Decision Making in Manufacturing and Services
Vol. 17 • 2023 • pp. 33–46

Digital Photogrammetry and CAD/BIM Technology in Reconstruction of Computer Models for Concept of Virtual Factory

Olena Stryhunivska*

Abstract. This research article aims to check the feasibility of combining digital photogrammetry and CAD/BIM technology in an effort to develop a 3D digital model for the concept of Virtual Factory. The main objective of this research is the evaluation and continuous improvement of all of the relevant processes of creating spatial layout planning. During the research, a 3D floor plan of a laboratory was created to find matching common features for these methods. The article presents a comparative analysis of the time that is needed to create a spatial layout in which one can see exactly where each particular element is placed in the spatial arrangement of a point-to-point montage. On this ground, one of the key elements that determines the success of a design result is the effectiveness of the design process. Furthermore, the article indicates the scope of possibilities for using modern photogrammetric techniques for inventory building interiors and compare the speed of the measurement processing using PhotoModeler Scanner and ArchiCAD software.

Keywords: Virtual Factory (VF), facility planning, model VF, BIM technology, digital photogrammetry

Mathematics Subject Classification: 93B51

JEL Classification: O14

Submitted: June 24, 2023

Revised: December 31, 2023

1. INTRODUCTION

Dynamic changes in facility management incline us to make decisions about coherent and progressive development in accordance with its established objectives. The effectiveness of the measures depends on many factors, including creating a comprehensive vision, obtaining investment costs, and analyzing market forecasts. In addition, the

* AGH University of Krakow, Faculty of Management, Krakow, Poland, e-mail: olestr@agh.edu.pl

DOI: https://doi.org/10.7494/dmms.2023.17.5992

main prerequisite for success is reducing the time that is required for implementating innovative solutions (e.g., the relocation of various machines or re-planning for the modernization and improvement of a factory). The consequence of decision-making is the need for a rationally located space with a functional and safe layout as well as the design of a plant and its technical equipment. However, the effectiveness of building-surface management largely depends on the selected methods of spatial layout planning. This publication covers the subject of using layout-plan modeling for the reconstruction of objects – particularly when searching for the best solution that helps develop virtual models quickly and efficiently. This article also offers an overview of the possible methods for 3D modeling and spatial-data transfer into ArchiCAD, thus enabling designers to collect and handle planning rules and design data with ease. The description of the methods focuses on taking measurements using laser scanning and digital SLRs as well as their advantages, disadvantages, and limitations according to a documented building. The next part of the article includes a spatial-data transfer into BIM (building information modeling) software (Stryhunivska, 2019).

2. DATA-ACQUISITION AND COMPARISON OF MEASUREMENT TECHNIQUES

In order to perform a reconstruction of a computer model, photos of parts of a laboratory were taken. The data was processed into a 3D model using PhotoModeler Scanner. The software provides the loading of photos from a camera as well as the production of accurate measurements, diagrams, and models from those photos. In addition, all of the appropriate measures of the parts of the laboratory were carried out analogously by means of a laser scanner in order to import data into the ArchiCAD software. The combination of measurement methods for 3D modeling is shown in Figure 1 – based on Stryhunivska (2015).

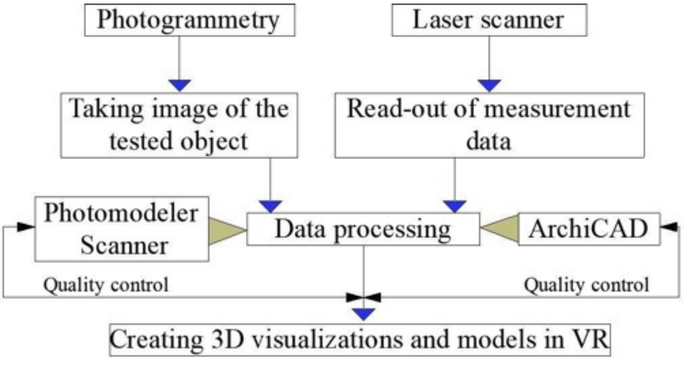

Fig. 1. *Combination of measurement methods for 3D modeling*

Data-flow management during layout creation allows for the exchange and systematization of information by using the same digital environment in which documents can be shared, verified, and updated. In this way, errors can be avoided during the project, and savings can be made by checking all of the stages of a project in advance (Guzzetti et al., 2020). However, the main factor is to compare the measurement speed and the processing of the input data; this allows us to manage the spatial-planning time.

2.1. Factors that affect measurements

Research has been carried out to check the influence of various factors on the results of room measurements. The experiment took the fact that the following elements were measured into account: the arrangement of the walls, doors, windows, and objects inside the room. Considering the influence of various factors on the performance of the measurements is an important element in making decisions in order to achieve the effectiveness and accuracy of the measurements. At the same time, one question arises: how will all of the factors that affect the measurements be verified? Taking these factors into account, they can be divided into two groups:

1) factors that are influenced by person performing measurements,
2) factors that are not influenced by person performing measurements.

Going back to the first group, the following factors can be included:

– performing or not performing check measurements,
– providing details on how compliance is to be measured and verified,
– taking measurements alone or with another person.

The second group includes the following factors (Stryhunivska, 2015):

– experience of person using measuring equipment devices,
– light (part of day – evening/morning), as measuring device reacts to daylight and artificial light,
– microclimate (hot/cold) – measurements can be carried out at different temperatures,
– fatigue at work (start/end of working day) – fatigue leads to slower measurement processes,
– mechanical vibrations and noise – in industrial facilities during working of technological equipment devices, shocks, specific vibrations, or noise may occur in the room (which make it impossible to carry out measurements),
– gaseous and particulate pollutants – particulate pollutants (crushing, grinding, cutting) and condensation (i.e., solidification or condensation of metal vapors make accurate measurements impossible).

2.2. Planning experiment: choice of factors

Based on an analysis of all of the possible modifiable factors, three factor were selected that were deemed to have the greatest impact on measurement speed. From the first group, the following factors were identified: performing or not performing check measurements, and the method of measurement (camera or laser scanner). From the second group, the following factor was selected: light (part of a day – evening/morning).

According to the experiment, the number of iterations should be equal to 2^3 (2^3 = 8 factor – level combinations). An important stage of the analysis is the plan of the experiment that is being tested with accurate measurement results in minutes and the full data package. As a result, diagrams are produced; thanks to this, one can carry out an analysis according to the experiment (Figures 2–4).

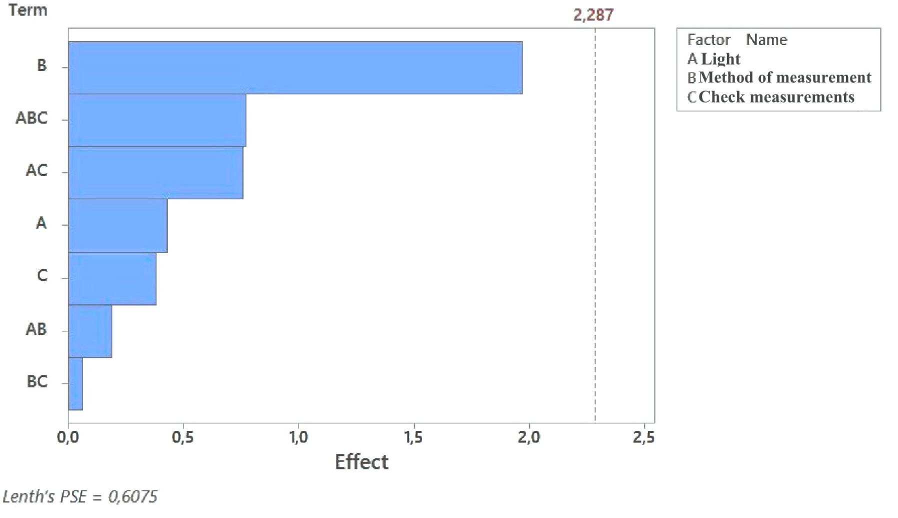

Fig. 2. *Pareto chart of effects: response in minutes;* α = 0.05

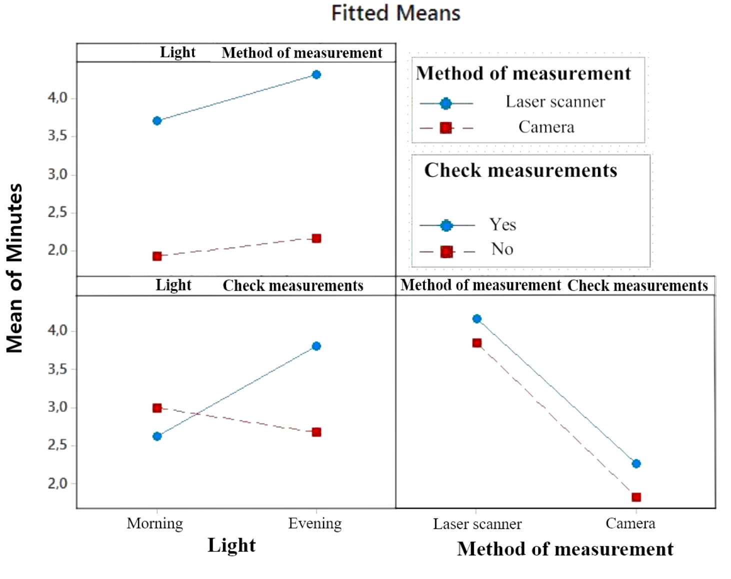

Fig. 3. *Interaction plot for minutes*

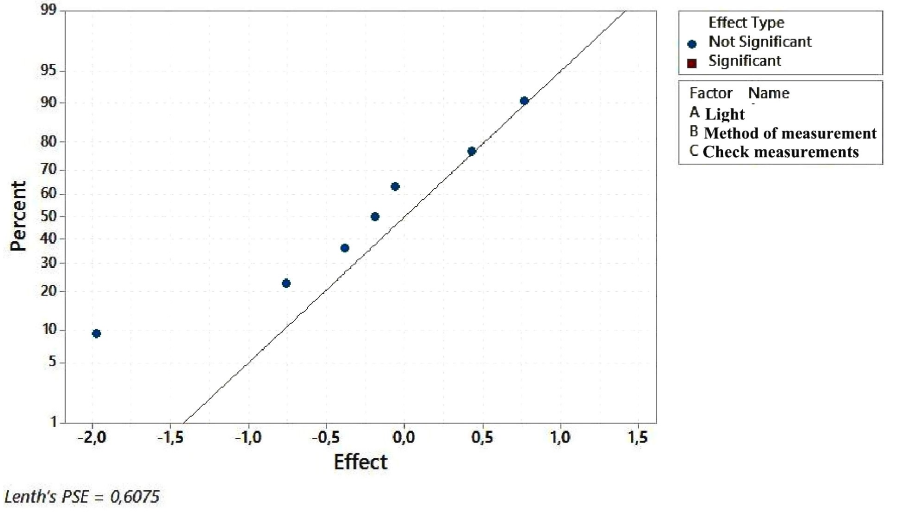

Fig. 4. *Normal plot of effects: response in minutes;* $\alpha = 0.05$

A Pareto chart that signifies the important factors was created. The chart displays which factor has the greatest impact on the results. The reference line for statistical significance depends on the significance level (denoted by α or alpha). As can be seen in Figure 2, Factor "B" (which is "method of measurement") is potentially important. Factor "C" ("check measurements") is another factor that needs to be considered. These factors are statistically significant at a 0.05 level with the current model terms. The Lenth's PSE (pseudo-standard error) indicator that is displayed in the chart is based on rare insignificant errors. In this experiment, Lenth's PSE was equal to 0.6075 (Figure 2).

The "interaction plot" chart (Figure 3) shows that an influential interaction can be observed between two factors: "method of measurement" and "check measurements" (however, this did not have a key impact on the results), while the remaining interactions were characterized by low levels of importance.

The next "normal plot of the effects" chart (Figure 4) demonstrates that the most important factor that affected the measurement speed was the "method of measurement" factor. The "Normal plot of the effects" chart displays the positive effects on the right-hand side of the chart and the negative ones on the left-hand side. The more a point is away from the normal plot, the more it affects the main effect. In the chart, the "method of measurement" factor is much further away from the chart line than the other factors; this ensures that the measurements using a laser or camera have the greatest impact on the results. Considering the outcomes, it was concluded that the "method of measurement" factor was distinguished and affected the measurement result.

The next "main effects" chart (Figure 5) presents the fact that the greatest angle to the y-axis of the chart characterizes the "method of measurement" factor. This is the most significant factor that confirms the conclusions that were drawn from the previous charts. The other two factors ("light," and "check measurements") were of little importance; however, they can be meaningful in the interactions. The "main effects" chart shows that the "check measurements" factor had a greater effect on the results than the "light" factor did. Due to the "main effects" chart, it can be emphasized that the best combination of factors that guaranteed an impact on the speed of the measurements was the combination with a camera without a check measurement. All of the charts displayed the greatest impact of the "method of measurement" factor on the measurement efficiency. The shortest time for obtaining the measurement data had a measurement factor using a camera in the morning without a check measurement. Comparing the charts with the outcomes of the experiment, it can be concluded that the result of the factor that obtained the fastest data was 1.57 minutes (Table 1). Based on knowledge and experience, it can be observed that cameras take worse photos in the evening. Furthermore, it can be assumed that the "method of measurement" and "light" factors are very dependent on each other; from this data set, however, it can be acknowledged that they did not make that a relationship.

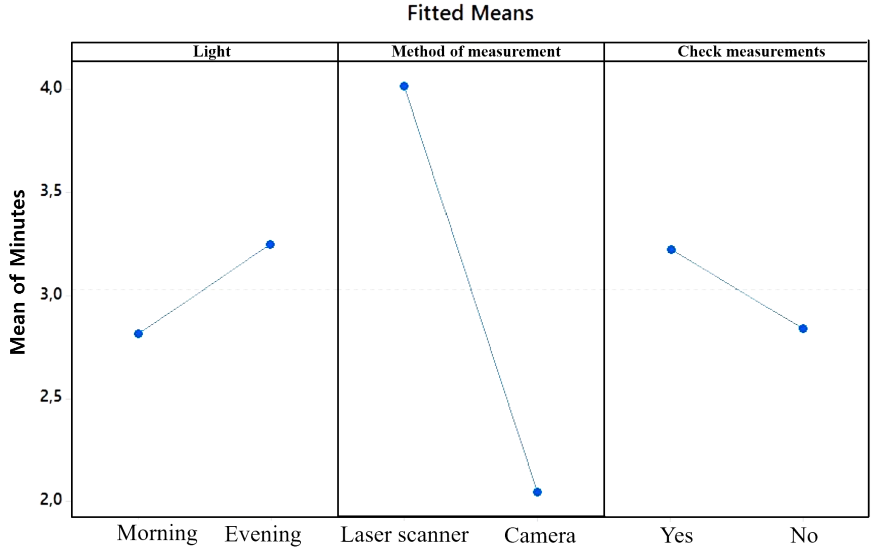

Fig. 5. *Main effects plot for minutes*

In the cases of advanced experiments with large numbers of factors on many factor-level combinations, those effects that affect measurements can be distinguished. The "method of measurement" factor (the measurements that were taken using the camera or laser scanner) contains information on the speed of measurement. The advantage of this is a feasibility to create 3D models directly on-site after taking measurements with a laser. Photos can be taken faster with a camera (1.57 minutes) — in this research, a Canon EOS 100D camera was used; however, the editing required more time (Table 1). The point is to download photos to a computer and edit them with the assistance of the PhotoModeler Scanner software.

Table 1. *Advantages and disadvantages of group decision-making: analysis of results that affect creation of 3D models*

Light	**Method of measurement**	**Check measurements**	**Measurement results [min]**	**Measurement time [min]**	**Time of creation of 3D models – Photo-Modeler Scanner [min]**	**Time of creation of 3D models 3D – ArchiCAD [min]**
Evening	Laser scanner	Yes	23.55	23.6	–	143.6
Evening	Laser scanner	No	11.47	11.5	–	131.5
Morning	Laser scanner	No	9.3	9.3	–	129.3
Evening	Camera	Yes	4.41	37.9	44.4	–
Morning	Laser scanner	Yes	18.32	18.3	–	138.3
Morning	Camera	Yes	3.11	36.6	43.1	–
Evening	Camera	No	2.38	35.9	42.4	–
Morning	Camera	No	1.57	35.1	41.6	–
Average time for camera				36.4	42.9	–
Average time for laser scanner				15.68	–	135.7

Importing photos to PhotoModeler Scanner takes about one minute. The next stage includes determining the dimensions of a room of a part of a laboratory and determining the control dimension (this takes about 1.25 minutes) in order to scale the object. It can be observed that obtaining measurements using a laser equals the time that is required to measure a room. The average time to obtain measurements using a laser is 15.7 minutes. However, the average time to obtain measurements using a camera is 36.4 minutes after taking the editing of the photographs into account. The average time to create 3D models with PhotoModeler Scanner is 42.9 minutes, whereas the average time for creating 3D models with ArchiCAD is 135.7 minutes. It should be taken into account that the time for obtaining laser measurements is 2.3-times shorter than the time for obtaining camera measurements. Furthermore, the time for creating 3D models with PhotoModeler Scanner is 3.2-times shorter than the time for creating 3D models with ArchiCAD. It is also noteworthy that the advantage of photogrammetric measurements is the rapid acquisition of real information in the form of photos (from which any information that is required at a later time can be received) (Stryhunivska, 2015).

3. CREATING VIRTUAL MODEL

Creating a virtual model requires solid knowledge from the participating designers; therefore, using a tool as powerful as BIM may be too difficult for most. It can be noticed that Graphisoft's ArchiCAD first implemented BIM under the virtual building concept (Sacks, 2013). Consequently, the transition to BIM does not require considerable effort for those designers who use ArchiCAD, as BIM implementation has been included. On the other hand, designers who have experience in designing are able to obtain the best performance from using BIM. To resolve the important barriers that are related to integrated work in design, the required competencies to use BIM should be clearly specified (Siebelink et al., 2021).

The exchange of models and input data between different software platforms is important for integrated and collaborative project teams. Designers are currently exchanging models with 3D-drawing packages and then exchanging models with computer design (CAD) applications (Pezeshki & Ivari, 2016). In a BIM design process, there are items of information that are assigned to the building elements in a BIM model that make up the whole project (2D or 3D geometric) and there are interactions among the elements (Dall'O' et al., 2020). In fact, all of the information that characterizes an object or a certain material is associated to the following (Daniotti et al., 2020):

- geometrical characteristics,
- performance of functional characteristics,
- typological characteristics,
- procedural characteristics,
- descriptive characteristics.

The second approach is based on loading a point cloud directly into the BIM software. This software supports the majority of basic point cloud data formats, and point clouds can be imported into the software; then, it can create a 3D model in the desired format using BIM software instruments. This approach can be effectively used to solve the problem of data transfer, and the level of detail in model-creation can be selected directly according to the needs of the BIM designer. The original point cloud is still easily available to a designer for editing (Faltýnová et al., 2016). With the PhotoModeler Scanner software, the scanning process produces a dense point cloud (dense surface modeling – DSM) from photographs. Based on photos of virtually any sizes, it can produce a scale-independent object modeling.

Data processing to create a computer model was carried out using ArchiCAD and PhotoModeler Scanner. The model-creation structure had an impact on the final result. The advantage of ArchiCAD is the possibility of making the model easier to design. The 3D computer model can be used to give dimensions to 3D elements, the repetitive calculations of objects, and shape properties due to the intelligence that is contained in the model (Dadi et al., 2014). In addition, it provides the possibility to create both external and internal layouts. In contrast, PhotoModeler Scanner only allows for applying a texture on the walls, but the thickness of a window cannot be verified (for example). Consequently, there is a fundamental difference between these models; however, the dimensions of parts of the laboratory are the same. Due to the further analysis of the model in PhotoModeler Scanner (Figure 6), it could be observed that, after creating the model, the next step was to apply the texture of the photo.

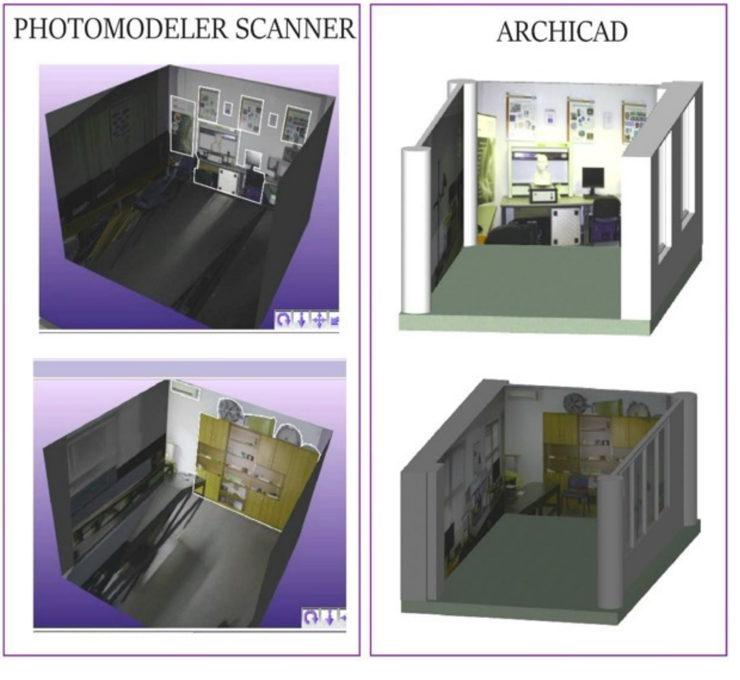

Fig. 6. *Comparisons of 3D visualization models – based on Stryhunivska (2015)*

Therefore, the quality of the model is affected by the texture (in this case, they were photos). If a photo was taken in the evening, the texture on the surface of the room looked dark; this affected the quality of the visualization.

If the speed of the model creation and the reproduction of all of the elements that are in a room are considered, PhotoModeler Scanner dominates in this case. In this study, it was necessary to divide the room into two parts and create two models of the right- and left-hand sides of the room in order to create a whole room model, as the camera was unable to take a picture of the whole area. However, this method did not significantly affect the speed of the model creation when compared to ArchiCAD. After analyzing the final models, it can be concluded that the model's appearance, visualization quality, speed, and accuracy differed significantly (Figure 7).

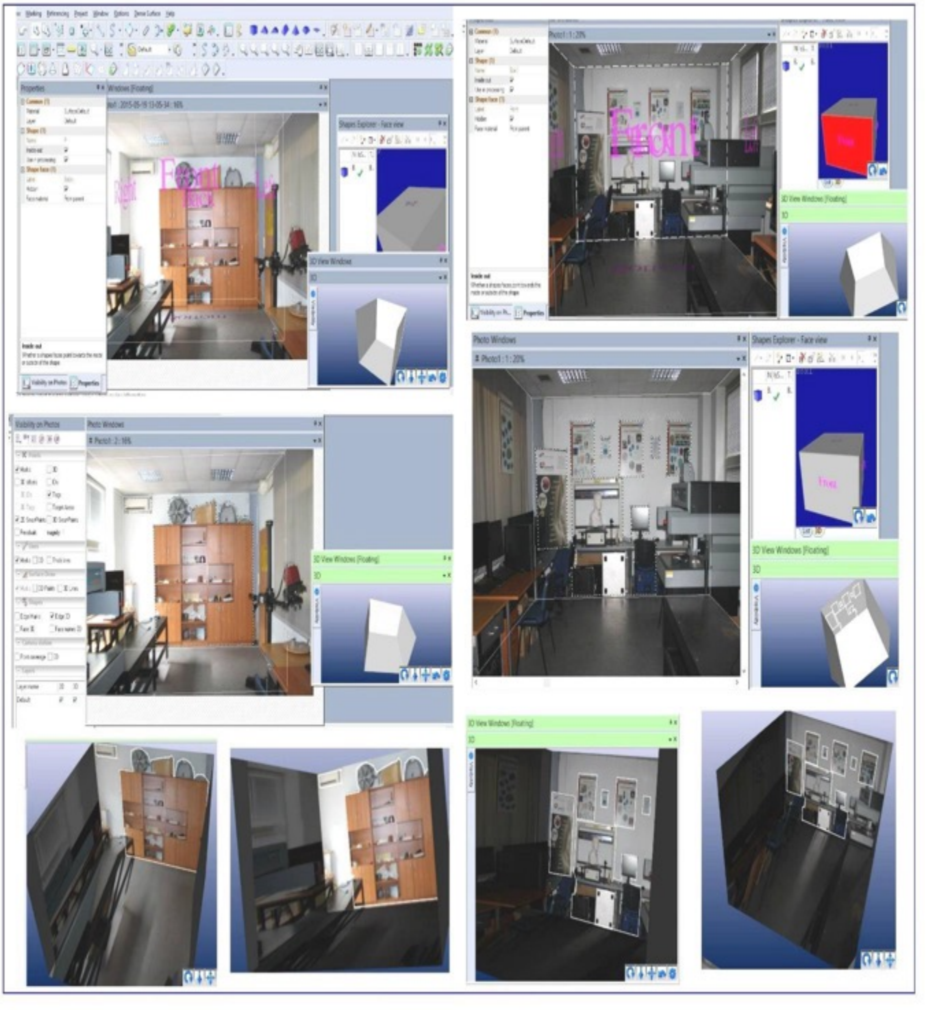

Fig. 7. *Comparisons of 3D visualization models – based on Stryhunivska (2015)*

Last, ArchiCAD software was used for real-time rendering in order to create a virtual reality. It should be emphasized that a visualization between users and objects in virtual reality certainly takes place using interaction metaphor techniques. Each 3D object that is stored in a room has its own characteristics (size, shape, color, etc.) (Nugraha Bahar et al., 2014).

The advantages and disadvantages of the discussed software are indicated. The key goal is to determine the effective measurement method for converting measurement data into a digital 3D model. A detailed a summary of the pros and cons can be seen in Table 2.

Table 2. *Advantages and disadvantages of group decision-making*

ArchiCAD		**Photomodeler Scanner**	
Advantages	Disadvantages	Advantages	Disadvantages
Detailed 3D model, Standard Parts Library 3D,	Measurement time is longer than when taking photos	Measurement time using camera is shorter	Lack of 3D-parts inside
Creating 2D and 3D model at same time	More time to create 2D model	Exact 3D model using texture	Long rooms require taking many photos and composing them
Software generates high-quality CAD 2D and 3D models	3D element library limited	Photorealistic concept of project	Visualization quality depends on photo quality
Creating internal and external visualization of room at same time	More time to master basic scope of knowledge of software	Less time to master basic scope of knowledge of software	Internal or external visualizations of room depend on appropriate photos
CAD 2D and 3D models are used to compile technical files	Expensive software	Cheaper software	Photos are basis for visualization, not for compilation of technical files
It is easy to change layout of room	3D graphics card and more RAM are required	Graphics card with good 2D rendering capabilities is recommended	New photos are needed to change layout of room

Depending on the design method that is chosen, the exchange of information affects the quality of the communication, product quality, and delivery time. BIM defines building-information modeling, not an object. Information modeling involves creating a virtual representation of a room. The BIM model consists of intelligent objects and verifies their locations. In particular, the assigned parameters specify their geometry, locations in space, relationships with other objects, and other specific features (Ustinovichius et al., 2018).

4. DISCUSSION

The research article highlights the merging of digital photogrammetry and CAD/BIM technology to construct a 3D digital model for the concept of a virtual factory, with a primary focus on evaluating and enhancing those processes that are related to spatial-layout planning. The study's key objective was to assess and refine the efficiency of spatial-layout planning through the integration of these technologies. One of the pivotal aspects of the research involved generating a 3D floor plan of a laboratory in order to identify commonalities between the digital photogrammetry and CAD/BIM technology. Through a comparative analysis, the study examined the time that was required for creating spatial layouts, underscoring the significance of efficiency in the design process. Additionally, the article explored the potential of contemporary photogrammetric techniques for inventorying building interiors and compared the processing speed of the measurements that used PhotoModeler Scanner and ArchiCAD software. The findings of the research underscored the substantial influence of the design process's effectiveness on the overall success of the design outcome. Moreover, the study identified various factors (including measurement methods and environmental conditions) that affected the speed and accuracy of the measurements. Notably, factors such as performing check measurements and choosing between camera and laser-scanner methods were recognized as significantly impacting measurement speed. Furthermore, the study discussed the strengths and weaknesses of different software tools like ArchiCAD and PhotoModeler Scanner for constructing 3D models, highlighting the pivotal role of BIM technology in generating virtual representations of rooms that encompass intelligent objects and parameters. The study contributes significantly to understanding how different measurement methods influence the efficiency and performance of spatial layout design. Through empirical experiments and result analysis, the research provides valuable insights into optimizing the design process for creating 3D models within the framework of the Virtual Factory concept.

Further research developments hold significant potential. There are plans to integrate these design methods with Archicad AI Visualizer, which augments details, context, and ideas to an original concept by generating design alternatives during the early design phase. This integration is poised to revolutionize the early design phase by leveraging the capabilities of AI in order to generate an array of refined design variations seamlessly and efficiently. By utilizing text prompts, Visualizer can produce a diverse range of design alternatives without necessitating the manual creation of multiple intricate models. The envisioned combination of design methods with Archicad AI Visualizer holds substantial potential for enhancing design exploration and decision-making in the Virtual Factory context. This planned integration signifies a continued effort toward enhancing the capabilities and applicability of these technologies in advancing spatial-layout planning and design processes.

5. CONCLUSION

Combining measurement methods in order to obtain a high-quality 3D model is increasingly being used. Laser-scanning and photogrammetric methods have been used and tested for designing parts of laboratories. The tests showed that both methods could be used when creating a layout (Stryhunivska, 2019). The use of a specific method is based on taking the project requirements and the speed of its implementation into account. This paper's primary contribution to the body of knowledge is identifying how different measurement methods influence the performance of created layouts. By conducting a cognitive task experiment, the performance and speed of creating a 3D.

REFERENCES

Dadi G.B., Goodrum P.M., Taylor T.R.B. & Maloney W.F. (2014). Effectiveness of communication of spatial engineering information through 3D CAD and 3D printed models. *Visualization in Engineering*, **2**(1), art. no. 9. DOI: 10.1186/s40327-014-0009-8.

Dall'O' G., Zichi A. & Torri M. (2020). Green BIM and CIM: Sustainable Planning Using Building Information Modelling. In: G. Dall'O' (Ed.), *Green Planning for Cities and Communities: Novel Incisive Approaches to Sustainability.* Springer International Publishing, pp. 383–409. DOI: 10.1007/978-3-030-41072-8_17.

Daniotti B., Pavan A., Lupica S.S., Caffi V., Pasini D. & Mirarchi C. (2020). Standardized Guidelines for the Creation of BIM Objects. In: *BIM-Based Collaborative Building Process Management.* Springer International Publishing, pp. 39–70. DOI: 10.1007/978-3-030-32889-4_3.

Faltýnová M., Matoušková E., Šedina J. & Pavelka K. (2016). Building Facade DocumentatioN using Laser Scanning and Photogrammetry and Data Implementation into BIM. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, **XLI-B3**, pp. 215–220. DOI: 10.5194/isprs-archives-XLI-B3-215-2016.

Guzzetti F., Anyabolu K.L.N., D'Ambrosio L. & Marchetti Guerrini G. (2020). From Cloud to BIM Model of the Built Environment: The Digitized Process for Competitive Tender, Project, Construction and Management. In: B. Daniotti, M. Gianinetto & S. Della Torre (Eds.), *Digital Transformation of the Design, Construction and Management Processes of the Built Environment.* Springer International Publishing, pp. 17–26. DOI: 10.1007/978-3-030-33570-0_2.

Nugraha Bahar Y., Landrieu J., Pére C. & Nicolle C. (2014). CAD data workflow toward the thermal simulation and visualization in virtual reality. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, **8**(4), pp. 283–292. DOI: 10.1007/s12008-013-0200-5.

Pezeshki Z. & Ivari S.A.S. (2016). Applications of BIM: A Brief Review and Future Outline. *Archives of Computational Methods in Engineering*, **25**, pp. 273–312.

Sacks R. (2013). Modern Construction: Lean Project Delivery and Integrated Practices. *Construction Management and Economics*, **31**, pp. 394–396.

Siebelink S., Voordijk H., Endedijk M. & Adriaanse A. (2021). Understanding barriers to BIM implementation: Their impact across organizational levels in relation to BIM maturity. *Frontiers of Engineering Management*, **8**(2), pp. 236–257. DOI: 10.1007/s42524-019-0088-2.

Stryhunivska O. (2015). *Digital photogrammetry in the reconstruction of computer models for the concept of the Virtual Factory* [Master's thesis, Wroclaw University of Technology].

Stryhunivska O. (2019). *Integration of 3D visualization with methods of designing of manufacturing processes* [Doctoral dissertation, AGH University of Science and Technology].

Ustinovichius L., Popov V., Cepurnaite J., Vilutienė T., Samofalov M. & Miedziałowski C. (2018). BIM-based process management model for building design and refurbishment. *Archives of Civil and Mechanical Engineering*, **18**(4), pp. 1136–1149. DOI: 10.1016/j.acme.2018.02.004.