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Original Research Article

MODELING OF A PUBLIC UTILITY FACILITY FROM TOTAL BIM DATA

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A b s t r a c t

The purpose of this work is to present the possibilities of using tacheometric measurement technology in the development of a 3D geometric model of an existing building and the directions of using BIM technology in the process of building operation. General information on the development of BIM technology was presented, and issues related to the construction of 3D models were discussed. Attention was also drawn to the need to update the information assigned to the model on an ongoing basis in order to effectively manage the building. Supplementing the model with metadata regarding the building materials used will allow for a precise and quick analysis of all renovation assumptions. The created 3D model can be used to control the condition of structures or in safety and risk management.

Keywords: tacheometric surveying, public utility facility, 3Dmodel, BIM

1. INTRODUCTION

Building Information Management (BIM) is a concept that has revolutionized the possibilities of modelling and managing information about objects in the field of construction investments, from design, implementation to building management [10, 15]. The versatility of this method allows you to document every part of the construction-related process - from the design stage, through the execution part, to the moment of acceptance and use of the objects [36,33,19,5,37]. It can be said that the essential and revolutionary aspect of this method is that the virtual image of a given object created thanks to it contains information processed in all three dimensions, which enables the ongoing updating of the project at every stage of its implementation. These are measurable benefits, as it enables simultaneous and easy access to information for both designers and as well as engineers, contractors and facility managers [38]. The ability to integrate geodetic and cartographic resources with this system is also of key importance, which involves importing a vector map as the basic element needed to generate a specific spatial model. Nevertheless, with such a wide range of possibilities of this method, it should be remembered that it is

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not possible to use BIM from the beginning of the investment process in every case [4, 15, 38]. Such a situation forces the reconstruction of the original design documentation using the inventory of the object's condition and the presentation of a 3D model by using advanced reverse engineering technologies [40]. In this case, in the next stage, further integration of the created models with BIM technology takes place [41]. The article will discuss the directions of using the BIM method of a 3D model of a public utility building from the Rzeszow district (Poland). The existing building was inventoried using the tacheometric measurement method and the forward angular cut method. Thanks to these methods, a set of data was obtained, which in the next step enabled the creation of a 3D geometric model of the measured building in the AUTOCAD program.

2. TOTAL INVENTORY MEASUREMENTS FOR BIM

BIM technology (Building Information Modeling) is a reflection of broadly understood concept of presenting given product's image, adapted to the needs of the construction industry [26]. This method is one of the most promising solutions in the field of architecture, engineering and construction [27, 28, 29, 36, 35]. Since its implementation in the 1970s, BIM has been developed and refined over the next three decades and is now the basic technology for capturing, storing, sharing and managing information about buildings [8]. This technology is used not only for the design process of a given facility, but also for its management, and even for demolition purposes [43,23,12,6,7].

The introduction of the method requires designers to change the perception of the flow of information about buildings from the beginning of the design process to the decommissioning of the facility. Using traditional methods, we obtain flat or three-dimensional documentation, which is only a graphic representation of the shape of the object. In the concept of modelling information about a building, a digital, three-dimensional building model contains additional information that is necessary in work at individual phases of the construction of a building or its explanation [39]. The advantage of the digital building model is, above all, the possibility of including extensive information in it, e.g. data on the components of the building, spatial relations and relationships between them, the number and properties of the materials and construction products used [31, 30, 2, 26].

Laser scanning technology is increasingly used in construction and architecture, primarily due to the speed, ease and accuracy of the measurement data obtained [35, 32, 18, 20]. The saved image of the examined object makes it possible to develop detailed analyzes and tests of both selected fragments and the entire building [22, 9, 17]. A great advantage of this technology is the ability to prepare a model of a building structure in a short time and carry out a control of compliance of construction works with the design of the facility, which reduces the risk of execution and design errors. Laser scanning is a non-contact method that uses electromagnetic radiation emitted and received by the scanner during operation [14, 42, 16].

Another approach is to use traditional methods for modelling building objects, including tacheometric measurement methods with angular indentation and trigonometric levelling as calculation methods to obtain the coordinates (X,Y,H) of individual characteristic points of a building object in order to build its geometric model. Tachymetric measurements using the method of angular intersections consist in measuring the angles of deflection of the line that pass through a given point (measured point) in relation to the base line (attachment points) and determining the coordinates of the intersection point [11,21]. Reference points (e.g. A and B) are points with known X, Y, H coordinates and constitute the measurement base. From the appropriate calculations with the method of angular incisions, we obtain the (X,Y) coordinates of the points measured (cut)[13]. The third coordinate - the height H of the incised point is obtained by using trigonometric levelling. Unfortunately, this method is subject to some measurement error. The analysis of errors, which was carried out, shows that the smallest measurement error is obtained in the case of the location of the intersected point in relation to the tie points in such a way that the targets intersect at right angles and their lengths are equal, and this principle was tried to be followed performing measurements and own research [1,3].

3. EXAMPLE OF 3D MODELLING - A SCHOOL IN KRASNE

The aim of the research task was to make a 3D geometric model of the school building in Krasne. The task included:

- establishment of the measurement network
- measuring the length of the sides and the angles of the carcass
- levelling the control points in relation to the working benchmark
- taking measurements of individual facades of the building using the angular indentation method
- performing appropriate calculations using the angular indentation method
- making a geometric 3D model of the school building in AUTOCAD

3.1. Angular indentation method

Spatial indentation is to determine the spatial coordinates (planar coordinates - X and Y, and height - H) of the intersected point. Measurements are made with reference to control points with known spatial coordinates (X, Y, H). In order to determine the coordinates of the incised point, measurements of two horizontal angles - α and β (between the known points and the incised/measured/designated point) and two vertical angles (to the designated point) – *ZA*, *ZB*, one at each of the positions, should be taken in the field. In addition, it is necessary to measure the height of the horizontal axis of rotation of the instrument's telescope above the measuring station – *iA*, *iB*. Measurement of the height of the telescope rotation axis is performed after centering and leveling the instrument over the point. Horizontal and vertical angles are measured in two positions of the telescope.

To determine the plane coordinates of the measured point (X, Y) the method of angular incision forward was used. After the measurements were made, the azimuths of a given section in this case and the azimuth opposite to it were calculated from the known flat coordinates. Then, the azimuths of the incised sides and are calculated, respectively$A_{AB} A_{BA} A_{AP} A_{BP}$
$(A_{AP} = A_{AB} + \alpha;)A_{BP} = A_{BA} - \beta$according to figure 1.

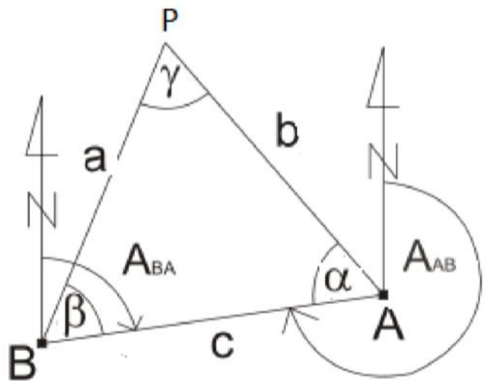

Fig. 1. Forward angular notch

The lengths c, a and b were calculated from the formulas 3.1-3.3

$$c = \sqrt{(X_A - X_B)^2} + (Y_A - Y_B)^2 \quad (3.1)$$

$$a = \frac{c}{sin\, sin\, (\alpha + \beta)} \cdot sin\, sin\, (\alpha) \quad (3.2)$$

$$b = \frac{c}{sin\, sin\, (\alpha + \beta)} \cdot sin\, sin\, (\beta) \quad (3.3)$$

However, the coordinate increments between the known points and those determined along the intersecting sides were calculated as (formulas 3.4 to 3.7):

$$\Delta X_{AP} = b \cdot cosA_{AP} \quad (3.4)$$

$$\Delta Y_{AP} = b \cdot sinA_{AP} \quad (3.5)$$

$$\Delta X_{BP} = a \cdot cosA_{BP} \quad (3.6)$$

$$\Delta X_{BP} = a \cdot cosA_{BP} \quad (3.7)$$

The coordinates of point P were calculated twice - based on the coordinates of point A (formulas 3.8 and 3.9):

- point A:$X_P = X_A + \Delta X_{AP}, Y_P = Y_A + \Delta Y_{AP}$ (3.8)
- point B: $X_P = X_B + \Delta X_{BP},, Y_P = Y_B + \ \Delta Y_{BP}$ (3.9)

In the next calculation step, the heights of individual points were determined. Using trigonometric levelling, the height of point P was determined from (formulas 3.10 to 3.11):

$$H_P' = H_A + i_A + b \cdot Z_A \quad (3.10)$$

$$H_P'' = H_B + i_B + a \cdot Z_B \quad (3.11)$$

$$Hp = \frac{Hp' + Hp''}{2} \quad (3.12)$$

where: - known heights of measuring stations, $H_A H_B$
- the height of the horizontal axis of rotation of the telescope measured at individual positions,$i_A i_p$
- vertical angles, $Z_A Z_B$

Using the presented calculation algorithm, it is possible to estimate the spatial coordinates of a selected measurement point, in this case point P (, ,).$X_P Y_P H_P$
In order to build a geometric model of a building structure, tachymetric measurements should be carried out for characteristic points of the structure that guarantee obtaining a model of appropriate accuracy

and quality in accordance with the level of detail of LoD 4 (LoD-Level of Development). Due to the fact that there are no Polish standards defining the accuracy levels, the LOD/LOI classification in accordance with the British guidelines is most often used and the author refers to these requirements.

3.2. 3D geometric model of a public facility

The location of the selected object is shown in the figure below (fig.2).

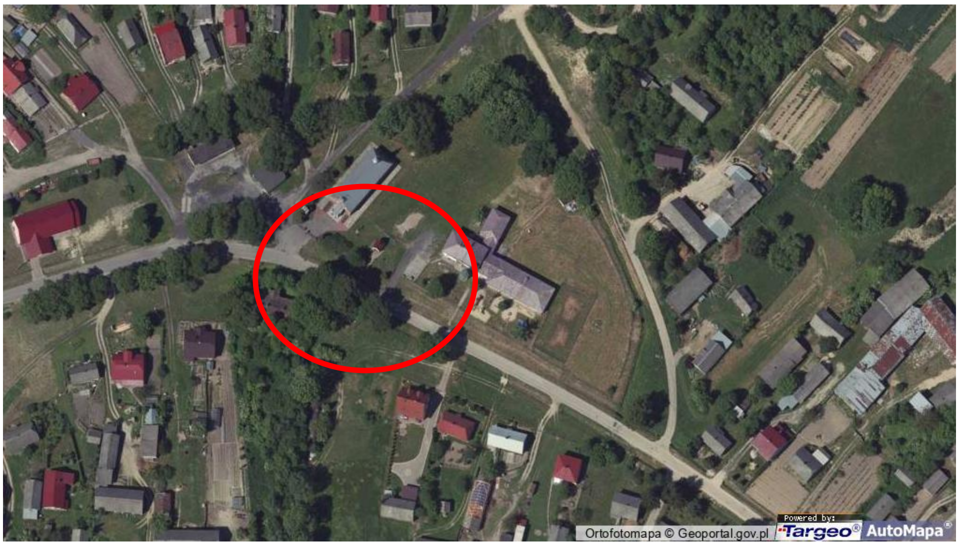

Fig. 2. Location of the public facility - Rzeszów district [https://mapa.targeo.pl/im-kornela-makuszynskiego-w-krasnem-krasne-145-22-417-krasne~17432105/szkola-podstawowa/adres]

The measurements and calculations (Tables 1 and 2) were the basic source of information for the construction of a 3D geometric model of the object (Fig. 3, Fig. 4).

Table 1. Sample data obtained from measurements and calculations of the X coordinate during the inventory of a selected building object

point no	**Horizontal angles [g]**	**Azimuths AND [g]**	**Side lengths - d [m]**	**cosA [-]**	**d*cosA [m]**	**d*cos(z) [m]**	**x [m]**
1	90.93	**50.00**	31.91	0.7071	22.56	22.57	**100.00**
2	**118.90**	131.10	22.08	-0.4693	-10.36	-10.35	122.57
3	292.52	38.59	24.35	0.8218	20.01	20.02	112.22
4	**103.84**	134.75	36.69	-0.5191	-19.05	-19.04	132.23
5	109.48	225.27	21.51	-0.9222	-19.84	-19.83	113.19
6	280.39	144.88	41.52	-0.6480	-26.91	-26.90	93.36
7	**115.15**	229.73	33.01	-0.8929	-29.48	-29.47	66.46
8	194.36	235.37	32.37	-0.8496	-27.50	-27.49	36.99
9	101.37	334.00	26.64	0.5090	13.56	13.57	9.49
10	102.74	431.26	20.32	0.8818	17.92	17.93	23.06
11	297.23	334.04	29.14	0.5096	14.85	14.86	40.99
12	201.23	332.81	17.20	0.4929	8.48	8.49	55.84
13	110.60	422.21	13.90	0.9398	13.06	13.07	64.33
14	281.28	340.93	37.69	0.5995	22.60	22.61	77.40

Table 2. Sample data obtained from measurements and calculations of the Y coordinate during the inventory of a selected building object

point no	**Horizontal angles [g]**	**Azimuths AND g]**	**Side lengths [m]**	**sinA [-]**	**d*sinA [m]**	**d*sin(z) [m]**	**Y [m]**
1	90.93	90.93	50.00	31.91	0.7071	22.56	22.58
2	118.90	118.90	131.10	22.08	0.8830	19.50	19.51
3	292.52	292.51	38.59	24.35	0.5697	13.87	13.89
4	103.84	103.84	134.75	36.69	0.8547	31.36	31.38
5	109.48	109.48	225.27	21.51	-0.3866	-8.32	-8.30
6	280.39	280.39	144.88	41.52	0.7616	31.62	31.64
7	115.15	115.15	229.73	33.01	-0.4502	-14.86	-14.84
8	194.36	194.36	235.37	32.37	-0.5274	-17.07	-17.06
9	101.37	101.37	334.00	26.64	-0.8607	-22.93	-22.91
10	102.74	102.74	431.26	20.32	0.4715	9.58	9.60
11	297.23	297.22	334.04	29.14	-0.8604	-25.07	-25.06
12	201.23	201.23	332.81	17.20	-0.8701	-14.97	-14.95
13	110.60	110.60	422.21	13.90	0.3418	4.75	4.77
14	281.28	281.28	340.93	37.69	-0.8003	-30.16	-30.15

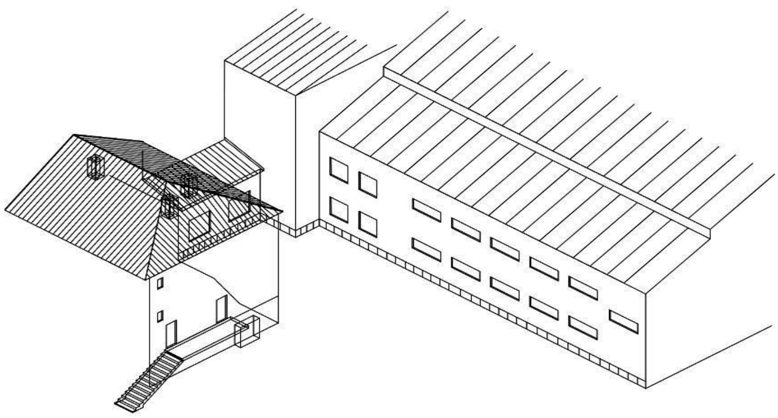

Fig.3. An example of obtained illustrative data regarding a 3D model of a primary school building from the Rzeszów district; Source: own study

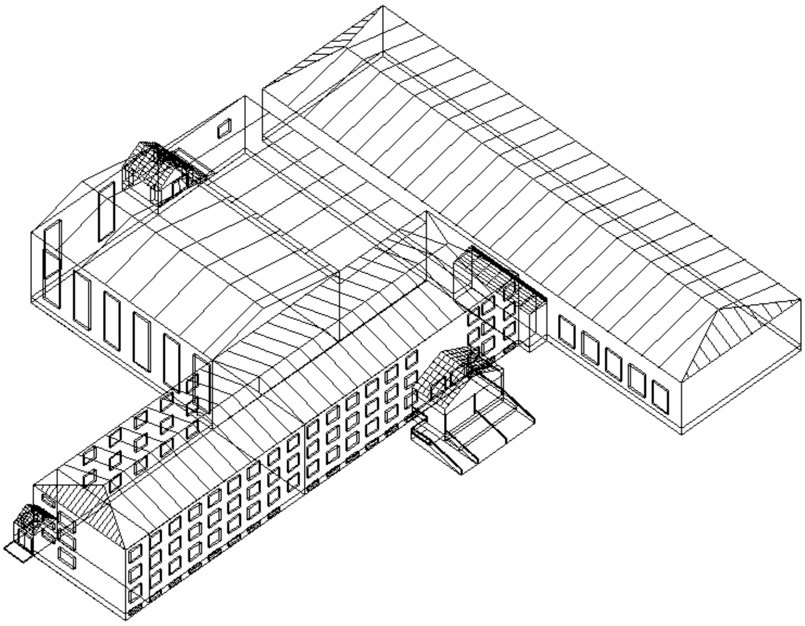

Fig.4. An example of the obtained illustrative data regarding the 3D model of a school building in the Rzeszów district Source: own study

4. SUMMARY

The performed calculations and the 3D model geometrical of the building developed on the basis of the obtained data showed the usefulness of the selected tacheometric measurement technology. The developed 3D model could undoubtedly be the basis for taking further, planned actions towards the implementation of BIM in facility management. The measurement and calculation technology used enables the development of lost or unavailable documentation for some reason.

A properly developed model with the use of tachymetric methods makes it possible to support BIM technology and the subsequent effective management of the existing building. Ongoing supplementation of the model with metadata on the materials used, design parameters, physical features or age of the building allows for a precise and quick analysis of all renovation assumptions. The model developed at that time can be effectively used in structural condition control, including safety and risk management. It should be emphasized that the use of BIM technology at the building operation stage is aimed not only at improving the management and renovation process of the facility, but also at reducing the related costs. Operating costs are the largest group of all expenses related to the construction and use of the building.

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