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Geoinformatics, 3D Modelling of Buildings with Drones for Civil Engineering Experts

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***Abstract* – Modern 3D modeling technologies and geoinformatics have become pivotal tools in civil engineering research. This study explores the creation of accurate 3D building models using dense point clouds captured by drones, comparing their precision to traditional measurement methods. Dimensions were measured with a tape measure, laser, and 3D modeling software. Analytical techniques, including linear regression, mean absolute deviation, standard deviation, and Welch's t-test, assessed the accuracy and reliability of the drone-based models. Results indicate that drones and 3D models provide a highly effective and accurate means of capturing building dimensions, with an average deviation of 0.46% compared to traditional methods.**

***Keywords* – 3D modeling, drones, dense point clouds, building measurement accuracy, civil engineering.**

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1. Introduction

Experts bring profound and unrivalled knowledge to tackle problems arising during and after construction [1]. One of the most burning legal issues involves commissioning expert opinions and their correctness [2]. Quality construction work must receive careful supervision during the whole process [3]. Upon finding a job undone, supervisors analyze the tasks at issue. Current cost and process monitoring methods in building projects lack practicality and accuracy [4]. Fierce competition in the construction market pushes building companies to tighten supervision and cost management, imposing effective measures for improving low-cost projects' profitability [5]. The trend of recent years has been to reduce the costs of various processes. This also applies to the processes of control and controlling, which can be replaced by a cheaper alternative of simple comparisons. This method can also be transferred to the field of construction projects [6]. On top of that, contractors often forge documents on the work performed, resulting in budget cuts and unjust enrichment of building companies [7].

Supervisors start by assessing the thickness and length of the walls, checking the outer limits for building deformities and calculating the used material [8]. 3D maps and models serve these purposes, covering many fields where 3D maps are used for measuring buildings [9]. Despite their utility, employing dense point clouds using drones yields even more accurate results, sparking the interest of architects and civil engineers [10]. With the expansion of drone related business, and their enlargement in number above people's heads, experts explore their strengths and utilities [11]. Civil engineers and safety managers can use drones to inspect the building site and monitor workplace safety, including less accessible places [12]. As security at the construction site is always the priority [13], the flight data may be invaluable [14]. During the recognition of the object, it is necessary to pay special attention to the individual surface materials [15].

Converting dense point clouds to a 3D model gives accurate information about the building dimensions, not requiring the author to be in the building in real time [16].

The thesis aims at exploring 3D models from dense point clouds using drones to allow experts to determine the building dimensions and their accuracy. Modern technologies like creating 3D models from dense point clouds using drones provide experts with new perspectives. Exploring the new possibilities of innovating expert opinions and integrating 3D models becomes an essential task within forensic practice.

RQ1: Can 3D models within expert opinions be effectively used and what are the possibilities of integrating the models into expertness activities?

Comparing the accuracy of 3D models created from dense point clouds using drones and conventional measuring methods for determining the building dimensions is a crucial step towards optimizing building and expert procedures. By resolving this issue, the accuracy and reliability of new technologies compared to traditional measuring methods can be assessed.

RQ2: What is the degree of accuracy of the 3D model created from dense point clouds using a drone and conventional measuring methods for determining the building dimensions?

Evaluating the economy and time saving of using drones and 3D models for expert opinions is essential for allocating funds and optimizing the job of forensic experts. The research question explores the economic and temporal impact of the new technologies compared to traditional techniques.

RQ3: What are the costs and time consumption of using drones and 3D models compared to traditional expert methods?

2. Literary Review

Civil engineering gradually transforms from a traditional industry into Civil Engineering 4.0, praising drones for their capacity to boost performance throughout construction [17]. [18] consider drones powerful tools, enriching the industrial sector with multiple innovations like monitoring the construction site at minimal labour costs [19]. [20] analysed which strategies to purchase iron building companies pursue, revealing a massive implementation of innovative technologies like drones for monitoring and controlling construction projects. [21] argue that drones and laser scanners can digitally record an object and transfer the data for IT 3D building modelling.

Using drones in civil engineering promises fast and flexible workflows. Forward-thinking contractors invest in digitalization, regularly using drones to monitor the building process in real-time. Deploying unmanned aircraft vehicles for inspecting the site may allow civil and safety engineers to withdraw workers from dangerous places and inform what is happening at the site incredibly fast. Lawani *et al.* [14] created an aircraft simulator to inspect a virtual construction site, focusing on potential safety hazards. [22] explored the application of drones in civil engineering, revealing several economic, operating, legal and environmental impediments preventing unmanned aircraft from using their full potential.

The authors suggested five practical measures to encourage using drones in civil engineering in developing countries. The proposed institutive actions involved adopting a coherent government policy and legislation, investing in training courses and pilot licenses, permitting the use of drones in the airspace above construction sites, including operating costs and the costs of drones in the project budget and fostering an organizational culture of supporting innovations. [23] argue that although drones significantly strengthen civil engineering, their safety impacts have yet to be analysed. [24] revealed that fuzzy logic provides stochastic results with additional valuable information, stimulating the decision-making process and benefit and risk assessment. [25] introduce the AEROTRAJ system for fast, accurate and automated reconstructions of 3D models of large buildings using LiDAR mounted to a drone. Setting LiDAR point clouds in the correct position can generate a quality 3D model. [26] point to an increasing interest in 3D modelling using LiDAR for monitoring, planning, and managing urban areas.

Using LiDAR data improves modelling accuracy, streamlining urban policy-making and infrastructure planning. [27] argue that although using 3D models for documenting the site enhances the workflow, current scholarly studies lack analyses of its productivity compared to traditional 2D documentation. [28] suggest that many academic articles focus on 3D models for construction monitoring, stating that the development of 3D building technologies led to a considerable increase in using 3D models in multiple sectors. Although 3D modelling has become a hot topic offering a variety of innovations, few studies have so far expounded upon supervising the work performed and revising the building's dimensions. [29] explore the completion of the data on buildings in OpenStreetMap, suggesting the inclusion of population figures as reference data.

Their results show that both approaches, type-oriented and regressive, are convincing; the former indicated 80-99% accuracy, while the latter reached a high correlation between the population and number of buildings, validated by the t-test. Using the data on population showed an efficient method for assessing the completion of the data on buildings in OSM. [30] analysed twenty 3D models using intraoral scanners, comparing their results with milling. 3D models generated their average distances, standard deviation, and other parameters. The t-test and Mann-Whitney U test allowed the statistical analysis of parameter dissimilarities, contingent on the data distribution, indicating a high accuracy. [31] focused on monitoring and targeting the centre point within the laser meter system using the suggested technique. Correlated filtering and elliptic fitting determined the midpoint of a hollow angle mirror, while an extraction method of correlated filtering and adjustment established conflicting target points. The experiments showed high accuracy and efficacy of the technique, recommending its use within laser distance measuring.

The first research question involves a 3D model of a building in a photo using dense point clouds captured by a drone. The second research question encompasses the comparison of the results using linear regression and a mean absolute deviation, assessing the accuracy and concordance between the measured and reference data analysed by the standard deviation. create a histogram validated by Welch's t-test.

3. Methods and Data

ADJI Mini 3 Pro drone for shooting the analysed building is being used. The drone scouts the area to take enough pictures from various angles and perspectives, providing a comprehensive overview of the house. DroneDeploy software for creating 3D models processes the photos, hence, allowing to upload the pictures and construct a 3D model of the building. The process involves interconnected and processed dense point clouds, representing the building surface in the three-dimensional space. The procedure is fully automatic, relieving the user of manual labour.

Upon finishing the 3D model, the dimensions using a tool for determining the lengths, widths, and heights of various building parts in a digital 3D space within specialized software is measured. This method is highly accurate, allowing an in-depth analysis of the building dimensions and proportions. Parallel to this innovative technique, the dimensions are traditionally measured using either a tape measure or laser meter.

The conventional method provides the data used as reference values to the results obtained by the 3D model. This complex approach objectively compares the accuracy and reliability of both procedures, yielding highly accurate results.

After the measurement, the measured values will be recorded in a table in Excel software containing all the measured dimensions obtained from the 3D model using software and traditional manual work. The values will then be compared using several analytical tools.

After recording the measured values in an Excel table, the results will be analyzed using linear regression analysis. This statistical method identifies and quantifies the linear relationship between the measured values obtained from the 3D model and traditional measurement. In this way, linear regression analysis will enable the assessment of the accuracy and reliability of both, measurement methods and the evaluation of their relationship.

Simple linear regression analysis formula [29]:

$$y = \beta_0 + \beta_1 x$$

For the linear relationship between x and y.
Where:
y = response, i.e., dependent or expected effect variable
x = predictor, i.e., independent or explanatory variable

After performing the linear regression analysis, the data will be further examined using the mean absolute deviation (MAE). Each point in the data set involves the absolute difference between the corresponding values from the 3D model and the traditional method. These absolute differences are then averaged, yielding the mean absolute deviation, which expresses the average error between the two data sets. Higher values of the mean absolute deviation indicate more radical differences between the measured values.

Formula for the mean absolute deviation [30]:

$$MAD = 1/n * \Sigma |x\_i - M|$$

Where:
n = number of data
x_i = ith value (value of the 3D model)
M = median

MAD is calculated as the average of the absolute values of the differences between individual values and the median. In this case, the 3D model results with those of the tape measure are compared.

Subsequently, the standard deviation to quantify the degree of variability between the values measured by the conventional method and the 3D model with the formula is used:

$$\sigma = \sqrt{\Sigma(x_i - \mu)^2 / N}$$

Where:
σ = standard deviation of the population
x_i = ith value in the population
μ = population average
N = number of values in the population

In addition, Welch's two-sample t-test will be calculated to determine the statistical relationship between the conventionally measured values and the values measured from the 3D model.

Formula:

$$t = (\Delta \bar{X} / s\Delta \bar{X})$$

$t = (\Delta \bar{X} / s\Delta \bar{X})$
t = t-test statistical value.
$\Delta \bar{X}$ = difference between the averages of the sample ($\bar{X}$ - $\bar{Y}$). $\bar{X}$ is the average of X and $\bar{Y}$ is the average of Y.
$s\Delta \bar{X}$ = Standard deviation of the difference between the averages allows for the distributions of both groups and sample sizes.

$s\Delta \bar{X}$ formula:

$$s\Delta \bar{X} = \sqrt{\{ (s_1^2 / n_1) + (s_2^2 / n_2) \}}$$

s_1^2 = distribution of Group X.
n_1 = number of observations in Group X.
s_2^2 = distribution of Group Y.
n_2 = number of observations in Group Y.

The aim of methodology section is to describe how the research was conducted as well as to enhance credibility of that research. In case the research is quantitative, methodology should present the way numerical data was collected and how mathematical analyses were conducted to observe, analyse, access, and test experiments and hypotheses. Qualitative research involves collection and analysis of non-numerical data (e.g.: text, video, or audio) with the aim of explaining concepts, opinions, perspectives, or personal experiences.

4. Results

First, a drone to shoot 246 dense-point-cloud photos using cameras and a satnav system is deployed.

Thanks to the ample space around the house, the drone could go around the building several times, providing detailed data for the 3D model.

Figure 1. Dense point cloud photos shot by a drone

Figure 1 suggests dense point clouds used as a dataset for constructing the 3D model.

Figure 2 depicts the final 3D model. A detailed and aesthetic visualization of the building and its surroundings captures the building structure, landscaping, and other environment.

Figure 2. 3D model of the house

After creating the 3D model, the measurement tools in the software are used to analyze and obtain the dimensions of the house and its components.

One hundred dimensions were measured, representing widths, lengths, heights, and other characteristics of different parts of the property.

Table 1 provides a partial overview of these results, comparing the actual dimensions with those obtained using the 3D model.

Table 1. Actual measured values compared to values obtained from the 3D model

Measured distance (mm)	3D model (mm)	Difference (mm)	Variance (%)	Variance per 1 mm (%)
1700	1706.88	-6.88	0.405%	0.0002371%
2150	2142.744	7.256	-0.337%	-0.0001575%
2500	2493.264	6.736	-0.269%	-0.0001081%
2575	2566.416	8.584	-0.333%	-0.0001299%
1490	1493.52	-3.52	0.236%	0.0001582%
2750	2727.96	22.04	-0.801%	-0.0002938%
1635	1581.912	53.088	-3.247%	-0.0020526%
4065	4072.128	-7.128	0.175%	0.0000431%
3515	3517.392	-2.392	0.068%	0.0000193%
1000	1002.792	-2.792	0.279%	0.0002784%
700	697.992	2.008	-0.287%	-0.0004110%
1360	1359.408	0.592	-0.044%	-0.0000320%
1060	1060.704	-0.704	0.066%	0.0000626%
2150	2151.888	-1.888	0.088%	0.0000408%

The resulting actual values are very close to the figures obtained from the 3D model. The differences are mostly small, indicating an accurate model. Table 1 involves the first fourteen measured values from a total of one hundred observed dimensions. The dimension at 1635 mm shows the biggest deviation, implying a difference greater than 53 mm, indicating a divergence of -3.247%. The measure at 1360 mm demonstrates -0.044%, suggesting the smallest difference with a variance of 0.592 mm.

The average variation between the actual and measured values in the whole dataset equals 9.996 mm, indicating -0.4663% of the average difference between the measured figures and reality. The average variance per millimetre is 0.004663035 mm, implying a high accuracy. The average divergence of -0.00036% mm per millimetre is proportional to the previous case, showing a negligible average deviation per millimetre.

Table 2. Actual measured values compared to values obtained from the 3D model

Measured distance (mm)	3D model (mm)	Difference (mm)	Variance (%)	Variance per 1 mm (%)
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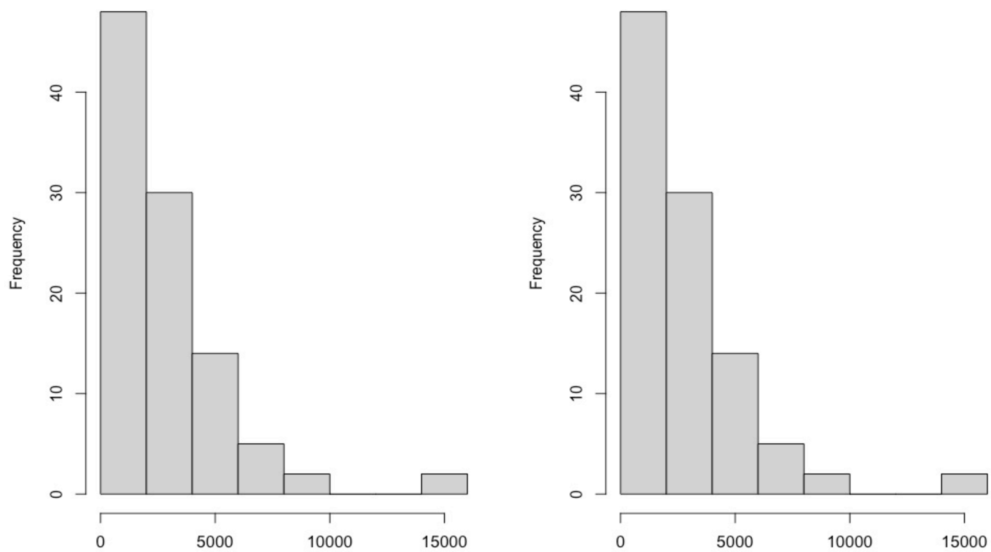
Table 3. Linear regression analysis comparing a 3D model and conventional measuring methods

Regression Statistics	***Conventional measurement / 3D model***
Multiple R	0.9999187
R Square	0.9998374
Adjusted R Square	0,.9983576
Standard Error	33.8206295
Observations	100

The results indicate a very strong linear correlation between actual and 3D model values. Multiple R, R Square, Adjusted R Square and Standard Error are 0.999918699, 0.9998374047, 0.999835762 and 33.82062948 respectively including 100 observations, indicating a high accuracy and minimal deviations between actual and measured values.

Subsequently, a conventional method for calculating a standard deviation was used, reaching 2639,03316. For values obtained from the 3D model, the standard deviation equalled 2628.22476.



Graph.1 Histograms of the measured values

Table 4. Results of Welch's two sample t-test

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        Welch Two Sample t-test

data:  estate$`skutečné mm` and estate$`naměřené mm`
t = 0.026974, df = 200, p-value = 0.9785
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -720.7954  740.7891
sample estimates:
mean of x mean of y 
 2823.059  2813.063 
```

Welch's two-sample t-test (with results t = 0.26974, df = 200, p = 0.9785) does not substantiate rejecting the zero hypothesis on the equality of averages between the samples. The 95% confidence interval (-720.7954 to 740.7891) shows that the actual difference between the averages of the samples lies within this scope. The estimates of the sample averages are 2823.059 for sample x and 2813.063 for sample y.

The conventional method, including a tape measure and laser, took roughly one hour. The construction of the 3D model involved roughly a fifteen-minute drone flight to take the necessary photos, requiring about 30 minutes. The follow-up measurements and data recording lasted approximately 30 minutes, including analyzing and comparing the values with the traditionally acquired results.

5. Discussion

RQ1: Can 3D models within expert opinions be effectively used and what are the possibilities of integrating the models into expertness activities?

Using 3D models in civil engineering expertise may be a convenient method to compensate for the shortage of project documentation, admitting experts to measure the dimensions and details of the object. 3D models also archive and keep records, streamlining the data processing and potential updates. Besides, 3D models are more reliable than conventional project documentation when brought before the court. Thanks to their attention to detail and accuracy, courts and legal subjects can get a clear picture of the estate and unbiasedly settle the dispute.

The drawbacks and limitations of this method include high costs and extensive technical knowledge required for constructing and analysing 3D models. The reliability and credibility of 3D models as evidence may be objectionable and challenged by the litigants. Besides, using drones at construction sites may expose workers to even greater danger, applying to all employees, including experts in the field [32].

On the other hand, drones allow experts to explore inaccessible places or areas requiring platforms for access, eliminating the hazard of moving in heights and substituting the equipment otherwise needed for accessing the out-of-reach premises.

RQ2: What is the degree of accuracy of the 3D model created from dense point clouds using a drone and conventional measuring methods for determining the building dimensions?

The results show that the actual measured values are generally very close to those obtained from the 3D model. Most of the differences are small, indicating high accuracy. Table 1 provides an overview of 14 measured values from 100 compared dimensions, with the strongest deviation being noted for the 1635 mm dimension, where the measured difference is greater than 53 mm. This shows the importance of detailed analysis and accurate measurement, especially in the field of construction assessments. The average difference between the actual and measured values for the entire dataset is 9.996 millimetres with an average deviation of 0.4663%. Furthermore, it can be stated that the average difference per 1 millimetre is 0.004663035 mm, being a very small value, which indicates a high measurement accuracy. Likewise, the average difference per 1 millimetre is -0.00036%, which means that the average variation concerning one millimetre is very small and almost negligible. The results of the linear regression analysis in Table 2 confirm a very strong linear relationship between the actual values and the values measured from the 3D model, indicating high accuracy and minimal deviations between the actual and measured values. The standard deviations for the measured values by the conventional method and from the 3D models also indicate a small data distribution and a higher reliability of the results.

The high degree of accuracy of the 3D model was also confirmed by the non-parametric Welch's t-test. This was applied because the illustrated histograms already visually stated distributions that did not match the Gaussian distribution of the data. The mean values of both samples were very similar – sample x = 2823.059, sample y = 2813.023.

With the resulting p-value of 0.9755, H0 about the equality of mean variances was convincingly supported, which means that no aspect would lead to considerations of the mutual influence of data characters (and thus their diversity).

These findings suggest that 3D models obtained from dense point clouds by drone can be an effective method for determining building dimensions and yield high accuracy and reliability, which has significant implications for surveying and construction practice. [10] agree that compared to the traditional method of surveying the constructed building, the method based on the use of drones provided greater operability in data collection as well as greater accuracy and reliability of the dimensions obtained from the point cloud.

RQ3: What are the costs and time consumption of using drones and 3D models compared to traditional expert methods?

Using drones and 3D models for expertise may reduce costs and speed up the data collection, decreasing the time needed for inspecting the estate and acquiring the necessary information to accelerate the expertise process. Given its detailed imaging and virtual measuring, constructing a 3D model from the acquired data may cut costs of manual measurements and documentation, saving time, costs and labour.

Although using drones and 3D models may bring considerable benefits, mastering this technology requires knowledge and training. Experienced staff must break new workers in, train them to control and maintain the drone safely and efficiently and educate them on using modelling software and constructing and analysing 3D models. As the drill involves complex data processing, calibrating and interpretations, the building companies must invest a lot of time and money in professional training to make this innovative technology pay off.

6. Conclusion

The primary objective of the paper was to evaluate the possibility of creating a 3D model created from dense clouds of points using a drone when determining the dimensions of buildings for the needs of expert work and to determine the accuracy of this model.

It can be assessed that the work brings important knowledge about the use of modern technology, specifically drones and the creation of 3D models, for the needs of expert opinions in the field of construction. Based on the collected data and the performed analyses, it can be concluded that this technology has the potential to be an effective tool for obtaining detailed information about buildings and real estate. Working with drones and creating 3D models brings many advantages, especially in the area of speed and accuracy of data collection. Drones can quickly and efficiently acquire a large amount of information from different angles and perspectives, which allows the creation of detailed 3D models with high accuracy. These models can then provide important information not only about dimensions but also have an essential information about the structure and condition of buildings, which is of fundamental importance for creating expert opinions.

Another important aspect is the analysis of the accuracy of 3D models obtained from drones and point clouds. Based on the comparison of the actual measured values with the values obtained from the 3D models, it can be stated that most of the differences are relatively small, which indicates the high accuracy of the models. The average deviation between actual and measured values is 0.4663%. This value indicates that the results obtained from the 3D models are very close to the real values, which is crucial for the credibility and reliability of these models. Analytical tools also confirm a strong linear relationship between actual values and values measured from 3D models.

However, working with this technology is not without its challenges. It requires some expertise and knowledge, both in the field of drone control and in working with modelling software to create 3D models. In addition, both the time and financial investment in training and professional education necessary to effectively use this technology in expert practice must be considered.

Overall, it can be stated that the benefits of using drones and creating 3D models for expert purposes in the construction industry are considerable. This technology limitations are not only the financial and procedural complexity but also the fact that drones cannot be used everywhere due to the need for flight space, which can be limited by trees or otherwise rugged terrain. The following research should be focused on the use of 3D models for expert purposes outside of exteriors, but inside buildings, where it offers a simplification of the process of creating the actual execution of the work.

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