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INTEGRATION OF TERRESTRIAL LASER SCANNING AND UAV-BASED PHOTOGRAMMETRY FOR HERITAGE BUILDING INFORMATION MODELING

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Summary

Building Information Modeling (BIM) is the process of generating 3D models based on object databases. They are made for various types of buildings, sites and objects, and their task is to represent all the structural and architectural features of the object using parametric models. The BIM technology involves the preparation of the model that is already at the design stage of the building, in such a way that it is used during conceptual and implementation works, as well as during its final operation. However, a BIM model of existing objects can also be generated. Historic buildings are a special group of objects The HBIM (Heritage Building Information Modeling) model is used not only as an inventory of the object in its current state, but also as a background and a tool for visualising the object in its restored state, or as a source of information about the building itself for conservation, renovation and documentation purposes. Such a model can be created based on various types of source data. The basis for the development of the BIM model can be formed by data acquired during the inventory of the facility using surveying methods, laser scanning and photogrammetry. This paper presents the process of data acquisition of a historic object using the example of Lamus Dworski with the use of TLS and UAV. The study also includes the process of HBIM modeling of the object using point clouds as well as photographic documentation and data recorded in the monument card.

Keywords

BIM • data integration • geospatial data • TLS • UAV • 3D model

1. Introduction

The BIM model is a digital record of the physical and functional properties of a building object. This model is presented in a parametric form and is used to store and present data about the object. An object can be not only a building, but also a complex of buildings as well as its individual structural elements [Adamus 2012]. BIM is also a digital description of the object, which is visualised in the form of a spatial model containing real information about all the stored elements of the building [Kasznia et al. 2017]. The model generated by BIM technology is the basis for multidimensional simulations, not just 2D drawings or 3D model presentations. Thanks to its use of object databases containing the information used for parametric modelling, multidimensional simulations and analyses are possible. The multidimensionality of the BIM model is demonstrated by its versatility. Adding the time parameter creates the fourth dimension in BIM technology, enabling the visualisation and simulation of changes taking place in the facility. The addition of costs (real-time estimates) generates a five-dimensional technology that provids information on the economic aspects of the project implementation. The sixth dimensional parameter is the energy analysis, which includes all spatial analyses. This information, stored in the model, is extremely helpful in real estate management during the operation of the facility, as well as in making decisions regarding the renovation, reconstruction, or demolition of buildings. Subsequent dimensions are created by successively adding and expanding information that is stored in the database connected to the model, which is its realistic visualisation and presentation. The BIM model serves as the basis for decision-making in all stages and life cycles of a building. The model contains geometric information, spatial relationships, geographic information, as well as other quantitative and qualitative data about individual family components and objects located in the building. The model is available to all participants in the investment process, from the design process through investments to execution and use, as well as at the stage of subsequent alterations, repairs and renovations [Tomana 216, Kasznia et al. 2017].

HBIM modelling belongs to the category of reverse engineering techniques – processing data on the dimensions and inventory of an existing object into a digital form stored in the form of a 3D model and technical and descriptive documentation [Yang et al. 2022]. HBIM consists of modelling building objects by combining artistic, historical, structural, building and architectural assumptions. The HBIM model is a spatial representation and visualisation of a real object together with an object database storing information on the building. HBIM allows to understand, document, and virtually reconstruct heritage buildings, as well as do their inventory and visualisation [Lopez el al. 2018, Klapa and Gawronek 2023]. Such a model also enables the management of the entire structure of buildings, the creation of comprehensive technical documentation of historical buildings and the exchange and storage of information about the object, which is necessary for the purposes of renovation, conservation and protection of the monument from destruction [Yang et al. 2022].

The source of data required for the BIM/HBIM can generally be 3D modelling information from laser scanning and broadly understood photogrammetry. Active and passive sensors are currently widely used to carry out building stocktaking, thanks to the generation of point clouds that precisely represent the geometry of places and objects, which translates into the possibility of their efficient and accurate modelling and visualisation later [Croce et al. 2021]. 3D point cloud data is an important data source for the virtual reconstruction of cultural heritage. It represents it in 3D and includes information about the spatial geometry, as well as information about the colour, structure and texture of the material from which it was made.

Such data can be collected using laser scanning technology, photogrammetry, remote sensing, unmanned aerial vehicles (UAV), mobile vehicles, ground vehicles and other platforms, providing a variety of approaches individually tailored to the nature, size and type of the object [Noszczyk and Gawronek 2020, Yang et al. 2022]. Laser scanning data is characterised by a large amount of information stored in the cloud, which preserves the geometry and scale of the mapped object. Both airborne (ALS) and terrestrial laser scanners (TLS) allow for fast and effective generation of high-quality and accurate geospatial data, which is why they are often used in the 3D modelling process and also for HBIM [Lopez et al. 2018, Klapa 2022]. Currently, laser scanning, especially TLS, plays a very important role in obtaining information about objects of tangible cultural heritage. They are used for inventories, detection of cracks and defects, as well as for modelling and visualisation of objects [Baselga et al. 2011, Mukupa et al. 2017]. However, the high cost of the equipment, the need for specialist skills and the software for processing measurement data limit the widespread implementation of this technology. In addition, the scanning process itself takes a lot of time and requires several (a dozen or so) measuring stations to ensure a comprehensive acquisition of the information about the object, which still does not guarantee its 100% effectiveness due to the possibility of places with difficult access (e.g. roofs or high-lying elements of the object, as well as places obscured by other objects) [Lopez et al. 2018]. An alternative to laser scanning is terrestrial and UAV photogrammetry. Despite the problems that can arise during the post-processing of photographic reconstructions, as well as the need to use GCP for scaling the results of a photogrammetric study [Ravi et al. 2018] this technology is widely and commonly used due to the speed, ease and low cost of measuring equipment (UAV) [Lopez et al. 2018]. UAVs are one of the main devices used for modelling sites and objects, and this data is also increasingly used in architecture, construction, civil engineering, as well as 3D modelling and BIM [Guan et al. 2022].

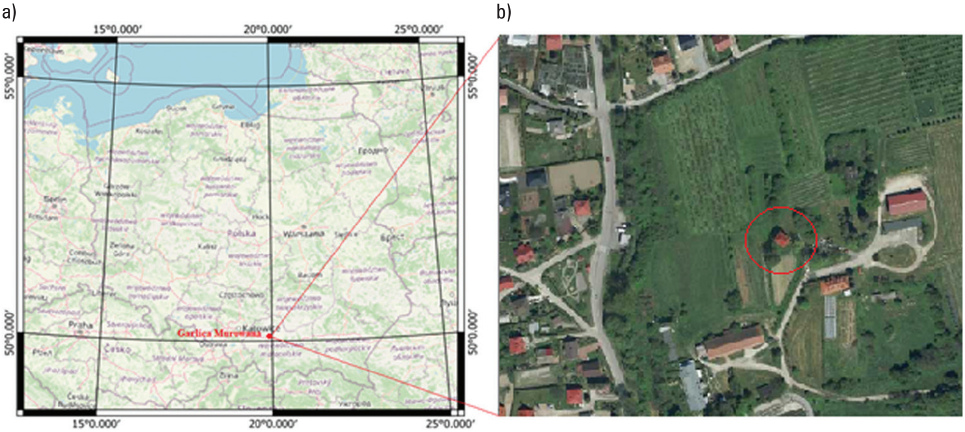
For the purpose of generating a comprehensive object database (saved in the form of a point cloud), an often used procedure is the integration of data from various sources. The synergy of information obtained with the use of various tools allows to eliminate the weaknesses of one of the measurement methods whilst benefiting from the advantages of the other. An important aspect of data integration is the selection of measurement devices so that the their results complement each other. An example of such a combination is TLS and UAV [Alshawabkeh et al. 2021]. Terrestrial laser scanning acquires point clouds for objects from the ground surface, thus includes only those elements of the object that are visible from the ground. UAV as an aerial measurement gathers information on inaccessible and hard-to-reach places, however, it also has limitations, e.g. the interior of objects or elements with very complicated geometry. The purpose of the integration is also to maintain the cohesion of the combined measurement data. This is done by using common points for both measurement techniques, which then serve as reference points during the transformation to a common coordinate system. Marks, points, geometric elements and other types of points uniquely identified in the field, on photos and on the point cloud can be used as target points. Another common practice is to measure these points using total stations or GNSS receivers in order to determine the coordinate values in the adopted global coordinate system and to georeference the obtained point cloud [Klapa et al. 2022].

The aim of the research was to carry out field measurements enabling the subsequent synergy of data from TLS and UAV based on georeference, obtained thanks to the orientation to common GPC (Grand Control Points). The paper will analyse the possibility of using an oriented point cloud from the integration of data from laser scanning to generate spatial models in the BIM technology on the example of historic buildings. The paper discusses the assumptions of the HBIM as well as TLA and UAV as data sources for building this model. The scope of fieldwork, geospatial data processing, 3D modeling and research work on the integration of TLS-UAV data for the purposes of generating a BIM model of a historic object were presented.

2. Research subject and methodology

As a part of the research, an outbuilding was analysed, which is part of the manor house complex located in Garlica Murowana, Zielonki municipality, Kraków county, Poland (Fig. 1a, b).

a) b)



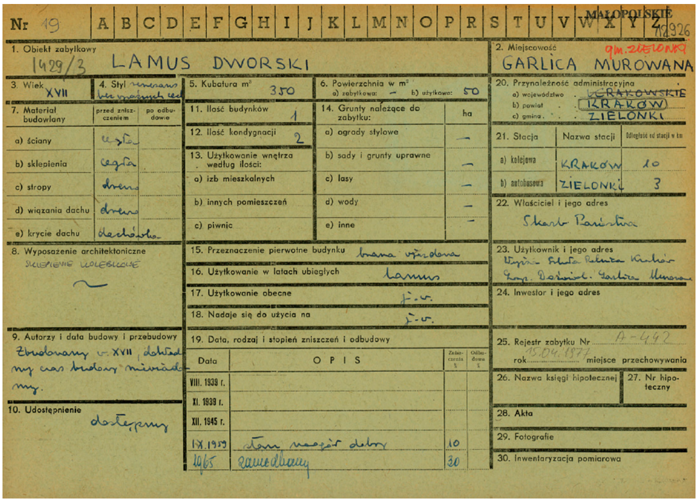
Source: Author's own study

Fig. 1. Location of the research object: a) on the map of Poland, b) the location of the research object in Garlica Murowana

The object is called "Lamus Dworski" – a building with utility rooms in the form of warehouses and storage rooms. Lamus belongs to the manor complex, it has been entered on the list of monuments of the Małopolskie Voivodeship (Poland) and its monument card is kept by the National Heritage Board of Poland. The building has the features of a Renaissance object, and it was built in the 17th century. It is made of brick on a square plan, two-storeyed, the first level is below the ground surface, while the external staircase leads to the room on the second level, with a sloping tent roof covered with tiles [Monument Card No. 1429/3 Lamus Manor] (Fig. 2a, b). The building is under the care and management of the University of Agriculture in Kraków, as part of the Murowana Experimental Station run in Garlica. In the 1980s, the building was reconstructed and adapted to the administrative needs of the farm. This function has been fulfilled to this day [https://wbio.urk.edu.pl/index/site/7938].

a)

b)



Nr 19 | A B C D E F G H I J K L M N O P R S T U V W X Y Z | MAŁOPOLSKIE 12926

1. Obiekt zabytkowy: 1429/3 LAMUS DWORSKI
2. Miejscowość: GARLICA MUROWANA (gm. ZIELONKI)
3. Wiek: XVII
4. Styl
5. Kubatura m³: 350
6. Powierzchnia w m²: a) zabytkowa: – b) użytkowa: 50
7. Materiał budowlany (przed zniszczeniem / po odbudowie): a) ściany; b) sklepienia: cegła; c) stropy: drewno; d) wiązania dachu: drewno; e) krycie dachu: dachówka
8. Wyposażenie architektoniczne: SKLEPIENIE KOLEBKOWE
9. Autorzy i data budowy i przebudowy: Zbudowany w XVII, dokładny czas budowy nieznany.
10. Udostępnienie: dostępny
11. Ilość budynków: 1
12. Ilość kondygnacji: 2
13. Użytkowanie wnętrza według ilości: a) izb mieszkalnych; b) innych pomieszczeń; c) piwnic
14. Grunty należące do zabytku (ha): a) ogrody stylowe –; b) sady i grunty uprawne –; c) lasy –; d) wody –; e) inne –
15. Przeznaczenie pierwotne budynku: brama wjazdowa
16. Użytkowanie w latach ubiegłych: lamus
17. Użytkowanie obecne: j.w.
18. Nadaje się do użycia na: j.w.
19. Data, rodzaj i stopień zniszczeń i odbudowy

Data	OPIS	Zniszczenia %	Odbudowa %
VIII. 1939 r.			
XI. 1939 r.			
XII. 1945 r.			
IX. 1959	stan nagół dobry	10	
1965	zaniedbany	30	

20. Przynależność administracyjna: a) województwo: KRAKOWSKIE; b) powiat: KRAKÓW; c) gmina: ZIELONKI

21. Stacja	Nazwa stacji	Odległość od stacji w km
a) kolejowa	KRAKÓW	10
b) autobusowa	ZIELONKI	3

22. Właściciel i jego adres: Skarb Państwa
23. Użytkownik i jego adres
24. Inwestor i jego adres
25. Rejestr zabytku Nr A-442; rok 15.04.1977; miejsce przechowywania
26. Nazwa księgi hipotecznej
27. Nr hipoteczny
28. Akta
29. Fotografie
30. Inwentaryzacja pomiarowa

Source: Author's own study

Fig. 2. Research object: a) front wall of the building; b) "Lamus Dworski" – monument card

The field measurements were taken using the Leica ScanStation P40 terrestrial laser scanning system (Fig. 3a), as well as the DJI Phantom 4 Pro unmanned aerial vehicle with a camera equipped with a 20Mpx CMOS sensor (Fig. 3b).

a) b)

Source: Author's own study

Fig. 3. Measurement equipment: a) Leica ScanStation P40 (TLS), b) DJI Phantom 4 Pro (UAV)

Ten TLS measurement stations were made, of which five for the exterior of the building and five for the interior – three stations connecting the interior to the exterior of the building and two stations for rooms located on the first and second floors. All scans were recorded with a scan resolution of 2 mm/10 m. As part of the UAV measurement, one photogrammetric observation was made with 90% longitudinal and transverse coverage – a total of 14 photos of the object were taken. The UAV observation was intended to fill the gaps in the TLS point cloud and cover the roof of the building.

Spheres with a spatial marker (photopoint) served as common points for both measurements (Fig. 4). The Trimble R8 GNSS receiver was used to determine their coordinate values. The measurement was carried out using the RTK method, which allowed to determine the coordinates of points in the global system Poland CS2000 zone 7 (EPSG: 2178). Spheres were used for the orientation and vectorisation of point clouds. Individual TLS measurement stations were merged into one point cloud with an accuracy of 0.002 m Point clouds were processed with TLS in the Leica Cyclone software.

The reference marker on the sphere was used as a photopoint in the process of aerial triangulation of UAV images. The accuracy of the photogrammetric survey measured at the photopoints was 0.027 m, while at the control points it was 0.030 m. Photogrammetric elaboration along with the generation of a point cloud based on UAV photos was developed in the Agisoft Metashape Professional software.

a) b)

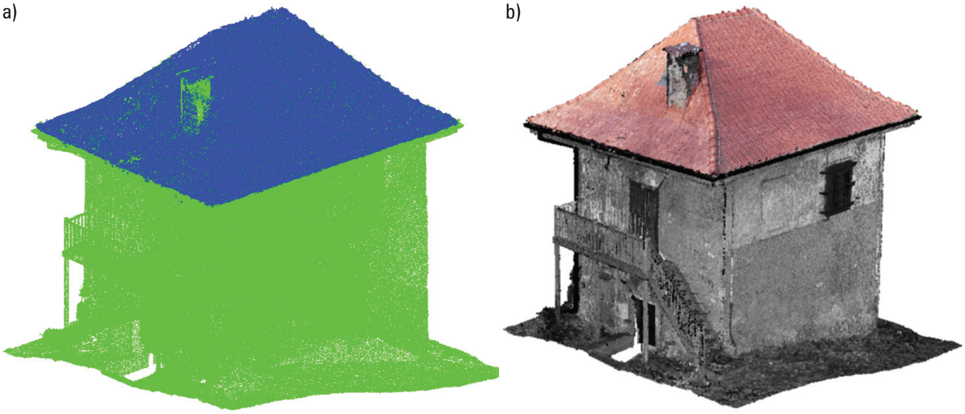
Fig. 4. Reference sphere with a spatial marker (photopoint): a) an image of the reference sphere, b) a scanned sphere with a fitted model

The GNSS-RTK measurement determined the coordinate values of the reference spheres in the global coordinate system As a result, it was possible to have a common georeferencing for both TLS and UAV measurement results. The spatial points used allowed for the integration of the TLS-UAV data – constituting common elements for all measurements. The accuracy of fitting the point clouds into the global coordinate system was 0.011 m – the accuracy of the geospatial database in the adopted reference system.

3. Results

3.1. TLS-UAV data synergy

The TLS-UAV data integration process was carried out in the Leica Cyclone software based on common reference points, allowing the assignment of a common georeference in the adopted global coordinate system. An important factor determining the effectiveness and accuracy of the synergy process is the continuity and consistency of information presented in the cloud. The visualisation of the integration process (Fig. 5) shows the compatibility and consistency of information between data from different sensors. Data obtained from UAV images supplemented the missing fragments of the TLS cloud. As a result, the TLS-UAV data synergy process enabled the acquisition of a comprehensive point cloud of the tested object (Fig. 5).

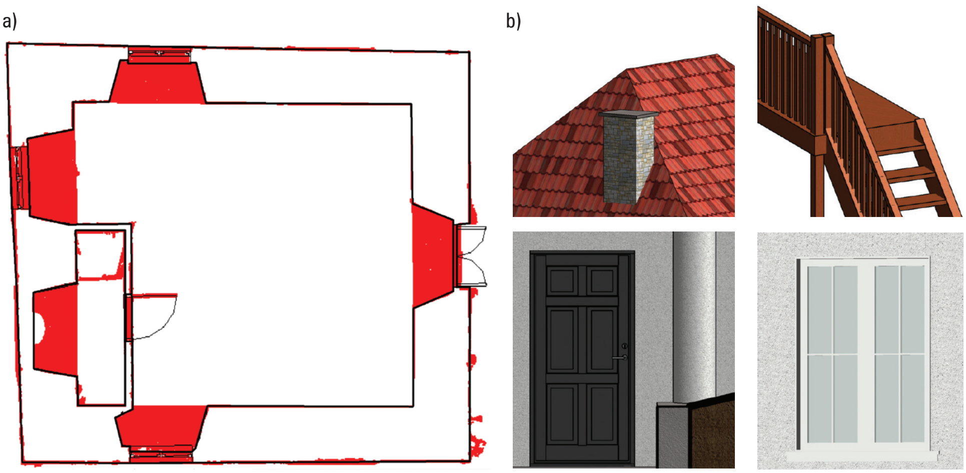


Source: Author's own study

Fig. 5. TLS-UAV data synergy: a) green colour – TLS, blue colour – UAV, b) comprehensive (integrated) point cloud of the tested object

3.2. Results of work in terms of generating the HBIM model

The generating of a BIM/HBIM model starts with the creation of an object database, which is then used as components, families and appropriate types of objects to generate a parametric model of individual structural and finishing elements of the building. The individual components were created based on a point cloud after TLS-UAV integration. Precise information about the geometry and spatial location of individual objects was obtained from the cloud (Fig. 6a).

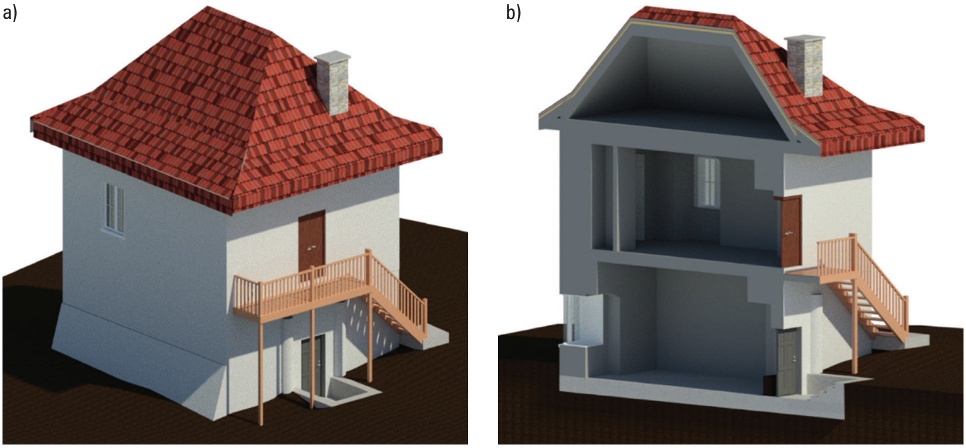


Source: Author's own study

Fig. 6. Generating BIM object databases: a) geometry of objects from a point cloud, b) construction of appropriate components, families and types

Based on the descriptive documentation, the monument card, and thanks to the information obtained from the building manager, the individual elements and the materials from which they were made were identified. This information allowed us to generate appropriate families and their types for individual components (Fig. 6b).

Using the generated components of the BIM model (Fig. 6), as well as the point cloud and photographic documentation and descriptions from the monument card, the BIM model was generated. The entire process was carried out in the Revit software (Autodesk), using the libraries of families and materials available in the program, the of components and families made available on the website [bimobject.com], as well as the created families. The HBIM model was generated for all structural and architectural elements of the building, including window and door joinery and external structural elements belonging to the building. Based on the HBIM models, realistic visualisations of the historic research facility – Lamus Dworski were prepared using rendering tools (Fig. 7 a, b).



Source: Author's own study

Fig. 7. Visualisation of the HBIM model: a) presentation of the entire building from the front side, b) cross-section through the building with the presentation of the interior of the building

4. Summary and discussion

The BIM model allows unlimited access to information in real-time for all participants in the construction process, such as managers, administrators, owners, investors, and other people associated with the building at all stages from its design, through implementation, to demolition [Tomana 2016, Kasznia et al. 2017]. The BIM model is also generated for existing buildings including historic buildings. The model of a historic object (HBIM) can be a source of valuable information necessary in the process of possible reconstruction of the monument and/or in case of its damage or destruction. It can also help in the process of its maintenance and renovation, ensuring the preservation of appropriate materials and components while maintaining the original features of the object [León-Robles et al. 2019]. The HBIM model can be created based on various types of 2D and 3D graphic data, as well as descriptive data and information obtained from historians, managers or owners of the facilities. A similar view is shared by Croce et al. [2021] and Yang et al. [2022], who used information from the TLS, UAVs and technical and descriptive documentation to generate the HBIM model. In this paper, the author used various data sources, i.e. TLS, UAV, monument cards as well as photographic and descriptive documentation. In order to obtain a comprehensive point cloud of the entire facility, TLS-UAV-GNSS data integration was carried out. Alshawabkeh et al. [2021] and Klapa et al. [2022] also used this approach to create a high-quality comprehensive object database for geodetic and cartographic purposes, as well as 3D modelling and generating technical documentation.

Based on the integrated, comprehensive and oriented point cloud, the HBIM model of the historic Lamus manor house located in Garlica Murowana was made. This approach is practiced [Baselga et al. 2011, Mukupa et al. 2017] due to the accuracy and precision of the generated model while maintaining a high level of accuracy in terms of LOD (Level of Detail), LOI (Level of Information), LOA (Level of Accuracy) and LOG (Level of Geometry). The model obtained in this paper (Fig. 7) – due to the preservation of architectural detail, identification of materials and the presentation of structural and decorative elements with high architectural detail – was referred to as LOD4 and LOI4, which is consistent with the adopted accuracy class of BIM models [Bruman et al. 2018, Maiezza 2019, Bim Standard_PL, 2020]. In terms of the LOA value, the model developed in the work has an accuracy level of 2–3 cm, which corresponds to the LOA20 class (5 cm–15 mm) [USIBD 2016]. The value of the LOG indicator adopted in accordance with the nomenclature [Abualdenien and Borrmann 2021] has been defined at the LOG350 level, due to the exact mapping of the object's geometry, the preservation of all building shapes, as well as the identification and determination of the materials from which the individual structural elements of the building are made.

6. Conclusions

Conducting field measurements with the use of various types of TLS-UAV-GNSS measuring devices with the additional use of photographic and descriptive documentation allowed for an efficient data synergy of all measurement results. The TLS and UAV measurements were taken using common reference points for which coordinate values were determined (using GNSS). These points resulted in the efficient allocation of a common georeference to all measurement results, and thus for an accurate and precise integration of the TLS-UAV data.

The use of a point cloud from the TLS-UAV data integration facilitated the creation of the HBIM model of the historic building, which is the Dworski Lamus in Garlica Murowana. Based on the analysis of the obtained qualitative results of the model, it should be noted that the high quality of the model in terms of LOD, LOI, LOA and

LOG was a derivative of high-quality measurement data, comprehensively reflecting the tested object with an accuracy of 2–3 cm (in the adopted global coordinate system).

Thanks to the use of various types of measurement data (TLS, UAV, GNSS) as well as the technical and descriptive data contained in the monument card and photographic documentation, it was possible to generate high-quality object databases, necessary for the parametric modelling of the HBIM, and later for the model presentation and visualisation.

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