Evaluating Site Scanning Methods: An Assessment System for Quantitative Comparison and Selection

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Abstract –
With the rapid advancement of digitization, a multitude of tools for as-built modeling has emerged, posing a challenge in choosing the most suitable product. This article presents an evaluation system for identifying and selecting a site scanning method to create a digital twin of existing buildings. The evaluation criteria developed for this purpose were integrated into an evaluation scheme that forms the basis for a quantitative assessment. A case study was conducted to validate the developed evaluation system. Two Operating Systems (OS) applications, a Faro laser scanner, and a handheld LumoScanner were selected to generate a 3D model for a floor with a 500 m^2 area. The presented method supports construction and design companies in their decision-making process when selecting scanning methods for practical building applications.

Keywords –
Evaluation System, Laser Scanner, OS Scanning Application, As-built Modeling

1 Introduction

This work is part of the research project NaiS (Nachhaltige intelligente Sanierungsmaßnahmen). It focuses on digitizing information that is hard to reach and on optimizing it through human collaboration. One of the goals of NaiS is to employ advanced technologies in the field of site scanning to generate the digital twin.

The AEC sector is embracing an increasing availability of site scanning technologies [1], revolutionizing construction processes. However, adopting these technologies faces technical, economic and awareness-related difficulties. Previous studies [2], have explored the challenges associated with adapting laser scanners. Our paper addresses these challenges by employing an assessment system, allowing a quantitative comparison of site scanning technologies. This approach contributes to overcoming barriers and promoting the effective integration of site scanning technologies in the AEC sector. Therefore, the primary aim of this work is to develop a concept for objectively evaluating site scanning technologies and hence supporting decision making.

For the development of the conceptual framework, qualitative criteria were defined based on existing literature. This decision resulted from the realization in [3] & [4], that the exclusive use of quantitative measures is not sufficient for a comprehensive assessment of the multiple dimensions that characterize the performance of technologies. As qualitative criteria cannot be measured directly, a new instrument is needed to evaluate them. A utility value analysis is proposed, as recommended in [5] & [6]. This is particularly suitable for complex decision-making problems, as it offers the possibility of quantifying all evaluation criteria and therefore subjecting them to a final assessment. Consequently, this approach enables the objectification of qualitative criteria.

2 Methodology

This paper presents a comprehensive assessment framework designed for the evaluation of building scanners. The framework covers all essential aspects and enables a thorough analysis. It aims to make the framework to be both accessible and practical for users. This framework is divided into three components: evaluation criteria, evaluation scheme, and utility analysis. Each component will be discussed in the following discussion.

2.1 Evaluation Criteria

Kühnapfel [6] addresses essential details to consider in selecting criteria. To ensure the practicability, particular emphasis was placed on formulating the criteria in a manner that makes them applicable to a broad spectrum of building scanning methods. Similar criteria were avoided to prevent collinearity, which could result in disproportionate weight of certain categories. Furthermore, attention was given to selecting criteria that are relevant to the decision-making problem.

Table 1 presents the content of the evaluation criteria which have been selected based on existing literature. The weights are determined based on a subjective weighting method known as point allocation. Decision makers assign 100 points to the criteria, with a criterion's importance increasing with the number of points it receives. The total weighting for all main criteria must equal 100, and the sum of all sub-criteria within each main criterion must also equal 100 [7]. The weighting of the criteria in the study presented in this paper were assigned based on the author's expertise.

Now, the criteria need to be made quantifiable and comparable. To achieve this, an evaluation scale must be defined, ensuring a shared understanding among decision-makers. Therefore, we developed an evaluation scheme, which is described in the following chapter.

Table 1: Evaluation Criteria for building scanner

Main Criteria	Weighting (%)	Sub-Criteria	Weighting (%)
Functionality	36	**·Technology [8]**	8
		·Data acquisition [9]	9
		·Data analysis [10]	25
		·Result [8]	25
		·Costs [8]	25
		·Internet connection [11]	8
Maintainability and Sustainability	8	**·Community [12]**	34
		·Maintenance readiness [12]	33
		·Evolvability [12]	33
Performance	10	**·Duration [9], [10]**	80
		·Performance [11]	20
Compatibility	4	**·Compatibility [12]**	100
Usability	28	**·Comprehensibility [12]**	15
		·Documentation [12]	11
		·Installability [12]	11
		·Learnability [12]	11
		·Self-descriptiveness [13]	15
		·Controllability [13]	15
		·Findability [14]	11
		·Support [12]	11
Reliability	3	**·Fault tolerance [13]**	100
Security	3	**·Data security [11]**	100
Portability	8	**·Operating System [12]**	50
		·Mobility [9]	50

2.2 Evaluation scheme

In the presented Assessment System, the 5-point scale was selected to meet the requirements described below, including the practicability of the assignment to a scale value, the representation of the number of scaling levels, the uniformity of the scale, and the directional equality of the value development, as discussed in [6].

To guarantee the uniformity of the assessment system, a rating scale is created, where each sub-criterion is rated from 1 (very negative performance) to 5 (very positive performance). Therefore, all criteria can be evaluated on a common basis. The assessment of the criteria depends mainly on the hands-on experiences and knowledge of the evaluator.

A common understanding of the scale concerning criteria among all assessors is crucial to achieving comparable and reliable results. Therefore, a scoring guideline is provided in an evaluation scheme. Positive and negative characteristics are compared. More positive characteristics result in a higher score, while a higher degree of negative impact leads to a lower score. Table 2 illustrates an example of the evaluation scheme.

Table 2: Evaluation Scheme for building scanner

Sub-criteria	**Target Value**	
	Positive Impact	Negative Impact
Compa-tibility	There are various interfaces to other software programs.	There are no interfaces to other software programs.
	Various data formats can be generated for export	Only one data format can be generated for export.

2.3 Utility Analysis

Zangemeister [15] declines utility analysis as an evaluation method designed to support rational decision-making. In this paper, it is used both to evaluate a building scanner and to compare multiple options. The evaluation criteria created above are integrated into the utility analysis. By applying weighted evaluation criteria, different options can be compared to determine an optimal result from a holistic perspective. Each sub-criterion weighted according to its relevance is added together to give the total value. According to [6], the criteria weights are determined individually. During the evaluation process, the target values can be determined by using the evaluation scheme and incorporated into the utility analysis. A maximum of 5 points can be achieved. The higher the score, the more capable the potential building scanner is.

Table 3 illustrates an example of the mathematical expression of the utility analysis.

Table 3: Example of an Evaluation

Main Criteria	**Weighting (%)**	Sub-Criteria	Weighting (%)	Unweighted evaluation (Points 1-5)	Weighted evaluation	**Sum of Main Criteria**
Security	**3%**	Data security	100%	4	4 (=1x4)	**0.12 (=0.03x4)**

3 Case Study and Results

3.1 Description

To validate the assessment system presented above, two mobile-phone-based Light Detecting and Ranging (LiDAR) OS applications (MagicPlan and PolyCam), a photogrammetry-based scanning device (LumoScanner), and a laser scanner (Faro Focus S Plus 150) were tested. The OS applications have been chosen as they fulfill the requirements for our case study. For example, the user license is free during a trial period, the acquisition settings can be customized, and a 3D model is generated as an Industry Foundation Class (IFC)-Model. The test occurred on an approximately 500 m^2 floor in an office building (Figure 1), located in Karlsruhe, Germany.

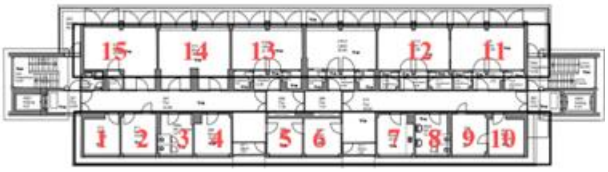

Figure 1: Floorplan of the study object

To guarantee the comparability of the recorded scans, all scans were performed, under consistent lighting conditions. The detailed procedure in the case study is presented below.

Two OS applications are separately installed on two iPad Pro 11-inch (3rd generation), both equipped with a LiDAR sensor with a detection range of up to 5 meters. PolyCam offers four scanning modes (e.g. LiDAR, Room, Foto, and 360). LiDAR and Room modes were chosen to generate point clouds along with 3D models. The results can be exported as point clouds or 3D models in various formats. In LiDAR mode, each room is scanned separately, creating individual point clouds (exportable as .las files). In CloudCompare, those point clouds emerged to create a complete point cloud. The emerged point cloud was processed in ReCap and Revit for as-built modeling.

MagicPlan captures the spatial data and supports various export file formats. It allows users to edit the layout and add various elements such as windows and doors. A Bluetooth-enabled laser range finder can be lined for increased accuracy within a five-meter range. Besides, an internet connection is not required during recording.

LumoScanner creates 2D point clouds from images. Each scan takes around 2 seconds and requires 1 to 2 scans per room. This highly depends on the room size and layout. Due to its 2-dimensional nature, a handheld laser rangefinder supplements the LumoScanner for more detailed measurements, such as the position and size of windows or doors. The floor plan was created in advance and saved in the LumoApp. The final 3D modeling process is conducted in Revit.

The Faro laser scanner offers up to 150 meters of scanning range and rapid data capture. In the case study, its settings were adjusted for a high scanning speed and a suitable quality, including a 10 m indoor range, a resolution of 1/32, and no color. One scan took approximately 40 seconds. The recorded point clouds were saved on an SD card, merged in CloudCompare, and used for 3D modeling in Revit.

3.2 Results

The case study was conducted in two separate days. On day one, MagicPlan and PolyCam were tested to scan 15 rooms and three staircases. Due to highly complex circumstances in room 15, the scanning result was not used in the as-built modeling.

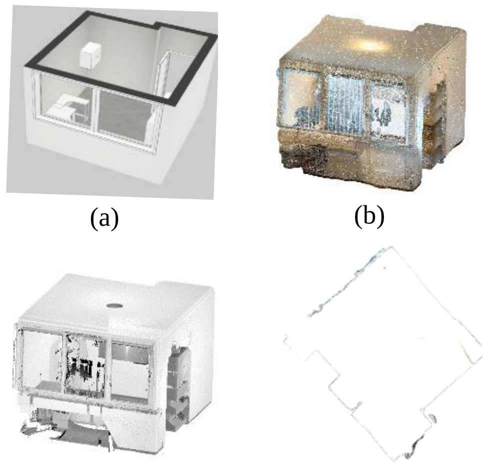

Figure 2: (a) 3D model in MagicPlan; (b) 3D point cloud model from PolyCam; (c) 3D point cloud model from Faro scanner; (d) 2D point cloud model from LumoScanner (illustration)

The data acquired with MagicPlan can be exported as an IFC model directly (Figure 2a), comparatively, the data from PolyCam was first exported as a set of 3D point clouds, each one of them represents a room or staircase (Figure 2b). On day two, the Faro laser scanner and LumoScanner were utilized to capture 14 rooms and three staircases. A set of 3D point clouds was exported from the Faro laser scanner (Figure 2c). The Data from LumoScanner were uploaded to Lumo Cloud, and a set of 2D point clouds was generated in the platform (Figure 2d) just for illustration, not original data).

Table 4 presents the data processing speed of the four scanning methods. Due to high integration of MagicPlan, it reaches the highest speed of 9.02 m²/min.

Table 4: The processing speed of the four methods

	MagicPlan	PolyCam	Faro	Lumoview
Area/Time [m²/min]	9.02	1.27	1.05	1.42

Table 5 presents the final evaluation results derived from the assessment system. The results and detailed explanations for the assigned ratings are recorded in a separate table. However, not all sub-criteria are qualitative, such as the sub-criterion duration. Therefore, the duration for each processing step is recorded also in a table. The approach streamlines the assessment process and provides a transparent documentation review and analysis. MagicPlan is evaluated as the best method with a score of 4.26. The scores of the remaining three methods range between 3.50 and 3.60 points.

Table 5: The final evaluation results

	Weighting (%)	Magic-Plan	PolyCam	Lumo-view	Faro
Functionality	36	1.44	1.23	1.37	1.22
Maintainability & Sustainability	8	0.29	0.29	0.27	0.28
Performance	10	0.48	0.37	0.21	0.45
Compatibility	4	0.16	0.2	0.20	0.13
Usability	28	1.31	1.15	1.01	1.09
Reliability	3	0.06	0.06	0.06	0.03
Security	3	0.12	0.12	0.09	0.09
Portability	8	0.4	0.16	0.32	0.24
Total	**100**	**4.26**	**3.58**	**3.53**	**3.53**

3.3 Discussion

MagicPlan results as the most efficient method, particularly in functionality, performance, and usability: (1) low cost (99.99€/year subscription); (2) high processing speed (9.02m^2/min); (3) user-friendly interface (editable room layout). It is noticeable that almost all the tested objects are at a similar level. It can therefore be assumed that mobile laser scanners can be used just as effectively as terrestrial laser scanners. This finding is also supported in studies [1] and [16]. The high ratings of MagicPlan in the Google Play Store and the frequency of downloads further validate our findings [17].

4 Conclusion

This work developed a comprehensive evaluation system for site-scanning methods to enhance decision-making for users. A case study was conducted to verify the evaluation system and assess the performance of various scanning methods. The results highlight that the system can deliver a reliable evaluation with limited accessible information in practice. It should be noted that its application is not limited to the field of site-scanning. Additionally, the weighting rate for each criterion can be adjusted based on the users' need and a particular use case. However, a wider range of scanning methods should be tested in a more diverse building environment to verify this system. In conclusion, the paper lays a solid foundation for developing an evaluation system for the applications in BIM and offers a practical tool for users.

References

[1] Teppati Losè L, et. al. Apple LiDAR Sensor for 3D Surveying - Tests and Results in the Cultural Heritage Domain. *Remote Sens,* 14(17):4157, 2022.

[2] Waqar, A., et. al. Complexities for adopting 3D laser scanners in the AEC industry - Structural equation modeling. *Applications in Engineering Science,* 16:100160, 2023

[3] Radujković, M., et al. Application of key performance indicators in South-Eastern European construction. *Journal of Civil Engineering and Management,* 16(4):521-530, 2011

[4] Chan, A.-P.-C., Chan, A.-P.-L. Key performance indicators for measuring construction success. *Benchmarking - An International Journal,* 11(2):203–221, 2004

[5] Gelbmann, U., et al., *Innovationsleitfaden: Der Weg zu neuen Produkten.* Graz: Eigenverlag, 2003

[6] Kühnapfel, J.-B., *Scoring und Nutzwertanalysen - Ein Leitfaden für die Praxis*. Wiesbaden: Springer Gabler, 2021

[7] Zardari, N. H., et. al., *Weighting Methods and their Effects on Multi-Criteria Decision Making Model Outcomes in Water Resources Management*. SpringerBriefs in Water Science and Technology, 2015

[8] Hudli, A., et al. An evaluation framework for selection of mobile app development platform. *Proceedings of the 3rd International Workshop on Mobile Development Lifecycle,* pages 13-16, 2015

[9] Catalan R. B., et. al. Evaluation of 3D Scanners to Develop Virtual Reality Applications. *Electronics, Robotics and Automotive Mechanics Conference,* pages 551-556, Cuernavaca, Mexico, 2007.

[10] Jang, A., et. al. Structural Stability Evaluation of Existing Buildings by Reverse Engineering with 3D Laser Scanner. *Remote Sens,* 14(10): 2325, 2022.

[11] Huy, N. P. and van Than, D. Selecting the right mobile app paradigms. *Fifth IEEE International Conference on Service-Oriented Computing and Applications,* pages 1-6, Taipei, Taiwan, 2012

[12] Jackson, M., et. al. Software evaluation: criteria-based assessment, *Software Sustainability Institute,* 2011.

[13] ISO 9241-110:2010-03, Ergonomics of human–system interaction, part 110: Dialogue principles

[14] Morville, P. Experience design unplugged. *Association for Computing Machinery SIGGRAPH 2005 Web program,* pages: 10-es, New York, USA, 2005.

[15] Zangemeister, C. *Nutzwertanalyse in der Systemtechnik - Eine Methodik zur multidimensionalen Bewertung und Auswahl von Projektalternativen*. 5., Hamburg: BoD – Books on Demand, 2014

[16] Di Stefano F. et. al. Mobile 3D scan LiDAR - a literature review. *Geomatics, Natural Hazards and Risk,* 12(1): 2387-2429, 2021

[17] GooglePlay-Magicplan. Online: https://play.google.com/store/apps/details?id=com.sensopia.magicplan&hl=de&gl=US, Accessed: 13/03/2024.