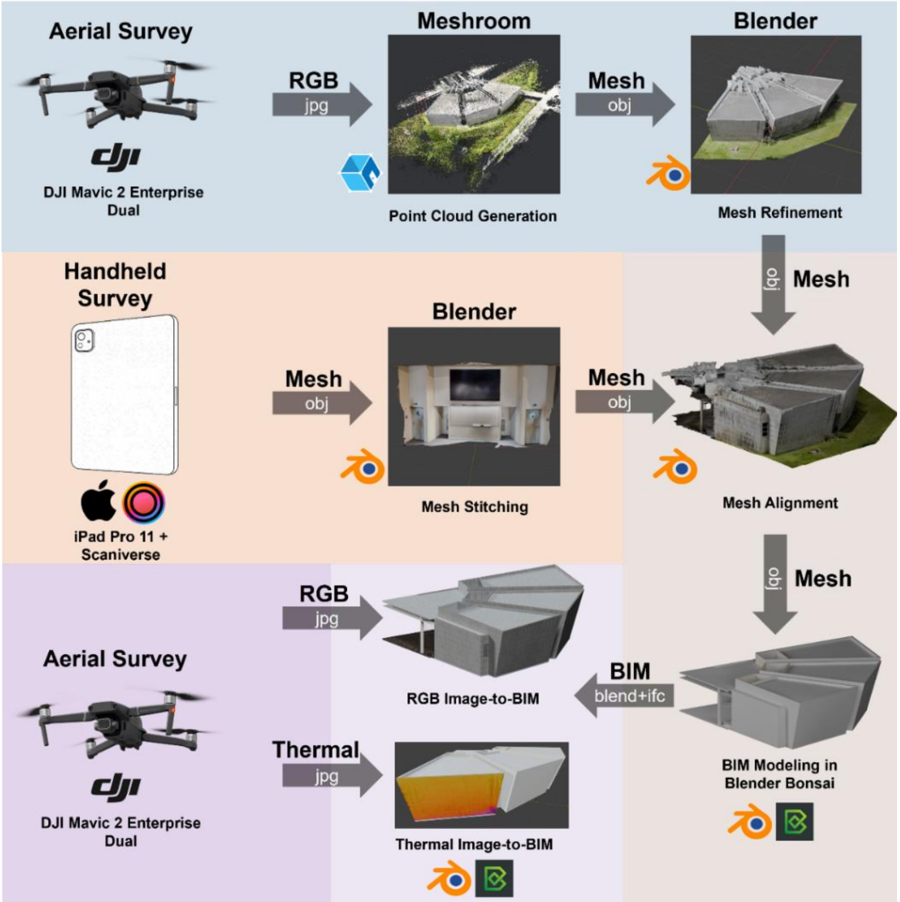

Figure 2: Methodology Workflow. Adapted from [18].

Using the photogrammetric data from the UAV flights (446 RGB images), a point cloud was generated with the open-source software Meshroom, which employs a structure-from-motion (SfM) pipeline, yielding accurate measurements. The workflow consists of a sequence of steps that enable automated feature extraction and matching, camera calibration, and a final step that produces a dense stereo-reconstructed model. This step, although straightforward, proved to be time-consuming due to the processing of the images and required significant CPU capacity.
For the interior, various mobile-based LiDAR scans were performed using the Scanniverse app, which digitally recreates the read geometry within the software. These geometries were processed and cleaned manually and through noise reduction inside Blender.
Once the collected data is ready, the different geometries are stitched together manually to recreate the complete model by using the “rotate” and “move” commands within Blender to systematically align shared surfaces and keypoints between them until the full model was assembled. This stage resulted to be the most laborious and time-consuming as it required extensive manual alignment, pointing to potential for automation within the Blender workflows (as already implemented in proprietary software). After the geometric model is complete, the Bonsai add-on is activated to start modelling the BIM elements (walls, roofs, stairwells, furniture, etc.). For this end, the multi-sensor mesh is used as a base, allowing the different IFC elements to be added by tracing them directly over the multi-sensor mesh using Blender's built-

in X-ray view, as shown in Figure 3. This mode allows the user to see through the mesh, enabling precise alignment and accurate reproduction of the as-built conditions.

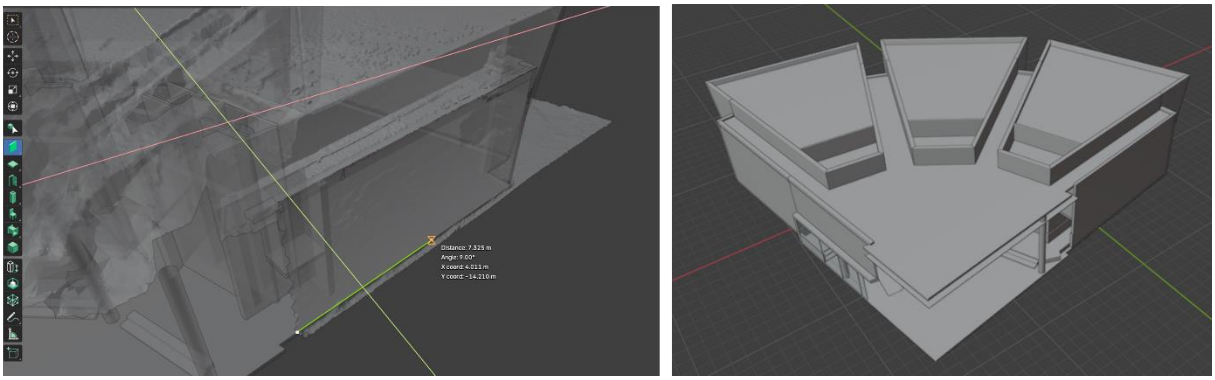

Figure 3: The IFC modelling process in Blender.

To complement this workflow, an Image-to-BIM process was conducted by projecting the collected RGB and thermal images onto the 3D geometry using Blender's built-in visual programming and texture-reprojection techniques. For the façade, an image from the UAV survey that represented the overall texture was identified and cropped, then tiled around the façade's surfaces, using Blender´s built-in visual programmer once again, thus achieving an Image-to-BIM workflow that simulates the real texture. Additionally, the collected parallel RGB and thermal images were projected onto the geometry using the same visual programmer. The results of these Image-to-BIM workflows are exposed in Figure 4.

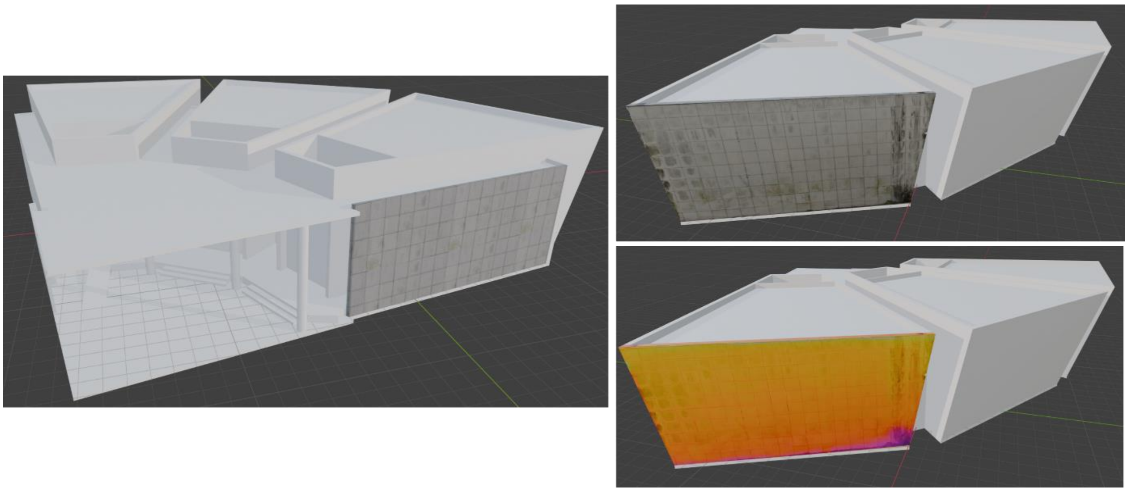

Figure 4: RGB and thermal Image-to-BIM results in Blender.

Overall, the methodology results in a non-proprietary pipeline for combining photogrammetric, LiDAR, and thermal sensing into a unified BIM representation, which additionally enabled Image-to-BIM integration. Through qualitative procedures, this workflow can support replicable UAV-based façade inspection, energy diagnostics, and heritage documentation, reducing the dependency on closed ecosystems, expanding accessibility, and facilitating future applications in asset management, conservation, and building performance assessment.

4. Results

Through a case study at FEUP, this section validates the suggested multi-sensor, open-source Scan-to-BIM workflow and demonstrates its practical use for digitally recreating interior and exterior building environments. LiDAR scans using the mobile app Scanniverse, UAV-based photogrammetry, and UAV-mounted thermal imaging were all used in data acquisition. LiDAR covered interiors, photogrammetry recorded exterior geometry, and thermal surveys allow for diagnostic analysis.

The processed data was imported into Blender, where the meshes were cleaned, optimized, and aligned, which proved to have millimetric-level accuracy by comparing the physical and digital measurements of a specific shared element (a square facade granite block). These multi-sensor meshes provided the basis for BIM modeling in Blender using the Bonsai add-on, which made it possible to trace parametric and custom elements over the 3D scans and produce a full openBIM model. Issues with IFC export, such as outline-only geometry and misaligned elements, posed significant challenges during the learning curve but were ultimately resolved, contributing to a better understanding of the software's behavior and required workflows. Ultimately, the workflow proved to have seamless interoperability with other BIM software platforms, demonstrating that the generated file could be opened and examined in commonly used IFC viewers. Confirming that the model retains its structural and parametric integrity, facilitating collaboration and further development across various BIM environments

Finally, the Image-to-BIM workflow was applied by texturing the model using UAV-acquired RGB images and thermal data. RGB textures were UV-mapped, tiled for repeatable elements (e.g., Porto granite façade), while thermal textures were applied untiled to preserve accurate temperature data. This integrated approach allows toggling between visual and thermal textures for analysis, producing detailed, semantically enriched models suitable for visualization, thermal evaluation, and further BIM-based applications. Figure 5 shows the different stages of the implemented workflow (all of these images were extracted from inside Blender).

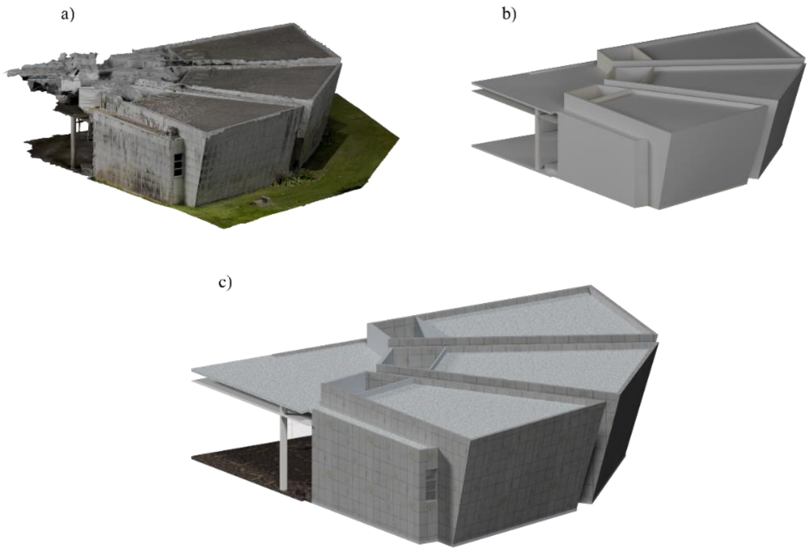

Figure 5: Overview of the resulting workflow: a) The mesh of the auditoriums, where the results of the photogrammetric and LiDAR surveys are combined; b) IFC model created using the meshes as a base; c) IFC model with the textures projected to its surfaces.

5. Discussion

This study shows that a low-cost, open-source Scan-to-BIM workflow is feasible, enabling educational institutions, small companies, and projects with limited resources to produce precise 3D documentation without expensive, proprietary software. Photogrammetry achieved millimetric-level accuracy, and its datasets aligned well with LiDAR surveys, supporting efficient multi-sensor integration. Blender, with the Bonsai add-on, proved to be a versatile open-source platform for managing complex Scan-to-BIM processes.

Some limitations were noted, including the workflow's continued reliance on specialized hardware (such as iOS devices and UAVs with RGB/thermal cameras), the fact that surveys primarily record surface geometry without internal data, and the substantial manual alignment required for LiDAR data, which could be improved by implementing automated processing pipelines in Blender. The workflow of Blender Bonsai presented usability issues and limited IFC export capabilities, and processing demands were high, particularly for photogrammetry and detailed modeling in Blender.

Nonetheless, the BIM-compatible and replicable process can also be applied to other BIM platforms, leveraging both the Blender user community and its ability to create custom scripts and capabilities, which enable easy integration of sensor data from multiple platforms. The research application, therefore, fills a void within the existing academic community, by creating simplified means to effectively utilize photogrammetry, LiDAR, and infrared thermography through an open-source platform, thereby expanding available research opportunities and usability in dynamic and very limited resources. Moreover, it is important to note that the entire Scan-to-BIM process was carried out manually. This deliberate choice served as a starting point to establish a fully open-source methodology; however, further research should explore how to automate the process, whether through rule-based approaches [21] or with deep learning methods [22] for instance.

To further advance the proposed open-source framework, future developments should consider AI-driven mesh stitching, temporal building analysis through Blender’s animation capabilities, enhanced thermal analysis and structural assessments, cost/schedule management, safety simulations, and the incorporation of internal nondestructive survey data to enrich the Scan-to-BIM workflow.

6. Conclusions

This study developed a fully open-source Scan-to-BIM workflow using multi-sensor surveying, combining spatial and thermal data from FEUP’s “B” building auditoriums to generate accurate 3D BIM models. The results show that such a workflow is feasible, precise, and affordable, making high-quality 3D documentation accessible to educational institutions, small businesses, enthusiasts, and projects with limited resources. Photogrammetry achieved millimetric-level accuracy, and LiDAR datasets aligned reliably with minimal scaling adjustments. Blender, with the Bonsai add-on, proved to be a versatile platform for managing complex Scan-to-BIM tasks, demonstrating that open-source tools can effectively replace costly proprietary software. The combined use of photogrammetry, LiDAR, and thermal imaging through a single, unrestricted source creates a methodology that can fill the current research gap. This method has the flexibility and scalability to be applied to projects of all sizes and complexities. Limitations include dependence on specialized hardware (UAVs, advanced sensors, high-performance computers), superficial data capture without internal building layers, manual LiDAR point cloud stitching, and certain export restrictions in Blender Bonsai. However, the process turns out to be repeatable, affordable, and promising for wider adoption, opening the door for further advancements and increased usage of open-source Scan-to-BIM solutions.

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