BULLETIN OF THE POLISH ACADEMY OF SCIENCES
TECHNICAL SCIENCES, Vol. 71(1), 2023, Article number: e144453
DOI: 10.24425/bpasts.2023.144453

CIVIL ENGINEERING

Photogrammetry-based approach for collecting and processing information about an existing building

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Abstract. Due to the organization of construction works, one of the most difficult situations is when a building is planned in a heritage or a densely built-up location. Fixing an existing situation manually takes a lot of time and effort and is usually not accurate. For example, it is not always possible to measure the exact spacing between buildings at different levels and to consider all outside elements of an existing building. Improper fixation of the existing situation causes mistakes and collisions in design and the use of inappropriate construction solutions. The development and progress in technologies such as BIM, laser scanning, and photogrammetry broaden the options for supporting the management of construction projects. It is important to have an effective fast collection and processing of useful information for management processes. The purpose of this paper is to analyze and present some aspects of photogrammetry to collect and process information about existing buildings. The methodology of the study is based on the comparison of two alternative approaches, namely photogrammetry and BIM modelling. Case studies present an analysis of the quantity take-offs for selected elements and parts of the buildings based on the two approaches. In this article, the specific use of photogrammetry shows that the error between the detailed BIM model and the photogrammetry model is only 1.02% and the accuracy is 98.98%. Moreover, physical capabilities do not always allow us to measure every desired element in reality. This is followed by a discussion on the usability of photogrammetry.

Key words: photogrammetry; building information modelling; building model development; quantity take-off; construction works; information processing.

1. INTRODUCTION

In recent years, the construction industry has faced the rapid development of various technologies that are expected to support processes in construction projects. Some of these technologies are building information modelling (BIM), laser scanning, photogrammetry, and the use of unmanned aerial vehicles (UAV), which may be specifically used for the development, collection, and processing of information about the terrain, buildings, and its surroundings. Information about an existing building is, in particular, needed for projects that include renovation or demolition works or simply for inventory. The technologies mentioned above may be used instead of traditional inventory work. Their implementation in various aspects of the development, collection, and processing of information is widely discussed in the literature.

BIM is a technology that empowers and supports digitization and automation of the architecture, engineering, and construction (AEC) industry and construction projects. BIM specifically aids in optimizing time, cost, and quality management processes in the design and construction stages of a project. In the occupational phase, it supports facility management [1]. The BIM model is assumed to serve as a source of information about the building throughout its lifecycle. The benefits of BIM use are presented in the literature; however, they may be difficult to achieve if appropriate actions focused on minimizing BIM implementation barriers are not taken [2]. Thus, BIM technology facilitates planning, effective control, and monitoring of construction project implementation, contributing to the successful execution of the project [3]. BIM may also be used for the management of existing facilities – especially the scan-to-BIM approach, which covers surveying, modelling, and implementation is applicable in this field [4].

The development of models for existing buildings may be based on laser scanning or photogrammetry which provides cloud points as a basis for further modelling and facilitates obtaining digital models [5]. Laser scanning has been used since the 1980s and its most common applications are various geodetic measurements. Today, it is considered a modern and fast method of obtaining information on object geometry [6, 7]. As a measurement method, it relies on the transfer of the real shape of a three-dimensional object to a digital form. In architecture and construction, it is used for buildings, facilities, and engineering structures that require monitoring or do not have up-to-date technical documentation (e.g., [8, 9]) or for historic buildings where the shape, geometry, and number of architectural details make traditional methods measurements especially ineffective (e.g., [10, 11]). The use of laser scanning allows us

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Manuscript submitted 2022-08-07, revised 2022-11-15, initially accepted for publication 2022-12-24, published in February 2023.

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to reach places that are hardly accessible even without light. The limitations of the method are mainly due to the geometry of the scanner-object system (ground, aerial, and mobile scanning) [12]. To evaluate the performance of the technology for 3D BIM modelling, the identified key factors are [13]: scanner performance expectancy, effort expectancy, organization self-efficacy, and user efficacy. According to some research [14], reverse engineering with 3D laser scanning and also photogrammetry survey processes is becoming a standard procedure.

The monitoring of structural deformations has always been an interesting research area in engineering architecture. Research into structural deformation monitoring is the most important way to reduce the risk of engineering construction. Recently, photogrammetry has been used in the monitoring of displacements and deformations of buildings and infrastructure. The change in the inclination of the building is calculated by the relative horizontal displacement and height change. Therefore, accuracy is determined by changes in the tilt of the building based on the photogrammetry of unmanned aerial vehicles [15]. Thanks to the scan, coordinates can be obtained for almost all points on the scannable surface and detailed information on the size of the object [16]. A systematic procedure to evaluate the stability of structural damage in historic buildings also used digital photography as a measurement technique, measurement parameters of the shape of the damage, and bootstrap tests to obtain reliability measurements [17]. In addition, photogrammetry equipment is certainly cheaper than typical terrain instruments used for engineering investigations, such as other methods for deformation measurements in roads, tunnels, and bridges to overcome some drawbacks of the state-of-the-art techniques. In fact, time is an important limiting constraint when operating in situations where it is necessary to stop traffic in regular cars or trains [18–20].

Photogrammetry allows us to determine the shapes, sizes, and positions of objects in space on the basis of a series of photos. The method relies on photos taken with the use of digital cameras (classified as non-metric cameras) or metric cameras designed specifically for photogrammetric surveys. Some authors [21] noted that the use of cameras for data acquisition results in lower geometric accuracy compared to laser scanning. On the other hand, the advantage is that the cameras can be used more flexibly and their costs are much lower. In terms of construction projects, photogrammetry can be applied in each state of the engineering workflow: design, construction, and maintenance [22]. In the initial stages of project planning, photogrammetry (most often with the use of UAV) may be used to measure large and topographically complex areas for the future construction site in high resolution. This approach is especially useful in road construction, rail construction, and complex earthworks [23].

Measurements are relevant not only in the construction sector. One example is the study of ancient forging devices. The first step in testing the accuracy of the findings is to model an old forge. Given that the literature did not provide plans or historical documentation of notes, direct measurements were taken, supported by photograms that gave the dimensions of all components of the complex structure [24].

The obtained orthophotos that fully reflect the actual conditions in the field may be a starting point for the design stage. In the construction stage, photogrammetry may help to follow and verify the progress of works on a construction site. Monitoring the progress of a construction project and checking dimensional compliance is essential to identify potential discrepancies between the planned and actual construction status of the project [25]. One of the works introduces an approach to monitoring the progress of construction works based on the comparison of a planned state of works derived from a BIM model to an as-built state represented by a photogrammetric point cloud [26]. In addition, other examples of the use of photogrammetry for the monitoring of construction works can be found [27–29]. The use of technologies such as photogrammetry or ground scanning that facilitate the perception and acquisition of information in real time is especially useful for large-scale projects [30]. The use of photogrammetry as a complementary technology for BIM and the benefits this combination brings are also discussed and presented for smaller projects [31]. The BIM protocols developed for these projects were reported to achieve a 20% reduction in costs per project and in working periods, leading to a productivity improvement that exceeds 27%.

When an occupational stage is analyzed, there are also some examples of photogrammetry applications for existing buildings discussed in the literature. Research conducted in Italy [32] reports the application of terrestrial and UAV photogrammetry for visual inspection of a standard concrete overpass. The results show a satisfactory identification and survey of deteriorated areas – photogrammetry made it possible to quantify metric information, such as the width and length of cracks and extension of weathered areas. Applications of photogrammetry also cover historic buildings, where the need for renovation and preservation work should maximize the potential benefits of the use of modern tools and technologies. The most common is architectural photogrammetry, which mainly focuses on geometric surveys [33, 34].

An interesting proposal for the use of photogrammetry in construction can be a problem in diagnosing the presence of alterations in buildings [35] – The authors' goal was to create an analysis approach, to detect damages in three-dimensional models providing more information on depth and volume.

Specialists in other fields are using similar photogrammetry methods. For example, one of the practical uses of scanning is to record the current situation of bridges. Low-cost RGB-D cameras and tablets were proposed to improve the inspection of the plane concrete surface. Surface measurement accuracy was extremely accurate, and regular infrastructure inspections are generally more satisfactory than naked-eye inspections. The proposed method also covers various types of defects, and the data are easily collected without significant changes to the bridge inspector routine [36]. And another use of scanning is during the analysis period, in which the scanning technique is proposed and performed as the first examination to determine the places for test holes. It is an excellent non-destructive solution that does not interfere with the historic building matter. The use of laser scanning can significantly facilitate the assessment of damage and the proposal of an appropriate restoration system. The accuracy of point clouds is sufficient to perform surface regularity checks. Therefore, the article presents a 3D scan to determine the deflection of the ceiling, the floor of which shows the elasticity recorded during the change in service load [37].

The purpose of the study was to present, analyze and discuss the usability of photogrammetry to collect and process information about existing buildings. The methodology of the study is based on the comparison of two alternative approaches, namely photogrammetry and BIM modelling. The analysis was based on several quantity take-offs of the selected exemplary building elements and parts. Specifically, it allowed one to assess the accuracy of the take-offs made on the basis of a photogrammetry model. The analysis is followed by a discussion of the usability and advantages and drawbacks of photogrammetry.

2. METHODOLOGY

The methodology of the study is based on the comparison of models developed for an existing building with the use of photogrammetry and BIM modelling. Models are supposed to serve as sources of information and quantity take-offs.

In the course of research, an existing building was selected. The selection criteria were based on the accessibility of the building (possibility of physical access to the building) and the possibility of making the necessary measurements. Then the study included the development of:

- A photogrammetric model based on photographs captured with the use of a UAV equipped with a camera.
- A BIM model based on real inventory measurements and parts of technical documentation, namely evacuation plans.

Both models served as a basis for quantity take-offs of selected exemplary elements and parts of the building, which were compared and discussed. The idea of the methodology is presented schematically in Fig. 1.

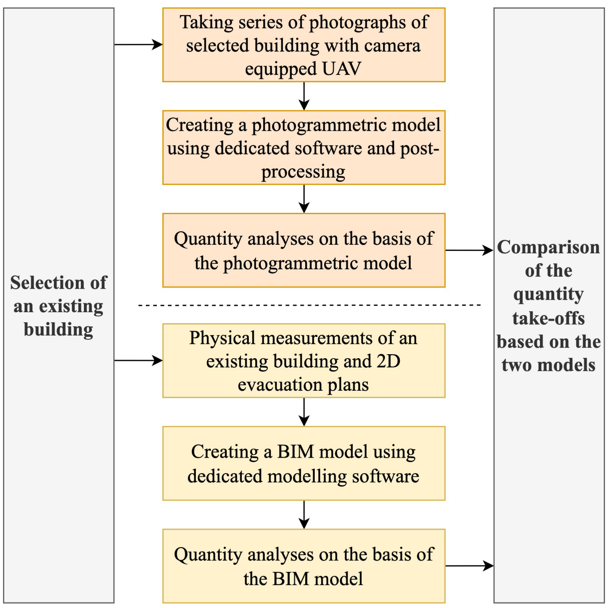

Fig. 1. Schematic of the analysis process (source: own study)

Analysis of obtained results and comparison for both models is followed by a discussion of the usability as well as the advantages and drawbacks of photogrammetry building models. It was decided to select the public building, Vilnius Gediminas Technical University, located in Vilnius, Lithuania, as the research case.

2.1. Development of a photogrammetry model

The first step of the creation of the photogrammetry model was taking a series of photographs of the chosen building. The photographs were taken with the use of a UAV equipped with a camera. Before the actual start of the capture of the building, the potential restrictions of UAV flights were investigated, and formal arrangements were made according to local procedures. A UAV task was planned to take into account the boundaries of the work area, the height of the flight along with the features of the terrain, the surrounding environment, and the objects located near the selected building.

In addition, the reference points, called benchmarks, were selected. These points made a kind of frame that is then used for optimization and equalization of the position of images in space while processing in photogrammetric software. They are marked around and inside the survey area according to the developed scheme. The benchmarks are presented in Fig. 2. It is important to note that the points of the photogrammetric network (photo points), which are selected, must be very visible in the photogrammetry model and on the map from which real coordinates are determined. The number of points can be different, but the more points there are, the more accurate the model will be.

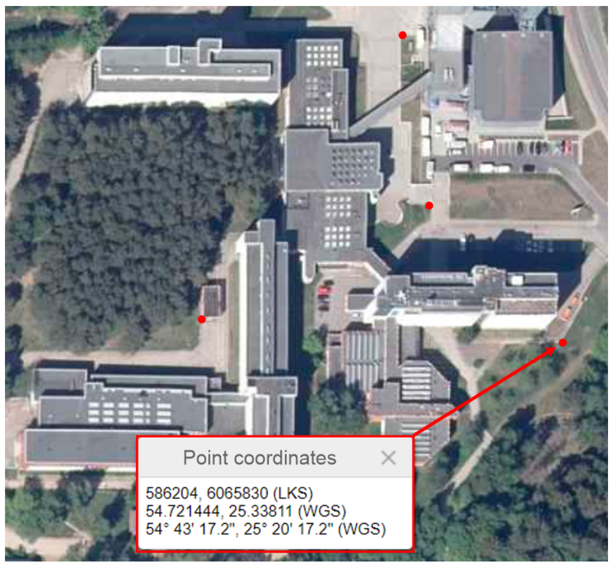

Fig. 2. Points of the photogrammetric network to capture photos of a building (source: own study, map source: www.maps.lt)

Given that the photogrammetric model is made of the exterior of the building and not of the interior of the building, it is not necessary to determine the coordinates using geodetic devices. Consequently, in this case, there is no need to determine the location in space.

Coordinates can be determined in different coordinate systems. In this case, the Lithuanian National Coordinate System (LKS) was used. However, the World Geodetic System (WGS) or others may also be used.

In the phase of capturing the building, the photographs were taken during good and stable weather. Based on the collection of photographs, a photogrammetry model was created using the specialized software, *Bentley Context Capture* (Fig. 3). The model was reviewed with dedicated photogrammetric software; consequently, an accurate and realistic model was created. Figure 4 presents the developed photogrammetry model.

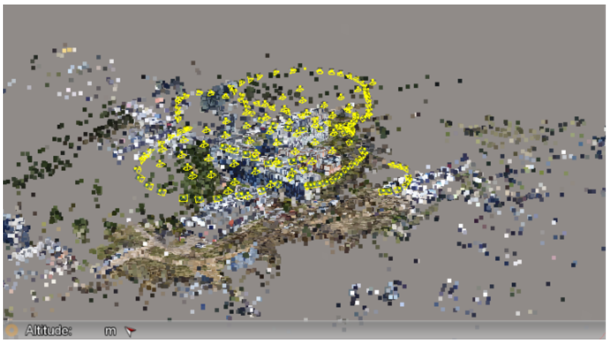

Fig. 3. Creation of a photogrammetry model in Bentley Context Capture software (source: own study)

Fig. 4. Developed photogrammetry model of the building (source: own study)

It should be noted that in this particular case the 3D photogrammetry model of the building presents its geometry, shape, and feature as seen from the outside. According to the linked coordinates, it was possible to start quantity take-offs for the external parts of the building.

2.2. Development of the BIM model

For the selected building, the BIM model was built on the basis of the evacuation plan, presented in Fig. 5, and the direct measurements made inside and outside the building. Evacuation plans that correspond to fire protection requirements are easily available for public buildings and may be a good starting point for BIM modelling.

For the modelling process, it was necessary to consider the structural parts of the building. The particular building was

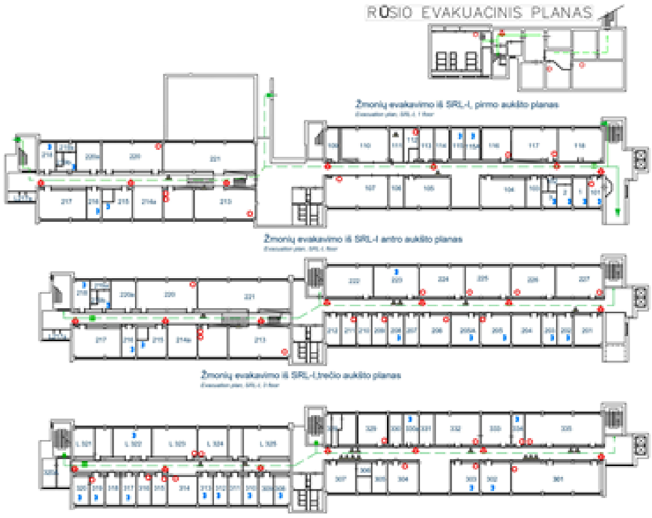

Fig. 5. Building 2D evacuation plans (source: own study)

erected with the use of a number of pre-fabricated elements of standard dimensions. Therefore, the measures taken for the building could be investigated and corrected based on the knowledge of the prefabricated elements and their characteristics that were in use at the time of building construction. Consequently, it allowed one to minimize the inaccuracy of model dimensions which were inevitable due to renovations, changes in finishing, rearrangements, etc. The actual modelling process was completed with the use of BIM software. As a result, the exterior and interior model of the building was obtained. The model is presented in Fig. 6.

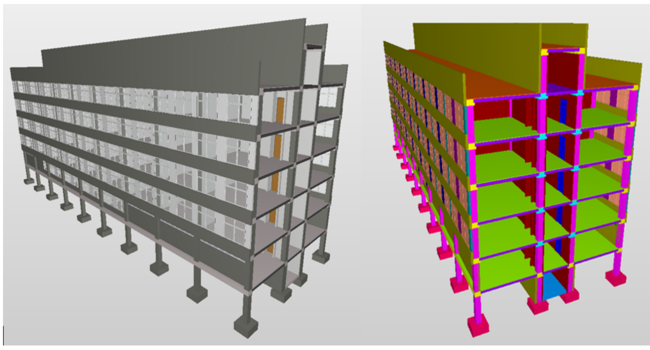

Fig. 6. Developed BIM model of the building (source: own study)

2.3. Quantity analyses based on the developed models

In the next step, the photogrammetry model was analyzed to check what kind of take-off-related information can be read from the model. The BIM model was also compared to investigate the availability of information and verify the accuracy of the photogrammetry model.

As mentioned above, the photogrammetry model does not contain any information on the elements or structures that are not visible from the outside. Therefore, this model may be used as a basis for take-offs of external elements such as façades, roofing, windows, and inserts between windows as well as other elements that are visible from the outside. Elements that may be measured on the basis of the photogrammetry model, along with the available information, are presented synthetically in Table 1.

Table 1

Elements available for the take-off process on the basis of the developed photogrammetry model (source: own study)

Element	Geometric information available
roof	length, width, surface
façade	length, height, surface
windows	length, height, surface, number of elements
inserts between windows	length, height, surface, number of elements

On the other hand, BIM provides the possibility to take off quantities of external and internal elements of a building. In addition, information about the thickness of the elements is also available. The elements along with the information available that can be extracted from the BIM model are listed in Table 2.

Table 2

Elements available for the take-off process on the basis of the developed BIM model (source: own study)

Element	Geometric information available
beams	length, width, height, volume, side surfaces
columns	length, width, height, volume, side surfaces
slabs	length, width, height, volume, surface
walls	length, width, height, volume, surface
openings	length, width, height, surface
roof	length, width, height, surface
façade	length, width, height, surface
windows	length, height, area, number of elements
inserts between windows	length, height, area, number of elements

In the next step, take-offs were prepared on the basis of elements available in the case of both models. As the BIM model was developed with the use of actual physical measures, it provides accurate take-offs of the elements. As such, it was used as a reference for the analysis of the accuracy of take-offs made on the basis of the photogrammetry model. The details are presented in the next section of the paper.

3. RESULTS

The take-offs obtained from the photogrammetry model revealed some inconsistencies and deviations when compared to the actual measures and the BIM-model. For further analyses, certain measures were assumed:

- pe_i – percentage error of the take-off i-th element,
- ac_i – percentage accuracy of the take-off i-th element,
- pe_{avg} – average percentage error for the take-offs of similar elements,
- ac_{avg} – average percentage error for the take-offs of similar elements.

Equations for calculations of the above measures are given below:

$$pe_i = \left| \frac{me_i - mr_i}{mr_i} \right| \cdot 100\%, \tag{1}$$

$$pe_i = \left| \frac{me_i - mr_i}{mr_i} \right| \cdot 100\%, \tag{2}$$

$$pe_{\text{avg}} = \frac{1}{n} \sum_i pe_i\,, \tag{3}$$

$$ac_{\text{avg}} = \frac{1}{n} \sum_i ac_i\,. \tag{4}$$

where:

- me_i – take-off of an i-th element made on the basis of a photogrammetry model,
- mr_i – reference take-off of an i-th element,
- n – number of take-offs for similar elements.

In Figs. 7 and 8, we can see a comparison of the way windows (as an example of elements of a relatively small building) are represented in the photogrammetry model and the BIM model.

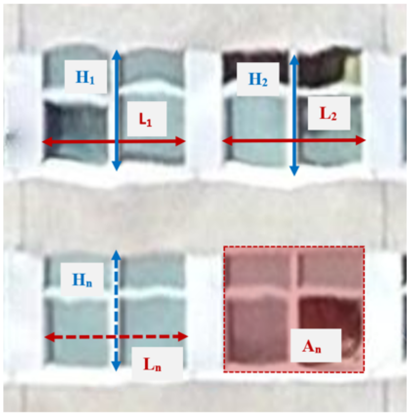

Fig. 7. Windows take-offs based on the photogrammetry model (source: own study)

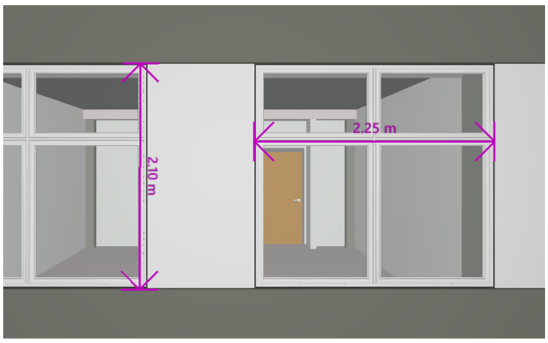

Fig. 8. Windows take-offs on the basis of the BIM model (source: own study)

The actual dimensions, which are also available from the BIM model of the standard window, are 2.10 m high and 2.25 m wide; consequently, the surface of the standard window is 4.728 m^2 – these values were taken as references. The inaccuracies of the take-offs based on the photogrammetry model (when compared to the known dimensions) that occur during the measurement process are set together in Tables 3 and 4.

Table 3
Accuracy of linear take-offs based on photogrammetry model for windows (source: own study)

i-th element	Length (L)			Height (H)		
	me_i [m]	pe_i	ac_i	me_i [m]	pe_i	ac_i
1	2.28	1.33%	98.67%	2.08	0.95%	99.05%
2	2.26	0.44%	99.56%	1.96	6.67%	93.33%
3	2.27	0.89%	99.11%	2.07	1.43%	98.57%
4	2.26	0.44%	99.56%	2.08	0.95%	99.05%
5	2.29	1.78%	98.22%	2.08	0.95%	99.05%
6	2.30	2.22%	97.78%	2.15	2.38%	97.62%
7	2.23	0.89%	99.11%	2.10	0.00%	100.00%
8	2.29	1.78%	98.22%	2.11	0.48%	99.52%
9	2.28	1.33%	98.67%	2.09	0.48%	99.52%
10	2.21	1.78%	98.22%	2.06	1.90%	98.10%

Table 4
Accuracy of surface take-offs based on photogrammetry model for windows (source: own study)

i-th element	Surface (A)		
	me_i [m]	pe_i	ac_i
1	4.74	0.32%	99.68%
2	4.43	6.24%	93.76%
3	4.70	0.53%	99.47%
4	4.70	0.53%	99.47%
5	4.76	0.74%	99.26%
6	4.95	4.76%	95.24%
7	4.68	0.95%	99.05%
8	4.83	2.22%	97.78%
9	4.77	0.95%	99.05%
10	4.55	3.70%	96.30%

The calculated average values of errors and accuracy in terms of windows are as follows: for length take-offs: $pe_{\text{avg}} = 1.29\%$, $ac_{\text{avg}} = 98.71\%$; for height take-offs: $pe_{\text{avg}} = 1.62\%$, $ac_{\text{avg}} = 98.38\%$; for surface take-offs: $pe_{\text{avg}} = 2.10\%$, $ac_{\text{avg}} = 97.90\%$.

When analyzing the values of the errors, as presented in Tables 3 and 4, one can see that most of them are relatively small. It is evident that the take-offs for element no. 2 diverge from the rest.

In Fig. 9 we can see the places where the linear lifts for the roof and façade of the building (as relatively large elements of the building) were made. The take-offs have been analyzed in a similar way as above – the reflex take-offs were taken from the BIM-model.

Fig. 9. Linear take-offs of the roof and façade on the basis of the photogrammetry model (source: own study)

The percentage errors and percentage accuracies of the take-offs are set together in Table 5. The calculated average values for the linear take-offs presented in Table 5 are $pe_{\text{avg}} = 1.29\%$, $ac_{\text{avg}} = 98.71\%$.

Similarly, as in the case of take-offs made for small elements, the errors are relatively small. The average accuracy is almost 99%. However, it must be noted that in the case of straight calculated differences between me_i and mr_i values, e.g., for the take-off no. 1 the accuracy may be disputable. In this exemplary case, the reason for the error may be caused by the way the ground level is modelled. If the relief near the building is not flat, it may be difficult to determine the correct level without precise geodetic measurements.

Table 5
Accuracy of linear take-offs based on photogrammetry model for roof and façade (source: own study)

i-th element	Designation in the figure	me_i [m]	mr_i [m]	pe_i	ac_i
1	H_1	17.78	18.30	2.84%	97.16%
2	H_2	3.66	3.61	1.39%	98.61%
3	L_1	53.79	53.95	0.30%	99.70%
4	L_2	5.75	5.75	0.00%	100.00%
5	L_3	15.98	15.87	0.69%	99.31%
6	L_4	5.64	5.63	0.18%	99.82%
7	L_5	4.04	3.90	3.59%	96.41%

Finally, in Fig. 10 one can see where the surface take-offs were made for the façade of the building. As a background, the take-offs extracted from the BIM model were taken.

Fig. 10. Linear take-offs of the roof and façade on the basis of the photogrammetry model (source: own study)

As for the elements previously analyzed, the measures of errors and accuracies of the take-offs are listed in Table 6.

Table 6
Accuracy of surface take-offs based on photogrammetry model for façade (source: own study)

i-th element	Designation in the figure	me_i [m^2]	mr_i [m^2]	pe_i	ac_i
1	F_1	182.41	178.04	2.45%	97.55%
2	F_2	81.78	84.09	2.75%	97.25%
3	F_3	68.59	64.74	5.95%	94.05%
4	F_4	66.67	64.74	2.98%	97.02%
5	F_5	60.26	64.74	6.92%	93.08%
6	F_6	71.28	64.74	10.10%	89.90%
7	F_7	148.02	151.06	2.01%	97.99%

The calculated average values for these surface take-offs are as follows: $pe_{\text{avg}} = 4.74\%$, $ac_{\text{avg}} = 95.26\%$.

When compared to the previously analyzed take-offs, the errors are greater, and the accuracy is lower. It is interesting that the positive and negative values of the differences between me_i and $mr_i$are compensated when the total surface is considered. The total surface obtained on the basis of the photogrammetry model is 679.01 m^2. Compared to the reference value equal to 672.15 m^2, it appears that the error is 1.02% and the accuracy improves to 98.98%.

4. DISCUSSION

The obtained results and their analysis show the potential of photogrammetry modelling for quick quantity take-offs in the case of renovation works of the outer elements of the existing building. These works can be, for example, roof renovation, façade renovation, window replacement, and similar ones. Most of the take-offs are of very high accuracy, so they may be used for cost analyses or work planning. However, due to the possibility of errors in the range of 10%, a few reference take-offs should be made to check the accuracy and assess risks related to inaccuracies. Such reference check measures could be made for easily available elements of a building with the use of traditional inventory methods. In general, case studies have shown that photogrammetry as a technology has the capability of being used for the take-off process in the case of the renovation of external elements and parts of buildings.

In terms of time, it took one day for UAV flights and for taking photos, and also one day to process and combine the photos and develop a photogrammetric model that works well. (It is worth mentioning that the flights and taking photos were completed during ideal weather conditions.) On the other hand, it took about three weeks to develop the BIM model on the basis of evacuation plans and actual measurements. However, one must not forget that the BIM model includes information on the outer and inner elements of the building, so the time consumption is not comparable in a straightforward way.

Some issues should be taken into account. The restrictions of UAV flights vary between countries, so all legal conditions must be checked and met before the flight. The duration of the whole process of model development includes flight planning, the flight itself and taking photos, processing captured photographs, and finally model development. The quality of an obtained model depends on the quality of the photos taken; here, one must consider both the available gear and weather conditions. The development of a photogrammetric model requires some specialized software to be used. Finally, the take-offs made based on such models are not fully automated.

Considering the above discussion, it may guardedly be concluded that photogrammetry-based modelling is more likely to be beneficial and justified for practical use as a tool for quantity take-offs in the case of outer renovation works planning for relatively large buildings. For small buildings, traditional methods may prove to be more effective, quicker, and less time-consuming (the determinants may be, e.g., the surface of façades, height of a building, and surface of roofs.) Some extended and deeper analyses and research are still needed to confirm that.

5. CONCLUSIONS

Due to the organization of construction works, one of the most difficult situations is when a building is planned in a heritage or densely built-up location. Manually fixing an existing situation takes a lot of time and effort and is usually not accurate. In most cases, data transfer from two-dimensional drawings or topographic photos is performed before starting the design process or even the construction site planning work. It is assumed that the altitudes of the heights did not change, and topographic photos were used to create the reliefs, which are mostly stored in municipal archives and are outdated. To avoid the complicated recording of the existing condition and to avoid errors, the photogrammetry method proposed in this article is very suitable for several practices – from identifying the smallest elements of the building façade to the planning construction site and assessing the influence of surrounding buildings.

Therefore, it can be concluded that to perform a quick and efficient analysis of the exterior of the building, it is enough to make a photogrammetric model. The error in the measurements is very small. In this article, the specific use of photogrammetry shows that the error between the detailed BIM model and the photogrammetry model is only 1.02% and the accuracy is 98.98%. Moreover, physical capabilities do not always allow us to measure every desired element in reality. For example, it is not always possible to measure the exact spacing between buildings at different levels and to take into account all outside elements of an existing building. Improper fixation of the existing situation causes mistakes and collisions in design and the use of inappropriate construction solutions. This causes many problems in the construction stage when the selection of construction technology is closely related to design solutions.

ACKNOWLEDGEMENTS

The photos for creation, analyzed photogrammetry model, and evacuation plans were delivered by Vilnius Gediminas Technical University, Technology center for building information and digital modelling.

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