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# Technologies for Cultural Heritage Preservation. The possibility of using spherical images in the inventory of cultural heritage - the case of the Royal Castle earthwork

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**Abstract:**

The article explores the integration of close-range photogrammetry, laser scanning, and spherical images in the inventory of cultural heritage, focusing on the Royal Castle earthwork. Geodesy-driven inventorying, crucial for object revitalisation, involves on-site activities, inspections, and meticulous documentation. Modern photogrammetric challenges, such as precision issues and restricted access to intricate areas, prompt the need for an integrated approach, combining active and passive techniques like Structure from Motion (SfM) and Multi-View Stereo (MVS).

The study employs the Leica RTC 360 scanner for point clouds and dense image matching, emphasising intricate artefact textures. A comprehensive workflow involving control points, photogrammetric networks, and advanced software (e.g., Cyclone REGISTER 360 plus, Agisoft Metashape, CloudCompare) is implemented. Despite challenges in the initial outcome, masks are introduced on spherical images to address field-of-view issues, resulting in a satisfactory 3D model.

The comparative analysis between the spherical image-based model and laser scanning reveals millimetre-level differences attributed to sand substrate characteristics. The study underscores the potential of spherical images as a cost-effective and accessible resource for high-precision photogrammetry, offering comparable results to laser scanning when similar photographic conditions are applied.

In conclusion, the article emphasises the valuable contribution of spherical images to contemporary photogrammetric applications in geodesy. Spherical images present a viable alternative for inventories and 3D model generation for monuments, providing high accuracy within the millimetre range. The accessibility and evolving applications of spherical images position them as a promising solution for future photogrammetric endeavours, accessible to a broad range of users.

**Keywords:** Laser Scanning, MVS, Photogrammetry, SfM, Spherical Images

## 1. Introduction

Currently, inventorying stands out as a rapidly advancing domain within geodesy. It constitutes a design process undertaken for the revitalisation or improvement of a specific object. This involves the meticulous preparation of pertinent documentation, depicting the monument's visual and descriptive characteristics, including diverse cross-sections and photographs [1,2]. The procedure is executed through on-site activities, involving inspections, measurements of the subject under consideration, and the subsequent analysis of their outcomes [3–6]. The outcomes of inventorying find application among professionals in the construction and architectural sectors, as well as heritage conservators [8,9]. Their primary objective is to execute conservation efforts and protect structures from impending deterioration.

In the context of active photogrammetric scanning, recent methodologies utilising laser 3D scanners or structured light have proven highly effective in acquiring detailed data regarding the shape and texture of objects. However, maintaining precision and accuracy in measurements within challenging areas, such as the recesses of historic structures, remains a formidable challenge. Passive photogrammetric techniques, grounded in the analysis of images from various sources, such as cameras or photographic devices, provide flexibility in documenting objects from diverse perspectives. However, the precise acquisition of 3D data can be hindered, especially for objects with complex structures or under conditions of limited illumination. The Structure from Motion (SfM) method enables the three-dimensional reconstruction of objects based on the analysis of camera motion. This is particularly advantageous for instances of an unsteady camera, as seen in drone-acquired imagery. Nevertheless, the accuracy of SfM is contingent upon various factors, including image quality and the quantity of available characteristic points [10]. Multi-View Stereo (MVS) technology facilitates the generation of detailed 3D models through the analysis of multiple perspectives of an object [11]. Although a powerful tool, it demands substantial computational resources and time, especially when processing extensive datasets.

In summary, the challenges associated with the utilisation of modern photogrammetric techniques for 3D documentation encompass issues of precision, access to difficult-to-reach areas, and the dependence of accuracy on lighting conditions and image quality. An integrated approach, considering both active and passive techniques, as well as SfM and MVS methodologies, may constitute a pivotal strategy for effectively addressing these challenges.

The article presents an example of an inventory approach based on close-range photogrammetry techniques. This approach facilitates precise reconstruction of the 3D form of the object and allows for a comparative assessment of the effectiveness of the laser scanning methodology combined with the simultaneous use of spherical images obtained simultaneously in the scanning process. This is an innovative method focusing primarily on the possibility of using spherical images in the inventory of historic objects.

## 2. Materials and Methods

This study endeavours to leverage spherical images for the creation of a 3D model, with a specific focus on capturing the intricate textures of the culturally significant artefact that is challenging to access. To achieve this objective, the authors opted to incorporate point clouds acquired using a Leica RTC 360 scanner, along with the outcomes of dense image matching derived from images captured using the same Leica RTC 360 device. Point cloud generation was facilitated by employing the Leica Cyclone REGISTER 360 plus and Agisoft Metashape software. Furthermore, for comparative analyses, the CloudCompare programme was employed.

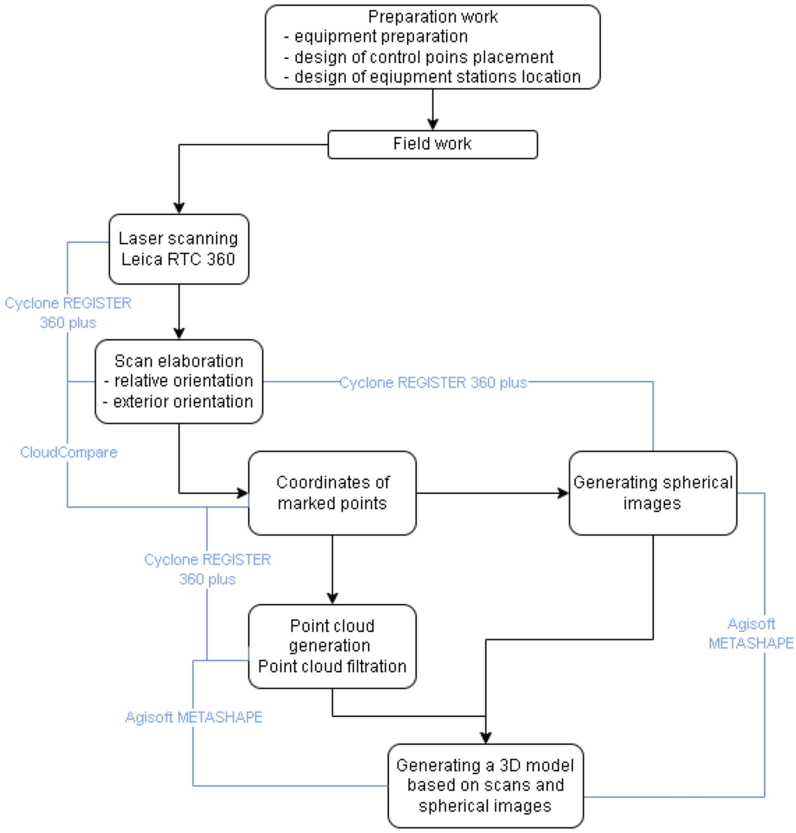


**Figure 1.** The block diagram of the work

The diagram illustrates the methodology employed in conducting the experiment and investigation. Consequently, it was imperative to meticulously plan and deploy control points, utilised subsequently as references for data orientation. These control points were strategically positioned alongside the scanner to be able to integrate them with spherical digital data.

Leica RTC 360 is equipped with three cameras with a resolution of 36 MP each, enabling the acquisition of raw data at a resolution of 432 MPx to process calibrated spherical images of 360° x 300°. However, to preempt potential challenges in aligning scans, the researchers implemented a photogrammetric network to encircle the subject. The view of the measured control points of the network in the images is illustrated in Figure 2. The scanner measurements were conducted from 39 positions, resulting in a cumulative point cloud of 2624057231 points and 595 connections between positions.

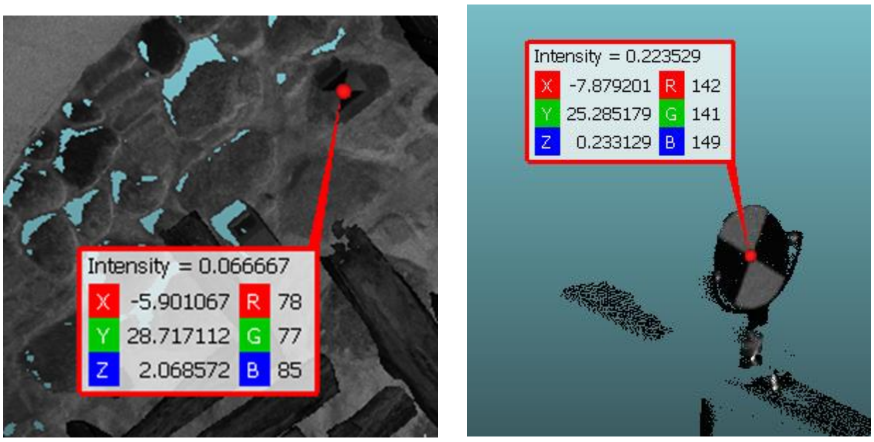


**Figure 2.** View of measured control points on point cloud from the scanner

The workflow encompassed several stages:

- Observation of control points (at least three for co-registration) - CloudCompare software
- Export of coordinates of control points needed for processing spherical images - CloudCompare
- Register all scans in the local coordinate system - (real-time preview on the tablet
- in the Cyclone REGISTER 360 plus software)
- Filtering object' point clouds (filter: Noise/SOR implemented in CloudCompare software).
- Generating spherical images (Cyclone REGISTER 360 plus)
- Assign 3D coordinates of control points based on the results from the TLS data,
- Generate a dense point cloud based on spherical images using the MVS method.
- Generating a 3D model based on spherical images and a point cloud based on laser scans.

This comprehensive approach set the stage for comparative analysis. The research aimed to create a 3D model based on TLS data and a model based on spherical images.

## 3. Results

The entire process was intricate, prompting a decision to partition and discuss key moments of the entire study, commencing with the outcomes related to the orientation of spherical images.

## 4. Result of spherical images orientation

The orientation of spherical images was carried out using Agisoft Metashape software. It was necessary to adjust the camera settings to "spherical" to ensure that the camera calibration considered spherical visualisations rather than regular ones. Subsequently, point measurements were conducted. Additionally, previously measured points in CloudCompare software were utilised, and their coordinate values were imported into Agisoft Metashape.

This step could have been omitted since these visualisations should have already been oriented relative to each other, as they were generated in dedicated scanner software immediately after their orientation. This is because they are images captured by a scanner that simultaneously acquired them during the object scanning process.

However, to showcase higher accuracy and the potential applications of panoramic visualisations, an additional measurement of control points was undertaken (Figure 3). This was done to facilitate the integration of these images with other data. A total of 35 spherical images were oriented in this manner, allowing the processing of each acquired spherical visualisation.

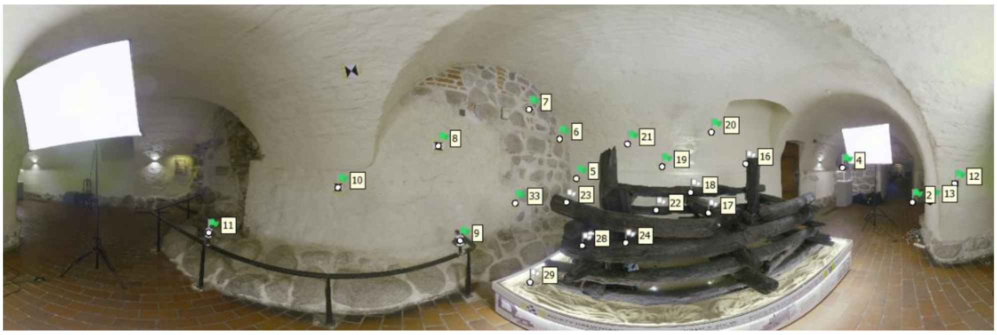


**Figure 3.** View of measured control points on spherical images

## 3.1 Results of model generation based on spherical images

Having generated a dense point cloud, it became feasible to create a 3D model solely based on spherical images. The initial outcome, as depicted in Figure 4, proved unsatisfactory. Despite proper station alignment and control point measurements, one crucial detail was overlooked - the field of view of the generated images. Consequently, black "spots" are evident on the floor and the object itself. This would not be significant if the data were acquired from a greater distance from the object, as observed from the front of the object. However, due to the object of interest being in close proximity to both the side and rear walls of the monument, the scanner had to be positioned at such close distances.

**Figure 3.** View of the 3D model generated in the first approach (black "dots" problem)

The issue was addressed by implementing masks on all acquired spherical images to prevent the black "spots" from directly impacting the quantitative and qualitative analyses of the studied object. The applied mask is illustrated in Figure 5.

**Figure 4.** View of the spherical image with a mask applied

Ultimately, a satisfactory 3D model was achieved solely from spherical images. The view of the obtained model is depicted in Figure 6. This prepared model underwent further analyses to compare how it deviates from the model acquired through scans, as illustrated in the subsequent stage.


**Figure 5.** View of the final 3D model obtained from spherical photos

### 3.2 Result of comparation with TLS

To compare two models – the first created based on spherical images and the second from laser scanning – an analysis was conducted by subtracting one model from the other to highlight the main areas where these differences were most prominent. The analysis focused on the target monument, specifically the beam structures present. The result of this processing is depicted in Figure 7.

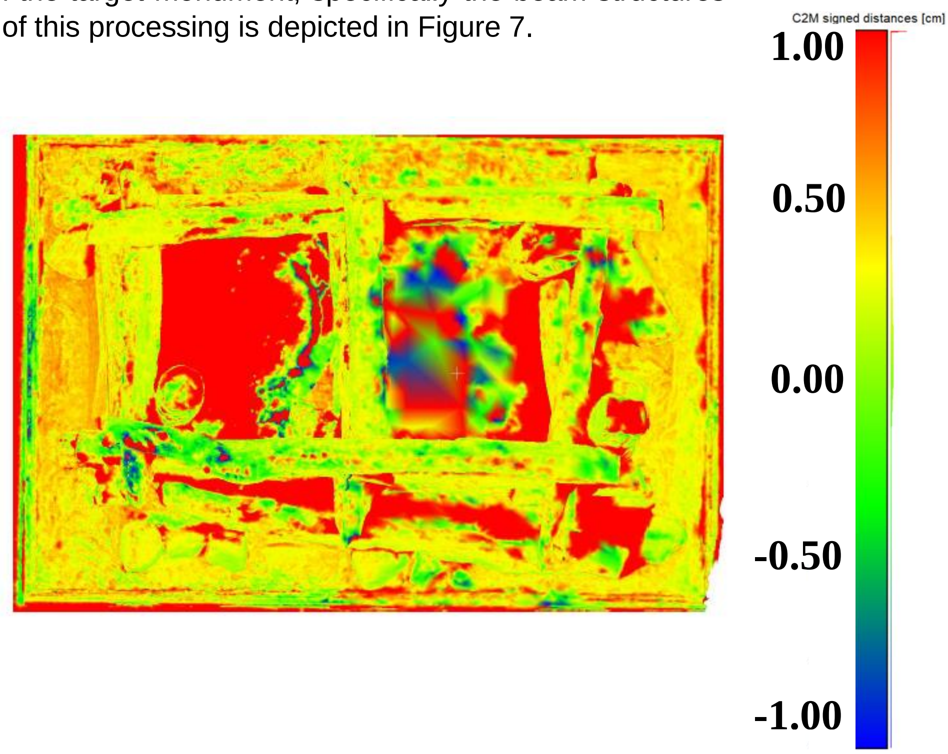


**Figure 6.** Calculated distance differences between the 3D model obtained from spherical images and the model obtained from scans.

As evident in the above analysis, all values on the beams are approximately within the millimetre range. However, it is crucial to consider that the foundation of the beam is made of sand, a material known for its susceptibility to displacement. This substrate is not ideal for quantitative analyses, especially considering that the scanner was placed inside the beam during measurements, resulting in variations in the middle of the monument. Nevertheless, since the focus of the analyses was solely on the beams, independent of the substrate, the millimetre-level differences were deemed satisfactory.

## 5. Discussion

The discussion focuses on interpreting the results obtained from the perspective of previous studies and the working hypothesis. The challenges associated with modern photogrammetric techniques for 3D documentation are multifaceted. Notably, laser 3D scanners and structured light methodologies have proven effective in capturing detailed data. However, precision in challenging areas, such as recesses in historic structures, remains a formidable task. Passive photogrammetric techniques, while flexible, face difficulties in acquiring precise 3D data, particularly for objects with complex structures or limited illumination. Addressing the challenges requires an integrated approach, combining both active and passive techniques. The Structure from Motion (SfM) method, especially advantageous for unsteady camera scenarios and Multi-View Stereo (MVS) technology, offering detailed 3D models from multiple perspectives, contributes to this integrated strategy.

### 4.1 Spherical Images as a Viable Alternative

The study presents an innovative inventory approach, showcasing the potential of using spherical images alongside laser scanning. The Leica RTC 360, with its three cameras, enables the acquisition of high-resolution raw data. To enhance precision and address potential alignment challenges, a photogrammetric network was implemented. This approach resulted in a substantial point cloud with numerous connections between positions. While the orientation of spherical images using Agisoft Metashape software proved successful, challenges in aligning scans were pre-emptively addressed by incorporating a photogrammetric network. The decision to measure control points, even though the images were theoretically oriented, aimed at showcasing higher accuracy and potential applications of panoramic visualizations. Despite initial challenges in the field of view of generated images, the study implemented masks on spherical images to mitigate their impact on quantitative and qualitative analyses. Ultimately, a satisfactory 3D model was achieved solely from spherical images, underscoring their potential as a valuable resource in photogrammetric applications. The comparative analysis between the model based on spherical images and the one from laser scanning revealed millimetre-level differences, primarily attributed to the sand substrate's susceptibility to displacement. While acknowledging the limitations, the focus on beam, structures showcased satisfactory results for the study's objectives.

The study provides a practical example of an inventory approach integrating close-range photogrammetry, laser scanning, and spherical images. The innovative use of spherical images in the inventory of historic objects demonstrates their high accuracy and potential as a cost-effective and accessible resource. The findings underscore the importance of considering spherical images in contemporary photogrammetric applications within geodesy, offering a valuable contribution to heritage preservation efforts.

## 6. Conclusions

The article presents a practical example of an inventory approach based on close-range photogrammetry techniques. This approach allows for precise reconstruction of the 3D form of objects and offers a comparative assessment of the effectiveness of laser scanning combined with simultaneous spherical image capture during the scanning process. The innovative focus on the potential use of spherical images in the inventory of historic objects signifies a valuable contribution to overcoming the challenges in contemporary photogrammetric applications within the field of geodesy.

As demonstrated in the study, spherical images exhibit a high level of accuracy, practically comparable to scans when the same photographic conditions are applied. The precision of the generated model is within the millimetre range, presenting a viable alternative to conventional images. Spherical images should be considered as an additional source of information in photogrammetric processes, particularly in inventories and the generation of 3D models for various monuments. Importantly, they are created without any additional financial investment or the need for extra equipment, only requiring a scanner equipped with digital cameras. This aspect may be overlooked by some scanner users, but it enables the production of qualitatively similar results to the scanner itself.

However, when creating a 3D model based on data other than laser scanning, it should be noted that the generation and processing of such a model are very similar to models derived from regular photographs, with only a few camera calibration settings differing.

As demonstrated in the study, the data were acquired with an accuracy in the millimetre range, suggesting that spherical images could serve as a promising solution for the future. This is particularly noteworthy considering that virtually anyone can capture spherical images, and their applications continue to evolve, introducing new possibilities.

**Authors Contributions:** N.S. and J.K organized the conceptualisation of the idea and the methodology employed in this paper. Following that, N.S. carried out the experimental design. N.S. and J.K worked on the data acquisition at the Royal Castle in Warsaw. N.S. carried out the original writing and draft preparation. N.S. and J.K undertook the data analysis. All authors have read and agreed to the published version of the manuscript.

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