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THE APPLICATION OF 3D SCANNER TECHNOLOGY IN BUILDING ARCHEOLOGY AND HERITAGE PRESERVATION

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Nowadays, the benefits that ground-based laser scanners (TLS Terrestrial Laser Scanning) bring to architecture and heritage site conservation are undisputed. The emergence and widespread use of Building Information Management (BIM) systems, their workflows, and standards, alongside the demand for reliable data, have made the demand for these tools even more justified. Many professionals cannot imagine planning reconstructions and renovations without point clouds, while, others still struggle with the challenges of this technology. The article summarizes fifteen years of experience in measuring, digitalization, and modelling of archaeological sites, castles, churches, and palaces. We illustrate our points with the results from various phases of the survey of the Visegrád monument complex, notably the Royal Palace.

Excavations and object surveys often reveal details like statues, reliefs, keystones, and other findings may be found where the laser scanner's resolution (the density of points captured per millimetre) is no longer enough for a detailed digitization. In such cases—like the ones presented in the paper—structured light projection and photogrammetry are used.

Keywords: laser scanning, building archeology, heritage preservation, point cloud, 3D modelling

LASER SCANNING AND THE USE OF POINT CLOUDS

We refrain from describing the technologies and tools in detail since numerous articles cover these subjects and focus instead on why those who are already using scanner-generated point clouds are satisfied and how they work with them, what negative experiences those hesitant about it might have had, and what to consider for those new to the technology.

During the research and development of the SziMe3D AR project, our primary goal was the surveying and presentation of cultural heritage using state-of-the-art tools. Over the following ten years, we worked on hundreds of buildings, dozens of churches (e.g., the Great Reformed Church in Debrecen and the Reformed Church of Nyírbátor), castles (e.g., Szigliget, Salgó, and the Visegrád Citadel), archeological sites (e.g., Győr Dunakapu Square and the Cathedral of Kalocsa) and palaces (e.g., the Falconieri Palace in Rome and the Alsópetény Palace), as well as industrial facilities, surveying and digitizing millions of square metres. This article builds on our experience and those of the architects, art historians, and archaeologists who have worked with us. In our opinion, the most significant advantage of point cloud technology is that, unlike in the case of a geodetic survey, where the surveyor must manually aim at each point to be measured, the scanner automatically measures every point of the building, thus eliminating point cloud selection and directional errors. It offers a precise, accurate, and reliable starting point, which often carries additional data or information about the building's history.

3D-scanned datasets serve a dual purpose. First, they aid future work by providing an accurate, up-to-date record of the present state. Second, they ensure that, even after renovations and reconstructions, one still has a reliable 'as it was' record at hand, which may not only be essential for monument preservation and protection but also aids the everyday work of architects. Knowing to have a reliable database at disposal at any time, from which one can derive dimensions and information that might not have been considered on-site, is reassuring. When the relation between building areas is complex and challenging to understand, the comprehensive visibility provided by a 3D model can represent a significant aid in interpreting spatial relationships. The Visegrád monument complex is a classic example. Due to the site's topography,

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visualising the various levels, cellars, and tunnels in a single view greatly aided the conceptual design. The advantage of documenting the present is that it can also be utilised in monitoring building motion over time by evaluating successive datasets.

Chief architect Márta Vörös[2] designed a glass roof to protect and display the medieval ruins using their point cloud. The respective point clouds played a crucial role in determining the positions of the supporting steel columns around the ruined walls. It was possible to accurately calculate the number of prefabricated glass panels needed and how many has to be cut to size on-site, which had clear and undeniable economic benefits. In her opinion, this task could not be executed using conventional geodetic methods or only at significant risk. Since we employ both, we do not intend to pit laser scanner technology against traditional geodetic methods. Traditional geodesy is essential for improving the registration accuracy of our measurements, minimizing error margins, and ensuring their integration into the geodetic coordinate system. Both procedures have their place and role. What can be said with certainty is that the significantly larger volume of data from laser scanning surveys offers a more reliable basis for planning and construction compared to the limited amount from geodetic surveys.

The digitization of its previous state aided the restoration of a weather-damaged Holy Trinity statue. This allowed an accurate determination of the optimal size of stone blocks needed and made it possible to adjust for each element's varying degree of roughness during carving.

Our clients have emphasized the value of additional information obtained from the variations in intensity values (i.e. the amount of light from the laser reflected from a surface) of the point clouds captured by laser scanners. These values can indicate wetness levels, expose previous layers, or reveal hidden structural components.

PROCESSING THE POINT CLOUD

What mistakes can be made during traditional surveys that can be discovered through working with point clouds?

Traditional manual surveying usually requires several teams of experts to 'digitize' a building. Inaccuracies between the measurements of the different teams and variations in representation techniques come to light during the editing done in the office. Only additional measurements, if possible at all, can correct mistakenly generalized elements, uniform fenestrations, and inaccuracies in wall or ceiling thickness. Using laser scanners for digitization minimizes on-site inaccuracy and generalization. The number of scanners and surveyor teams can be modified according to the time limitations and, with geodetic support, entire buildings can be measured with sub-centimetre accuracy.

Nowadays, one of the significant obstacles to the ease of use of point clouds is their vast size compared to the processing capability of architectural design softwares. Autodesk products like ReCap Pro and Revit handle laser-scanned data better. ArchiCAD, a software usually used by architects, limits the point cloud size to approximately 100 million points, or roughly 1GB of data, which can be exceeded easily. Hence, it is essential to filter, clean, and remove unnecessary parts by segmenting or resampling the point cloud. When drawing a building's façade, its connection to neighbouring buildings is essential. Still, whatever data is captured from the other side of the road is irrelevant, as is the large dataset captured from the trees obstructing the façade. When processing interiors, furniture, curtains, and "floating" points generated as artefacts should be deleted. For a dense point cloud, a decimated dataset might suffice, and cutting out the parts one wants to work with is an undoubtedly excellent solution. A few centimetre thick slice of the point cloud can yield an almost finished floor plan, section, or view (*Figs. 1–2*).

Many believe that 'masonry accuracy' (approximately 2 cm) is sufficient for point clouds, and only deviations bigger than that should be represented in drawings and models. For apertures, complex structures, highly detailed surfaces, finer details, or specific requirements, it may be necessary to survey them with half a centimetre distance between the recorded points. An inherent limitation caused by the technology, which

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Fig. 1. Coloured point cloud cross-section of the Lower Castle of Visegrád, Salamon Tower

Fig. 2. Coloured point cloud longitudinal section of the Lower Castle of Visegrád, Salamon Tower

cannot be remedied, is that the display of the imported point clouds is not parameterisable in ArchiCAD. This means that it is impossible to change the values of many of the features, which renders interpretation difficult in some cases. When creating cross-sections, the points do not get exported in 2D, and a combined display of the model and the point cloud can only be created using screenshots of the latter.

Spectacular façades, floor plans, and sectional views can be created from the point cloud using perpendicular projection. This results in images of the true size, which include every measured point in a pixelated format.

DRAWINGS AND MODELLING

It is often difficult to decide whether to create drawings or models. Practice has shown that 3D BIM models are more suitable for complex, intricate, and valuable buildings, while detailed 2D drawings are indispensable for depicting ornamental details and supporting reconstruction work.

WHAT MISTAKES CAN BE MADE DURING MODELLING?

If the data provider conducting the survey is not careful enough, built-in cupboards, concealed parts, suspended ceilings and floors, and concealed plumbing can cause mistakes when creating a drawing. Copying data from the point cloud automatically, without sector-specific interpretation, may lead to incorrect wall or floor thickness or the depiction of elements that aren't there. Architectural knowledge and experience are essential in processing because what the scanner could not see, the architect must uncover and interpret. In our experience, the processing of the point cloud is more reliable and faster when the person doing the survey has an architectural perspective and, thus, can 'see' the structure behind the walls. Glass entrance mirrors, especially in relatively narrow, wet areas, e.g., near water system outlets, can show anomalies (shapes and inconsistencies that cannot be interpreted on their own), which require expert knowledge to decipher. Special attention is needed from data providers when augmenting the point cloud generated with terrestrial laser scanners with another point cloud generated by drones for details not measurable from the ground, such as roofs, chimneys, and ornamental elements. In these cases, using an adequate number of control

Fig. 3. Coloured point cloud image of the Alsópetény Castle

points measured geodetically is essential. It should be mentioned that the Visegrád measurements were complemented with LiDAR recordings from a small aircraft, and were used to create the terrain model of the Visegrád mountains.

A traditional building survey includes photographic documentation. In many cases, the point cloud is as detailed as a black-and-white photo, with the added benefit of containing 3D data. If we take pictures during the scanning process, this documentation is produced in one step. Orthophotos, images devoid of perspective distortion, or undistorted perpendicular photos from the point cloud can make the understanding and processing of the obtained datasets more straightforward (*Figs. 3–4*).

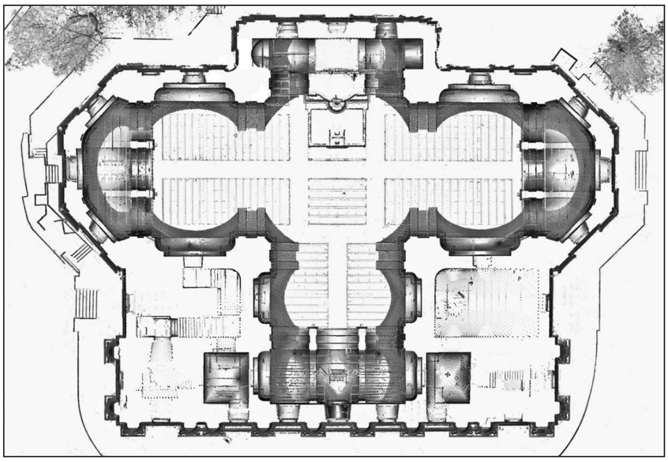

Fig. 4. Floor plan of the Great Church of Debrecen, generated from a point cloud

The point cloud display software and its settings have a significant impact on how much they support modelling. To demonstrate this, we show three images from the same dataset (*Figs. 5–8*).

Even with free software, there are numerous options for editing and segmenting the point cloud, resizing the points, setting up the display best suited to the user, configuring the displays, and creating a meshed file (surface model). With some programming knowledge, one can even implement unique ideas. One of the most popular open-source applications is CloudCompare, which, along with its user manual, is freely downloadable.

Experienced architects adhere to the school of thought that one must learn the building, which can only be done through making measurement notes, manual measurements, and freehand drawings in site visits. In their opinion, the point cloud cannot substitute the survey plan because it is a form of interpretation and, therefore, should be approached with caution. However, they also accept that 2D drawings aided by point clouds can be handy and provide additional information. Many believe a drawing complemented by a coloured point cloud image can evoke a ‘wow’ reaction in a competition or review for its authenticity and beauty.

Fig. 5. Details of the Visegrád Royal Palace cloister in BIMcollab Zoom software, without displaying intensity values, and with highlighted edges

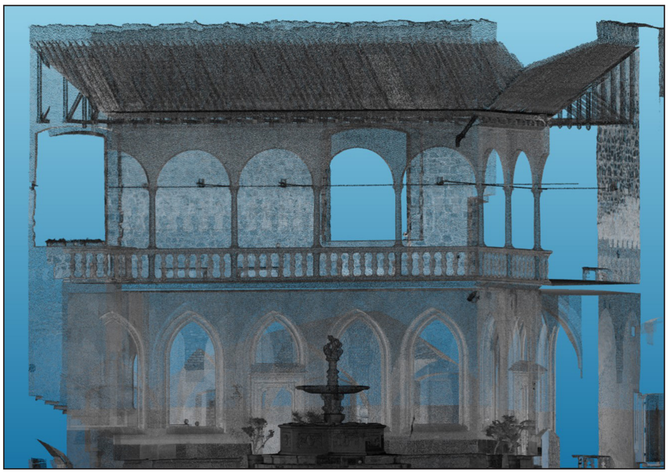

Fig. 6. Details of the Visegrád Royal Palace cloister in BIMcollab Zoom software

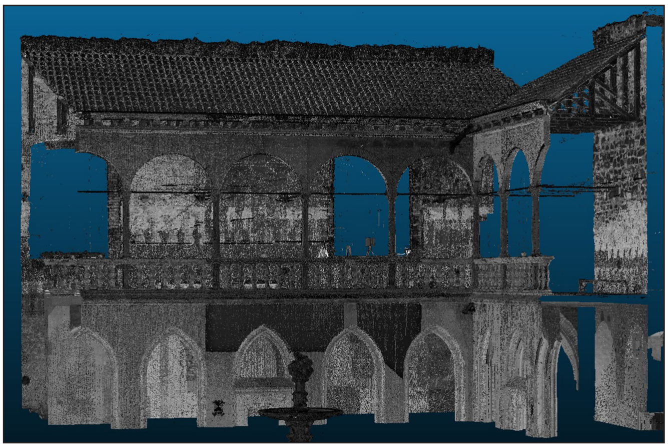

Fig. 7. Details of the Visegrád Royal Palace cloister in CloudCompare environment

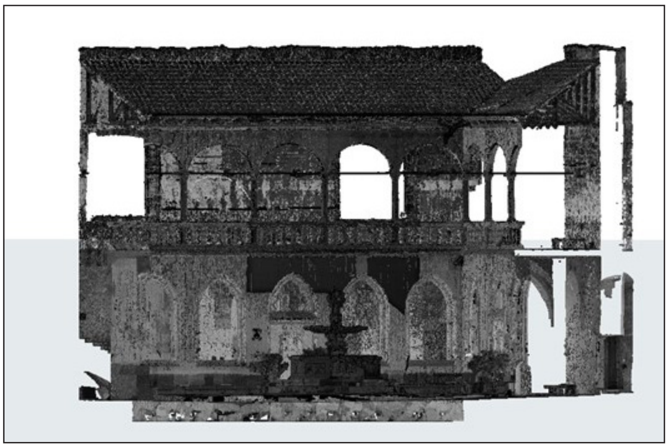

Fig. 8. Point cloud displayed in ArchiCAD

If we need a more detailed digitalization than what laser scanning can provide and the object's size to be measured allows it, we use structured light projection technology. Today, this technology has a serious contender: photogrammetry-based modelling. We use both, preferring photogrammetry when a lot of work needs to be done with more straightforward requirements and fewer details. Photo-based surface models often display rounded, blurred, 'melted' edges, as if the object were coated in a thick liquid forming a glaze on the surface. We often use engineering CAD softwares to create suitably sized and detailed object models, which facilitates the creation of the desired files. Models made of carved stones, vault ribs, intricately carved keystones, capitals, pedestals, or statues can be integrated into models of the entire object, enhancing their detail and beauty (*Figs. 9–12*).

The surveying and digitalization of the Visegrád Citadel, Lower Castle Salamon Tower, the wall connecting the Lower and Upper Castles, and the Royal Palace culminated in the creation of architectural models developed in ArchiCAD. Rhino 3D is the preferred software for 3D modelling involving complex geometry or parametric design because it provides true design freedom without the limitations found in other 3D design programs. The parametric design facilitates the realisation of organic shapes for buildings. One can create new shapes and structures that would be impossible to draw with the usual tools, and alter the entire geometry by changing parameters, allowing to explore variations in form and function. Designing more sophisticated details in ArchiCAD, such as the closed balcony that was planned during the Matthias era for the northwest wing of the Royal Palace, was a significant challenge. Where possible, we created three levels of conceptual models, depicting the current, surveyed state, the substantiated reconstruction,

Fig. 9. Keystone model with the coat of arms of King Matthias from the Visegrád Citadel

Fig. 10. 3D scan of a keystone in the Visegrád Franciscan friary

Fig. 11. Keystone model from the Visegrád Franciscan friary

Fig. 12. Reconstruction of the chapel vault in the Visegrád Franciscan friary, made using a set of scanned stones (SziMe3D AR project by Szőke Balázs)

and, where we lacked sufficient information, a hypothetical model. The design tasks were supported by the professionals who were the best acquainted with the monuments, participated in their archeological excavation, and had designed or contributed to previous constructions.

Our many years of experience and the examples presented above demonstrate no real alternative to a laser-scanned database in heritage conservation projects (*Fig. 13*).

Fig. 13. Salamon Tower (Lower Castle). On the left: the surface model created from point cloud; on the right: the established conceptual model

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