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Research paper

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Comparative analysis of terrestrial laser scanning and flatbed scanning for the visual documentation of decorative plaster tile surfaces

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Summary

This publication presents a comparative analysis of terrestrial laser scanning (TLS) and flatbed scanning in the context of visual documentation of decorative plaster tile surfaces. The aim of the study was to evaluate the effectiveness of both methods in reproducing both the geometric and visual characteristics of plaster surface textures, which, due to their irregular and rough structure, require precise measurement techniques. As part of the study, 52 tiles were collected, each with two plaster structures – 'lamb' and 'woodworm' – giving a total of 104 test fields. The measurements were carried out under controlled laboratory conditions using a Leica ScanStation P40 laser scanner and a Plustek OpticPro A320 flatbed scanner. Point clouds and images were obtained from the TLS, and high-resolution TIFF images were obtained from the flatbed scanner. Analysis of the collected data revealed significant differences between the two methods, particularly in terms of reproduction of quality of colour and texture. The flatbed scanner provided high colour fidelity, vivid colours, and detailed texture reproduction, including micro-protrusions and grooves. The images from the flatbed scanner were free of geometric distortions, offering controlled, perpendicular shots. In contrast, the scans made with the terrestrial laser scanner were characterised by dark, low-saturation images with blurred colour differences, often making it impossible to clearly determine the colour of the surface. Analysis of the texture from the TLS was difficult due to a lack of contrast and adequate lighting. In addition, the TLS images showed deformations and loss of focus.

Overall, the study clearly demonstrated that a handheld flatbed scanner (referred to in the summary as a handheld 3D scanner) offers a significant advantage over a terrestrial laser scanner

(TLS) in the context of visual assessment of plaster tile surfaces, particularly with regard to colour and texture fidelity.

Keywords

visual analysis • laboratory testing • terrestrial laser scanning (TLS) • types of decorative plaster

1. Introduction

Advances in techniques of digital spatial documentation have significantly influenced the quality and detail of analyses of building materials with complex morphology. Methods capable of mapping surfaces with irregular, rough structures – such as decorative plasters – have gained particular interest. Such materials, commonly used in both contemporary and historical construction, require precise measurement methods that can reproduce both the geometric features and visual textures of surfaces. In this context, terrestrial laser scanning (TLS) technology plays an important role, as do alternative imaging techniques, such as scanning with a handheld flatbed scanner.

Terrestrial laser scanning is one of the most advanced methods of acquiring spatial data in a non-contact way. This technology can produce dense point clouds that map the geometry of objects with high accuracy and repeatability, which makes it especially useful for architectural documentation, structural deformation analysis, cultural heritage protection, and monitoring of complex material surfaces [Hassanein et al. 2023, Mitka et al. 2016, Voegtle et al. 2008]. TLS offers the possibility of capturing both large structures and fine surface details with an accuracy of up to several millimetres [Zaczek-Peplinska et al. 2022]. Thanks to the ability to record the intensity of signal reflection, it also enables the analysis of the reflective properties of materials, which may be important in assessing their state of preservation [Mitka et al. 2016, Ulewicz and Pawłowicz 2022].

In the case of highly rough materials, such as decorative plasters, the accuracy of surface mapping depends on many factors, including the angle of incidence of the laser beam, the structure, micro- and macrotexture, colour and reflective properties of the material, as well as the density of registered points [Tan and Cheng 2017, Xu et al. 2017]. Experimental studies have shown that uneven, porous and matt surfaces – typical of plaster coatings – can cause signal dispersion and reduce reflection intensity, which affects data quality [Ulewicz and Pawłowicz 2022, Wójcik et al. 2019]. In such cases, appropriate setting of scanner parameters, such as resolution or measurement mode, is crucial in order to minimise systematic errors [Teng et al. 2022].

Such analyses increasingly use 3D roughness measurements, which capture the full morphology of the material. Research on road surfaces has found that 3D scanners can reliably reproduce varying roughness – from smooth to heavily degraded surfaces – and visualise it in the form of rich point clouds [Chang et al. 2006]. In turn, the use of terrestrial laser scanning enables spatial analysis in which roughness is described both along and across the surface, providing a more complete characterisation than traditional profilometric methods [Alhasan et al. 2015]. Experiments using triangulation scanners have demonstrated their usefulness in describing the texture of asphalt surfaces and parameters related to adhesion [Bitelli et al. 2012]. Meanwhile, in geology, 3D imaging has made it possible to determine the roughness coefficient (JRC) and map surface anisotropy [Mah et al. 2013]. These results indicate that a similar approach can also be effectively applied to plaster surfaces, where roughness plays an important role in both the documentation and analysis of their functional properties.

The use of TLS for the analysis of plaster surfaces also brings benefits in conservation research. The intensity of reflection can indicate local structural changes in the material, such as moisture, delamination, or the presence of biological deposits [Mitka et al. 2016]. Thanks to certain data processing algorithms, it is also possible to model the surface structure and analyse it in geometric and photometric terms [Zaczek-Peplinska et al. 2022].

Despite numerous advantages of TLS, for very small elements or surfaces with complex geometry, handheld close-range scanners become a viable alternative. Although limited in terms of operating range, they offer high resolution and texture detail. Scanners from the EinScan series have been used to document museum artefacts and sculptures, producing stable 3D models, albeit with some limitations on dark or homogeneous surfaces. The results were additionally compared with data from Artec Eva and Spider triangulation scanners [Morena et al. 2019]. Comparative analyses indicate that EinScan handheld scanners, such as the EinScan Pro 2X Plus and EinScan 3D Scanner, can be an effective alternative or complement to photogrammetry for documenting museum artefacts [Khries 2021]. They also reduce mapping errors thanks to the appropriate selection of scanning parameters, such as operating mode and model simplification level [Raza et al. 2023]. At the same time, researchers highlight their sensitivity to material properties and surface finish, which requires the use of appropriate calibration procedures [Zapico García et al. 2023]. In a broader view, their usefulness in cultural heritage documentation has been confirmed, especially for the accurate reproduction of sculptural and religious details [Ruiz et al. 2021]. A comparison of the two methods – TLS and flatbed scanner – allows to determine their usefulness in the context of documentation and analysis of plaster tiles.

2. Research materials

A key issue when scanning various building structures using TLS is the variety of their finishing materials. One of the most common choices is decorative plaster, which can vary in composition, colour and texture. In Poland, silicate and silicone plasters dominate, often coloured with acrylic. Their texture can vary greatly, both in terms of grain size (usually between 1.5 and 3.0 mm) and application method. The popular 'lamb' type plaster is applied with circular movements (Fig. 1a), while the 'woodworm' type plaster, imitating wood grain patterns, is formed by sliding movements (Fig. 1b).

a. b.

Source: Authors' own study

Fig. 1. Example structure of decorative plaster: a. 'lamb' plaster; b. 'woodworm' plaster

For the purpose of the experiment, 83 samples were collected in the form of hard fibreboards measuring 0.60 x 0.40 m, each containing two different plaster structures – 'lamb' and 'woodworm' – distributed over half of the surface. The boards came from the removed exhibition in a hardware shop, and showed varying degrees of damage (visible cracks, stains, and moisture). After careful selection, 52 unique tiles were chosen, characterised by a variety of colours and structures. This resulted in 104 independent test fields, representing both plaster structures in different variants.

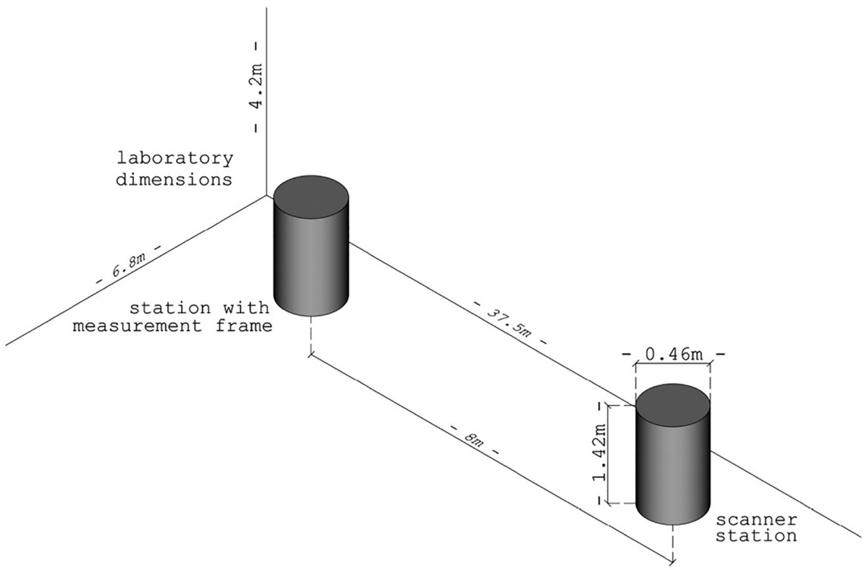
3. Course of the laboratory testing

Two independent methods of image data acquisition were used to conduct a comprehensive visual analysis of decorative plaster tiles: scanning with a terrestrial laser scanner (TLS) and mapping with a handheld flatbed scanner. The best results in testing the properties of instruments and reflective surface parameters are obtained under repeatable and controlled conditions – laboratory conditions [Kersten and Lindstaedt 2022, Muralikrishnan et al. 2017]. Therefore, the measurement was taken in a metrology laboratory located in the building of the University of Agriculture in Krakow. The measurement space is characterised by a constant temperature and uniform artificial lighting, thanks to which stable and comparable conditions were achieved for all recorded samples.

The room's dimensions are 37.5 m long, 6.8 m wide and 4.2 m high, and being located below ground level further limited daylight access. The laboratory's permanent equipment includes massive cylindrical measuring columns (1.42 m high, 0.46 m in diameter) with plates for forced centring of surveying instruments [Kwinta 2021]. During the survey, one of the columns was used to mount a Leica ScanStation P40 laser scanner, which was mounted on a centring plate with a special mounting holder guaranteeing stability and accuracy of positioning [Kwinta 2024]. The second column, located about

8 metres away, served as an exhibition stand for test tiles. The measurement sketch illustrates the dimensions of the room and the columns, along with their layout (Fig. 2).

In order to ensure an unambiguous and repeatable position of the tiles during each measurement session, a special measuring frame was used (Fig. 3). This structure was made of steel, coated with black powder paint and equipped with a mounting hole of internal dimensions 0.58x0.38 m, which corresponds to the dimensions of the test tiles. The frame was fixed to the centring plate on the post with screws, and each tile was inserted from the rear and secured with a precise clamp. To maintain constant pressure and eliminate errors caused by differences in installation, the pressure plate was screwed in place with four corner screws with a torque wrench.



Source: Authors' own study

Fig. 2. Measurement sketch of the room with the arrangement of columns

This solution provides full control over the geometry of the measurement system, provides stable data recording, and eliminates variables that could affect measurement quality, such as angle deviations or micro-shifts of the plates relative to the laser beam path.

The objects were measured from a single station using a Leica P40 scanner. After levelling and configuring the basic settings, such as scanning resolution (0.003 m) and distance from the object (8.000 m), the device could scan the entire surface of the test tile placed in a stationary frame. By using the 'scan + photos' mode, both a point cloud and photos in original colours (RGB) were obtained for all plasterboards. Limiting the scanning range to the test surface significantly reduced the measurement time and simplified further data processing.

Source: Authors' own study

Fig. 3. Measuring frame for positioning the plates during measurement

After each TLS measurement, the plate was moved and scanned using a Plustek OpticPro A320 flatbed scanner, which produces accurate colour reproduction at a resolution of 600 DPI. The plates were placed directly on the scanner surface, which ensured uniform lighting conditions and complete elimination of shadows and geometric distortions. This made it possible to generate 104 images with dimensions of 7200 x 10200 pixels, with very high focus, clear contrast and a full tonal range of colours, saved in TIFF format without lossy compression.

4. Measurement data

This research was based on two independent sets of measurement data obtained using different scanning technologies for the purpose of comprehensive visual analysis of decorative plaster tile surfaces.

The first data set came from the terrestrial laser scanner (TLS). It comprised:

- Point clouds: Representing the three-dimensional geometry of the studied objects, with information about the spatial coordinates of each point.
- Images in .jxr format: Associated with point clouds, recording visual (colour) data from a laser scanner.

The second set of data was obtained using a handheld flatbed scanner. The output of the scanning process was a series of image files in .tif format, each of which represents a precisely cropped, perpendicular view of the surface of the studied plate, without any geometric distortions.

Both types of data – .tif files from a handheld scanner and point clouds and .jxr images from TLS – provided the basis for a detailed comparative analysis, allowing for the evaluation of the effectiveness of each method in terms of visual representation of plaster surfaces.

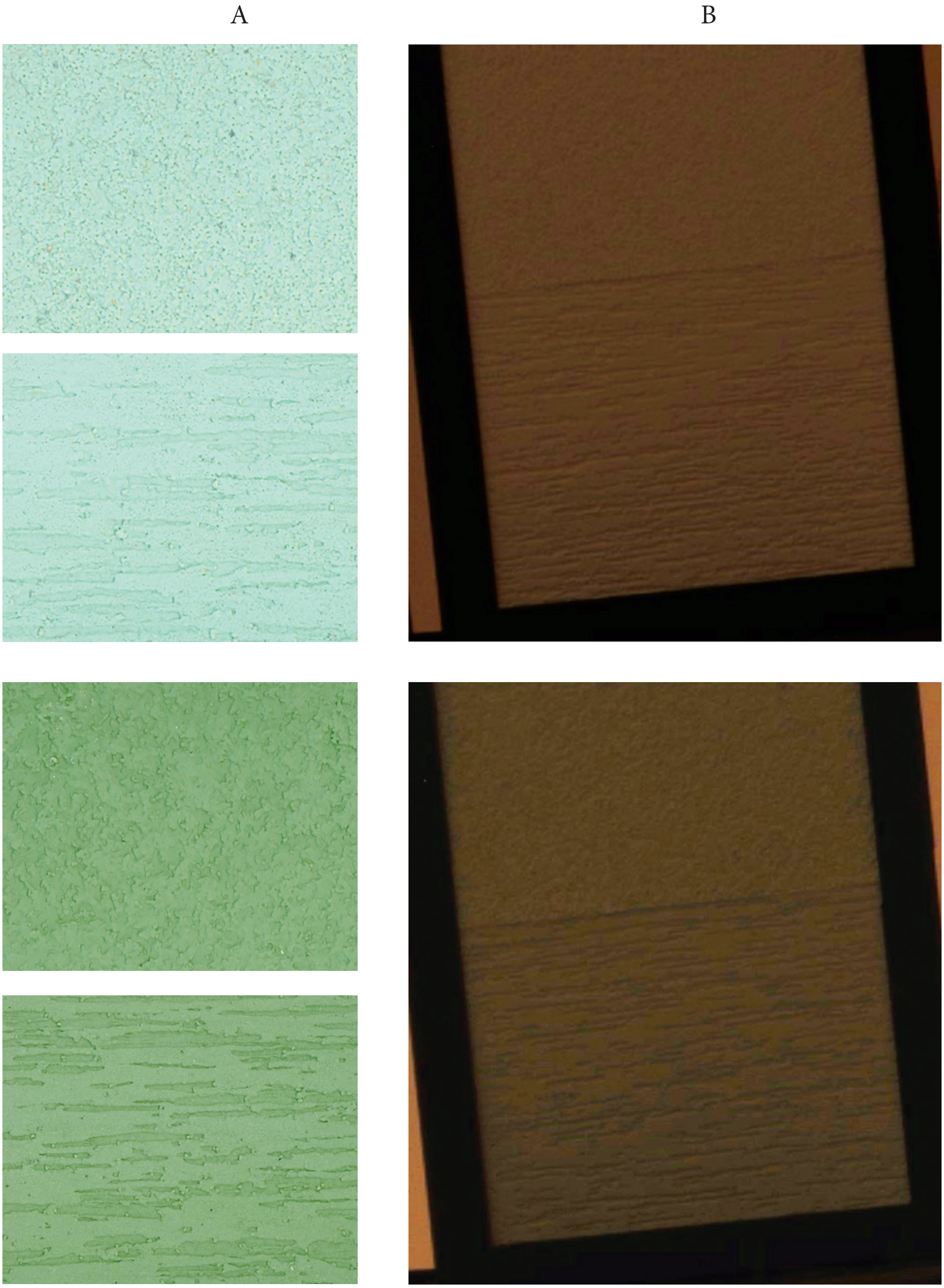
5. Analysis of measurement data

One of the most noticeable differences between the two types of scans was the colour reproduction quality. In the case of the handheld scanner, the obtained data displayed high colour fidelity – the colours were vivid, varied and accurately reflected the actual appearance of the surface. There were clear tonal differences between plasters of different colours and between two types of texture on a single panel. On the other hand, scans made with a terrestrial laser scanner showed significant imperfections in this respect – the images were dark, the colour saturation was low, and the colour differences between individual panels were blurred. In many cases, it was difficult or even impossible to clearly determine the colour of the surface. It can be assumed that this was due to both the optical parameters of the employed camera and the suboptimal lighting conditions during scanning.

The handheld 3D scanner allowed for controlled photography – perpendicular to the surface, with appropriate exposure and focus. The images were free of geometric distortions and artefacts due to the angle of recording. As a result, each plate was presented in an unambiguous and clear manner. In the case of the ground scanner, the images were taken from a greater distance and at an angle, which caused deformations in the shape of the plates, their partial cropping or distortion of proportions. There was also a visible loss of focus at the edges and greater variation in quality between individual images.

In terms of the ability to reproduce surface texture, considerably better results were achieved with the handheld scanner. Thanks to high resolution and appropriate lighting, it was possible to distinguish in detail the structures and granules of both types of plaster. Micro-protrusions characteristic of 'lamb' plaster and parallel grooves characteristic of 'woodworm' plaster were visible. In the case of data from the terrestrial laser scanner, although the outlines of the texture were partially visible, the lack of contrast and adequate lighting made surface analysis difficult. This was particularly the case with 'lamb' plaster, which lost its distinctive graininess in the absence of shading.

The differences in colour and surface texture reproduction between the two types of scanning are presented in Figure 4, which shows sample images of the same plasterboards captured using both technologies. The scans obtained with the handheld scanner are original, whereas the laser scanner images have been additionally brightened and contrast-corrected. In order to systematise the results of the comparative analysis of terrestrial laser scanning and flatbed scanning, they have been compiled in a table comparing both methods in terms of the visual quality of the documentation of decorative plaster tiles (Table 1).



Source: Authors' own study

Fig. 4. Sample images of two plasterboards obtained using the handheld 3D scanner (column A) and the terrestrial laser scanner (column B)

Table 1. Comparison of terrestrial laser scanning and flatbed scanning in the documentation of decorative plaster tile surfaces

Criterion	Handheld scanner	TLS
Colour fidelity	High – vivid colours, matching reality	Low – dark images, low saturation
Tonal contrast	Clear differences between boards and textures	Blurred differences, hard to discriminate
Mapping geometry	No deformations, images perpendicular to the surface	Deformations, cropped edges, perception distortions
Image focus	High and uniform across the entire frame	Loss of focus at the edges, quality discrepancies
„Lamb" texture visibility	Very good – micro-protrusions clearly visible	Weak – texture smoothed-out, no shading
„Woodworm" texture visibility	Good – parallel grooves clearly visible	Limited – low contrast hinders the analysis
Consistency of sample quality	High – consistent results for all plates	Low – high variability depending on angle and distance
Analytical potential	High – clear identification of colours and textures	Limited – analysis challenging, ambiguous

6. Conclusions

The research presented in this paper aimed to evaluate the visual mapping of decorative plaster tiles using two independent methods of image data acquisition: terrestrial laser scanner (TLS) and handheld flatbed scanner.

The presented comparative analysis clearly shows that a handheld 3D scanner offers a significant advantage over a terrestrial laser scanner (TLS) regarding the visual assessment of plasterboard surfaces. Colour fidelity is a key difference, as the handheld scanner produces vivid and realistic colours with clear tonal differences, while the TLS generates dark, low-saturation images with blurred colour differences, often making it impossible to identify colours. The image quality and framing are also significantly better with a handheld scanner, providing controlled, perpendicular shots without distortion, as opposed to the distorted and partially cropped images from TLS. Furthermore, the handheld scanner is much better in rendering surface texture and structure, capturing micro-protrusions and grooves in detail, unlike the TLS, where lack of contrast and adequate exposure impedes analysis, especially in the case of 'lamb' plaster.

In summary, although terrestrial laser scanners offer high geometric accuracy, when it comes to visual documentation, especially colour and texture fidelity, handheld 3D scanners have proven to be irreplaceable, providing high-quality, clear data that does not require advanced post-production.

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