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ORIGINAL ARTICLE

Synergy of BIM, GIS, and open-access geospatial data in 3D modelling for property management

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Abstract

Three-dimensional modelling of buildings requires reliable data sources and sophisticated tools capable of delivering exhaustive models that can facilitate property management. The authors devised a methodology for 3D building modelling using only open-access geospatial databases like Light detection and ranging (LiDAR) scanning, map and photogrammetry resources, and the relevant publicly available land and topography databases. The models integrate building geometry and detailed object information, which makes them versatile tools for property valuation, management, and structural health monitoring. The study brings together Building Information Modeling (BIM) and Geographic Information Systems (GIS) tools that can integrate spatial data and build precise models with details of critical parts of buildings, such as roofs, walls, window and door openings, balconies, terraces, hard infrastructure, and other structural and fit-out components. The methodology's performance and versatility were verified on single-family residential buildings in Kraków (Poland). The results have confirmed that the constructive collaboration of open-access geospatial data, GIS, and BIM yields high-grade 3D models for structural health monitoring, action planning, and building life cycle management. This approach leads to effective property (resources) management and streamlines planning and taking actions over the life cycle.

Key words: BIM, object-oriented database, property management, GIS, structural health monitoring, 3D models

1 Introduction

Property control can be viewed as a multi-faceted combination of legal, technical, and economic activities to order socioeconomic relationships in support of sustainable development, which are performed across different levels of operations: local, regional, and central (Siejka, 2015). The primary unit controlled is the real property asset, comprising a plot of land and and the buildings on it. Property control covers such activities as property trade, management, and valuation. Therefore, defining the property asset unambiguously based on reliable data sources is paramount, and it should cover the spatial position and current condition of the buildings (Siejka, 2017; Cienciała et al., 2023).

Active spatial databases are central for property control. In a market economy, many agents actively participate in the property market. The most noteworthy include developers, tenants, intermediaries, managers, and valuation surveyors. These actors require up-to-date property information to verify and evaluate the asset's condition for valuation, investment feasibility verification, land acquisition, and acquisition of facilities for rent (Altuntas, 2019; Bas, 2024). Information on the condition of primary structural components of buildings is pivotal for property management as it affects numerous aspects of safety, operating costs, and user comfort (Serrano-Jiménez et al., 2019; Healey, 1994; Głuszak and Belniak, 2020; Copiello et al., 2021; Fang and Hayunga, 2023). Regular building monitoring and maintenance are necessary to ensure the safety of people in the facility. Additionally, well-serviced buildings are cheaper to maintain. Regular maintenance prevents high-profile failures that may entail costly repairs. Care for the building's condition, including its insulation, promotes energy efficiency and

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reduced operating costs (Zhao et al., 2019; Gajzler, 2021; Marmo et al., 2020). While poor maintenance leads to energy inefficiency and higher heating and air conditioning costs.

Property management should be founded on a strategic approach to maintenance costs. Effective assessment of the design of individual structural and fit-out components facilitates repair and upgrade planning, which facilitates the budgeting activities. Regular maintenance contributes to the building's extended service life: When such parts as roofs, walls, external surfaces, doors and windows, and internal systems are serviced on time, the building can be used for an extended period, which is economically advantageous (Zavadskas et al., 2017; Olaussen et al., 2021; Fang and Hayunga, 2023). Moreover, insight into the current condition of the building is valuable for drafting repair and upgrade plans in long-term housing stock management programmes (Trembecka et al., 2023).

Advances in computer technologies made property information available at any time and place, with the only restriction of the availability of data and services in public registers placed on classified data, especially those relevant to public security, and protected data, including some data related to the administration of justice, tax, public statistics, environmental protection, personal data, intellectual property rights, as well as commercial data (Directive, 2007).

A 3D model is a digital reproduction of an object in three dimensions, representing its shape, size, proportions, and geometry. Three-dimensional modelling involves methods and tools for creating a digital representation of real-world objects (Costantino et al., 2021). Models are employed in diverse fields, such as: architecture, engineering, property management, and cultural heritage protection. Therefore, modelling can reflect the geometry, structure, and, increasingly more often, semantics of objectsmaking 3D models more than mere visualisations, and it positions them as analytical and managerial tools (Pepe et al., 2021). Building 3D modelling is a process of creating a digital reproduction of its geometry and structure in three dimensions. While it involves representing the shape, dimensions, and key structural components, the models can cover more than just accurate geometry includingdescriptions of materials, purposes of specific components, and their condition (Remondino, 2011; Klapa and Gawronek, 2022).

The 3D modelling process starts with the acquisition of spatial data from various sources, such as CAD drawings with geometric details and images from handheld cameras. The data are then analysed and integrated with image processing algorithms to be converted from 2D into 3D information. Engineers employ sophisticated technologies such as laser scanning (Light detection and ranging, LiDAR), photogrammetry, or mapping with unmanned aerial vehicles (UAVs) that also obtain 3D details. Their input is then processed into point clouds and then 3D models (Remondino, 2011; Lu et al., 2020; Costantino et al., 2021). Photogrammetry from UAV, terrestrial, or aerial images can map geometry and surface textures. Laser scanning (LiDAR), including terrestrial laser scanning (TLS), yields dense and highly-accurate point clouds that are instrumental in the case of complex structures and inaccessible places like parts of roofs or elevation details. When combined, the two methods can yield complete and precise 3D models that represent both the geometry and textures of the buildings, which makes them highly relevant to cultural heritage surveys (Remondino, 2011; Klapa et al., 2017; Pepe et al., 2021; Klapa and Gawronek, 2022). Large-scale 3D models, such as of entire cities, are often based on aerial laser scanning data (ALS), which offers dense point clouds of high precision. Engineers also use nadir and oblique image photogrammetryto deliver detailed visual data for model texturing and accurate mapping of geometric details (Costantino et al., 2021). For the data to be appropriately integrated, one must georeference them precisely, using coordinates of ground control points (GCPs) for the proper spatial orientation of the models (Pepe et al., 2019).

As technology advances, 3D models are becoming more versatile thanks to the integration of geometric, semantic, and spatial data. The process of modelling often employs Scan-to-BIM, which combines laser-scanning and photogrammetric data for a precise reconstruction of the objects in Building Information Modeling (BIM) and Geographic Information Systems (GIS) environments. This way, 'digital twins' can be created for buildings. These tools support building life cycle management, maintenance, and structural health monitoring (Pepe et al., 2021; Costantino et al., 2021). Such integrated approaches as CityGML can combine multiplatform data from LiDAR, photogrammetry, synthetic-aperture radar (SAR), and traditional architectural drawings. The models can cover the exterior as well as the interior of buildings while integrating geometric and semantic information. This way, they go beyond mere visualisation, becoming sophisticated analytical tools that further the design, management, and maintenance operations of today (Biljecki et al., 2015; Doumbouya et al., 2016).

Three-dimensional objects are modelled using BIM information and datasets that provide geometric and structural details combined with GIS data that contribute spatial and environmental information. These datasets can be integrated using such standards as IFC and CityGML, which can amalgamate information on various levels of the design environment (Kurwi et al., 2017; Ma and Ren, 2017). Input often comes from public databases, such as cadastral, aerial, or topographic databases, so that it is sufficiently detailed regardless of the specific application (Biljecki et al., 2016). BIM integrates geometric and semantic data in a single database, including material specifications, engineering diagrams, and environmental data. This way, building information can be managed effectively at any stage of the project, from conceptualisation to operation (Doumbouya et al., 2016). The versatility of 3D models has made them central to modern property management, infrastructure planning, and cultural heritage protection: They provide the framework for structural health monitoring, maintenance planning, and building life cycle management. The models, built with BIM, integrate geometric and semantic data, allowing for an amalgamation of material, cost, and functional information. In building management, 3D models help with valuation, maintenance, and spatial planning. Moreover, they add the spatial context to operational analyses thanks to their integration with GIS systems for more advanced environmental and urban simulations (Pepe et al., 2021; Biljecki et al., 2015; Klapa, 2025). In urban and infrastructural planning, 3D models are also employed in solar exposure, visibility, and irradiation analyses. Spatial mapping, crisis risk assessment, and environmental impact of buildings also make use of the models. In the case of urban cores, 3D models support precise restoration and maintenance of buildings while facilitating advanced urban science and architectural analyses (Costantino et al., 2021). Yet another use of 3D models is for infrastructure, bridge, and high-rise monitoring, where they visualise changes over time and predict failures, thus enabling engineers to investigate dynamic structural behaviour in reaction to variable loading and environmental conditions, thus facilitating repair and upgrade decisions (Li et al., 2016; Scuro et al., 2021). When integrated with BIM, 3D models are central to building management as tools for evaluating the condition, optimising life cycle, and real-time monitoring (Mishra et al., 2022; Panah and Kioumarsi, 2021).

Integration of BIM and GIS technologies is currently regarded as a key direction for enhancing real estate and facility management. The relevant literature review emphasizes that linking BIM models with GIS systems effectively – combining detailed building information with spatial context – allows for the creation of precise three-dimensional building models and the analysis of their technical condition in relation to the surrounding environment, which directly translates into support for operation and maintenance decision-making (Congiu et al., 2024). Combining BIM and GIS data significantly improves the management of distributed building portfolios – the system they propose, integrating BIM, GIS, and Business Intelligence tools for a university campus provides a digital representation of assets by coupling geometric data with performance and occupancy information, thereby allowing for continuous monitoring of facilities and more effective, timely decisions regarding their operation (Di Giuda et al., 2024). Additionally, Kang et al. (2016) developed a BIM/GIS data-integration architecture for facility management, in which information from BIM models (both 3D geometry and attributes) is automatically extracted and transformed into the GIS environment using an ETL (extract, transform, and load) process – an approach which improves data consistency and reusability, minimizes errors arising from manual data fusion, and thereby supports the correctness of decisions concerning building maintenance. Moretti et al. (2021) presented the concept of GeoBIM – integrating BIM and GIS data – aimed at assessing the technical condition of the existing built environment and supporting asset-management decisions. In their studies, an integrated 3D model of urban fabric was developed by combining detailed BIM models with geographic data at the district scale; this approach enabled efficient inventory and visualisation of large volumes of building-condition data and provided essential inputs for decisions on renovation and maintenance planning. Thanks to BIM–GIS synergy, interactive visualisation of assets within their real spatial context is achieved, which supports ongoing monitoring of operational conditions and surroundings, as well as operational and emergency decision-making in near-real time (Meschini et al., 2022). Moreover, (Congiu et al., 2024) proposed a bidirectional information flow between BIM and GIS based on open-source tools (such as QGIS and Dynamo) and the COBie standard, ensuring seamless switching between building-model databases and GIS databases without losing key information. This solution enables, among other things, the display of BIM model information on interactive 2D/3D GIS maps and the parallel enrichment of BIM models with spatial data, which streamlines space management and maintenance planning across entire asset portfolios (Congiu et al., 2024). A further step towards the integration of BIM and GIS was presented by Meschini et al. (2022), who introduced the concept of cognitive digital twins – these enable dynamic, autonomous monitoring of the real-world condition of distributed facilities (e.g., a university campus) and immediate decision-making in emergency situations or those requiring resource-use optimization, which significantly enhances the effectiveness of operational and maintenance activities (Meschini et al., 2022). The combination of semantically rich BIM models with GIS analyses provides a comprehensive information platform for property managers, integrating data on the physical characteristics of a building with its context. Such a holistic approach results in improved monitoring of technical condition, more efficient management of operational data, and better-informed, data-driven planning of conservation and renovation strategies throughout the building life cycle (Di Giuda et al., 2024).

This study aims to employ open-access geospatial databases to generate complete 3D models of residential buildings to support property management, valuation, planning, and design while streamlining property control operations. The focal point is the constructive collaboration of BIM and GIS for spatial data integration and processing, leading to more versatile models using a precise reproduction of building geometry with spatial context and semantics, which are critical for building life cycle management. The authors also analyse the role of GIS tools in combining spatial data and BIM models to improve their accuracy and versatility.

The article consists of four parts that follow the process of building comprehensive 3D models and investigate their use in property management. The introduction emphasises the importance of 3D modelling for property management, focusing on the BIM and GIS constructive collaboration. The second part details the research methods, including the geospatial data sources, such as LiDAR and photogrammetry data or open-access cadastral and topographic databases, and documents a flowchart that summarises the overall pipeline. Data integration using GIS tools and BIM is then discussed followed by a verification of the methods showcased by three selected single-family residential buildings in Kraków (Poland). Next, the authors present the results of 3D model analysis regarding geometric fidelity, level of detail, and semantic information in the context of BIM and GIS integration. The final part summarises the results and conclusions on the role of BIM and GIS synergy in property management, including cost considerations linked to the use of open-access datasets. Finally, the authors offer recommendations on optimising the modelling process and on scaling the approach and extending it with additional attributes and datasets, providing guidelines for portfolio-scale practical applications in property life cycle management.

2 Methods

2.1 Location of the study site

The study site is in Kraków, Małopolskie Voivodeship, Poland (Figure 1a). Its specific position was in the northern part of the city, Kraków-Swoszowice (Figure 1b, 1c).

Three residential buildings were chosen for the studybased on the following criteria: they were occupied, situated in the same area for monitoring of influencing factors, and covered by the same spatial databases (Figure 2a). Their structure differed in geometry and building materials. The diversity was improved by selecting a wooden building without thermal upgrades (Figure 2c) and two masonry buildings with thermal upgrades and varied geometries (Figure 2b, 2d).

2.2 Analysis of the open-access geospatial databases used in the study

LiDAR generates a point cloud, a set of coordinates in three dimensions (X, Y, Z) obtained from laser pulses reflected from the ground and objects on it, such as: buildings, trees, and components of infrastructure. ALS involves collecting data from aerial platforms like aircraft or UAVs for rapid and precise representation of large areas as point clouds, which are the basic output of the process and provide the foundation for digital terrain models (DTMs) and 3D models of objects. The technique can provide information about the height of buildings and roof shapes and slopes. It is also employed for detailed spatial analyses for topography, spatial planning, forestry, and environment monitoring (Mehendale and Neoge, 2020). In Poland, LiDAR measurement data are available for free for any use as LAS or LAZ filesdownloadable from the National Geodetic and Cartographic Resources or from Geoportal at www.geoportal.gov.pl (Geo-information Service, 2025).

The Database of Topographic Objects contains detailed spatial information about geographic features at the level of topographic maps. It offers spatial location, attributes, and metadata of such features as: transport networks, buildings, land cover, and hydrographic areas. It is the critical source of information for GIS, and it supports spatial management, planning, and strategic decisions by public administration and the private sector (Ślusarski and Jurkiewicz, 2019). The data for the territory of Poland are available free of charge from the National Geodetic and Cartographic Resources, viewable and downloadable through WMS and WMTS from Geoportal (Geo-information Service, 2025).

Cartographic resources are thematic collections of geographic space information presented as maps, plans, 3D models, and surveying records combining spatial data and their visualisations so that spatial relationships can be analysed and information can be shared easily. They are used in urban planning, environment monitoring, property management, and 3D modelling, which is necessary for spatial engineering and real property control. Thanks to their accuracy and level of detail, these sources facilitate spatial analyses, project planning, and monitoring of dynamic environments (Suveg

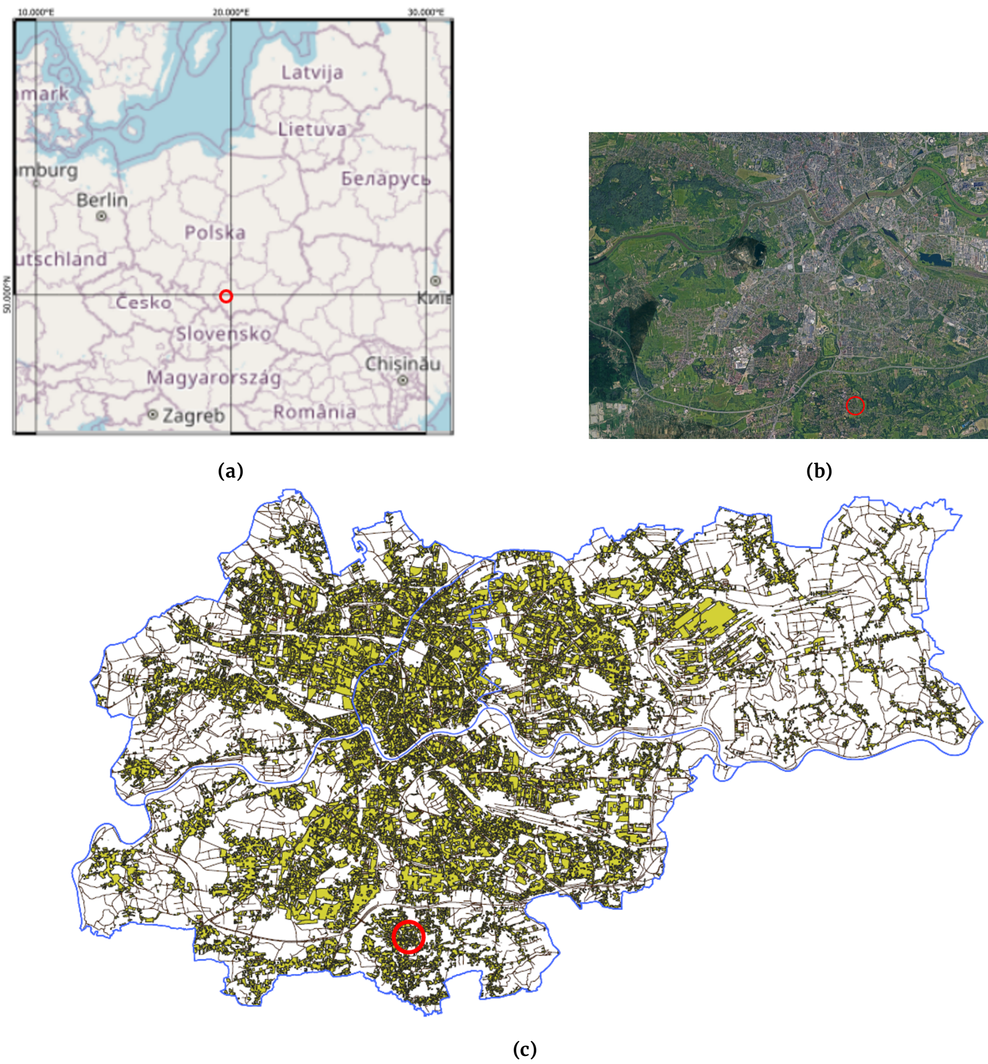


Figure 1. Location of the study site: (a) Kraków, Małopolskie Voivodeship, Poland; (b) orthophoto of the study site; (c) single-family residential buildings in Kraków with roads and administrative divisions of the city

Figure 2. The selected buildings: (a) locations of the buildings; (b) building No. 1; (c) building No. 2; (d) building No. 3

and Vosselman, 2004; Habib and Okayli, 2023). Cartographic documents can be obtained from the National Geodetic and Cartographic Resources. They can also be viewed and downloaded from spatial data websites like Geoportal (Geo-information Service, 2025).

An orthophoto is a raster image of the Earth's surface composed using processed aerial or satellite images. This digital map obtained through the orthorectification of photographs combines the geometric accuracy of a map with the visual properties of photographs. It is used mainly for terrain visualisation, spatial change monitoring, topographic analyses, and spatial planning. In property control, orthophotos are useful for identifying features, evaluating land development, and in spatial analyses (Liu et al., 2018). The orthophoto is one of the most popular sources of spatial data. In Poland, orthophotos can be viewed and downloaded free of charge from the National Geodetic and Cartographic Resources and as a WMS from Poland's official geoportal (Geo-information Service, 2025).

The land and building register database is an organised collection of information on land, buildings, and property comprising descriptive and geometric data, such as location, boundaries, area, and rights in the property. As the fundamental tool for spatial management it supports spatial planning, environment protection, and property control. The database is used for legal and tax purposes, statistical analyses, and geodetic and cartographic processes (Jurkiewicz et al., 2023). The data are commonly employed in property control all over the world. In Poland, the land and building register is accessible for a feewith the exception of some data, such as register plot and building geometry with basic attributes that are accessible free of charge. The data can be downloaded through the geoportal's WFS service for vector data sharing (Geo-information Service, 2025) in the GML format from district administration websites based on the user's requirements.

Aerial photographs are images of the Earth's surface from specialised aircraft-mounted cameras. There are two main types of aerial photographs: First, nadir images are made virtually vertically (deviation up to 5°) to represent the surface of the Earth in the form of a map. They are taken with at least 60% forward and 30% side overlap so that every piece of land is on at least two photographs. Second, oblique images are taken at a greater angle (35° to 50°). This way, not only the terrain but also building facades and other vertical features are represented. These photographs come with greater overlaps: 80% forward and 60% side. Each point is shown on over ten images for improved detail and accuracy. Aerial photographs are widely used for orthophotos, spatial analyses, environment monitoring, urban planning, research, and property management. They are particularly useful for surveys of natural resources, infrastructure planning, and assessment of natural disasters, and, in Poland, they are available from authorised geodetic institutions and public administrations that manage geodetic resources and from online spatial-data platforms (Geoportal, 2025).

Table 1 presents the methodology of acquiring and processing geospatial data, detailing data sources and formats, the software and tools employed, the nature of the derived information (geometric, imagery, attribute), and its intended use within BIM–GIS integration.

The methodological framework presented in Table 1 is further illustrated by the flowchart below (Figure 3). The diagram summarises the relationships between open geospatial data sources, processing environments, and their integration into BIM models within a BIM–GIS workflow.

2.3 Modelling – integration of open-access databases, BIM, and GIS tools

Integration and generation of BIM models – methodology

In the second stage, geospatial sources were integrated and used to create complete, detailed BIM models. Information exchange was

Table 1. Methodology for geospatial data acquisition and processing

Data source	Data format	Quality characteristics	Software / processing tools	Data type	Obtained information / processing results
LiDAR (ALS)	LAS / LAZ	Vertical: 0.10 m; Planimetric: 0.25 m; Density: 12 pts/m^2	Autodesk ReCap Pro; CloudCompare	Geometric data	Building information: building heights; assignment of storey heights; determination of roof slopes and heights; location of balconies, chimneys, terraces, and roof windows; (minor details verified jointly with orthophotos/oblique imagery)
EGiB – Land and Building Register (cadastre)	Database / GML	Depends on acquisition method and source; 0.10 m for situational details, accuracy group I – building objects (Regulation, 2020)	QGIS (field calculator, databases, database attributes)	Geometric and non-geometric data	Building outlines; building corner points; object areas; side lengths of objects
Aerial images	TIFF / JPEG	Ground sampling distance 0.05 m	Photointerpretation of image content	Imagery data	Materials, colours, technical condition of elements; façade and roof features
BDOT500 – Topographic database	Database / GML	Depends on method and form of acquisition from the National Geodetic and Cartographic Resources (Regulation, 2021)	QGIS (field calculator, databases, database attributes)	Geometric and non-geometric data	Classes and attributes of topographic objects; spatial relationships; support for validation of building location and surroundings
Orthophoto	GeoTIFF	Ground sampling distance 0.05 m	QGIS (content interpretation, identification of object locations)	Imagery data (georeferenced)	Location; materials; roof-cover and surroundings features; objects associated with the building
BIM object libraries (BIM families)	RFA	LOD3 / LOD4	Revit 2025 (creation and editing of BIM models)	Object / semantic data	BIM objects for individual building components

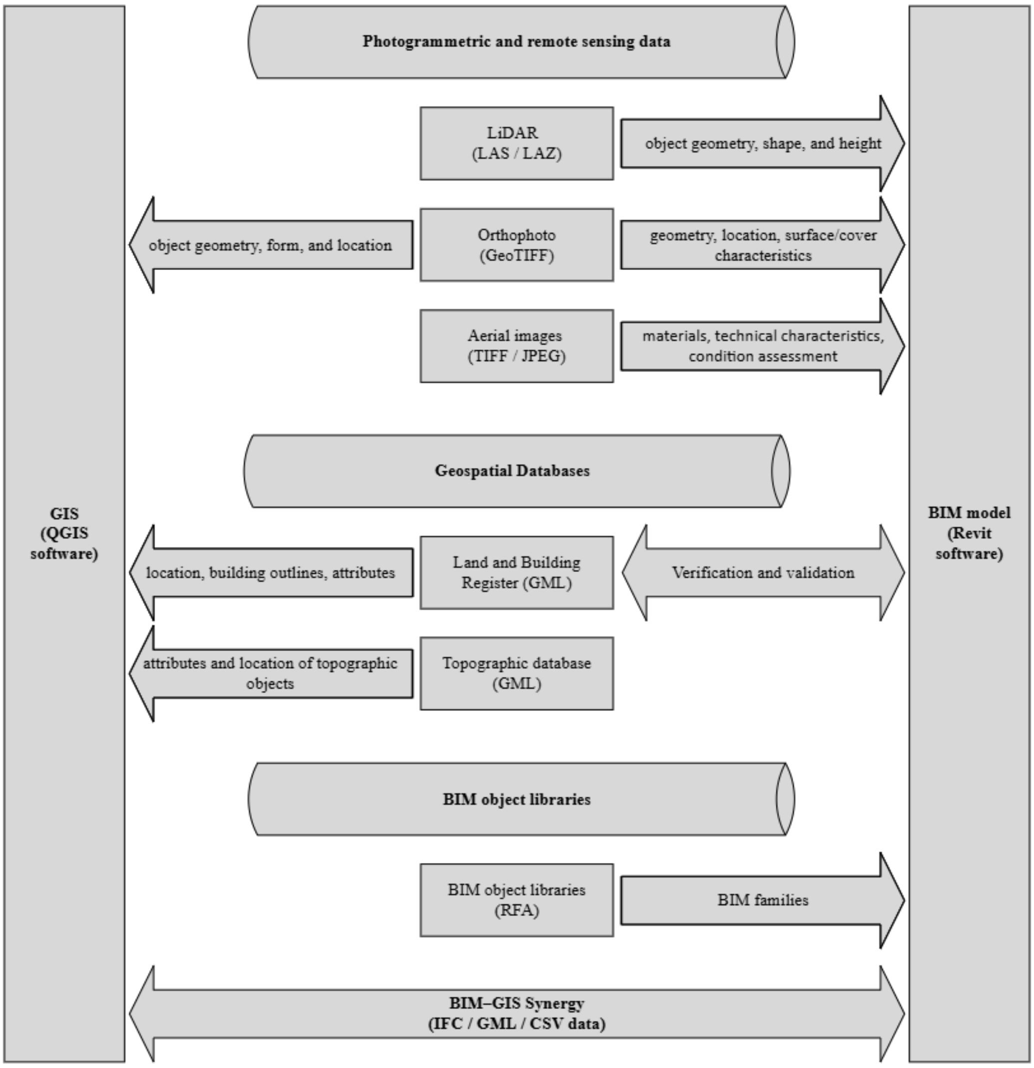


Figure 3. Open geospatial data sources, formats, and processing for BIM–GIS integration

bidirectional (import/export) between QGIS (GIS) and Autodesk Revit (BIM): context layers from GIS (vector and raster) were passed to the BIM environment as reference drawings (DWG/DXF) or attribute tables (CSV/XLSX), while models and attributes from BIM were made available for spatial analyses by exporting to the open Industry Foundation Classes (IFC) format and to tabular datasets. Modelling began with the reconstruction of building geometry from processed ALS point clouds (LAS/LAZ), integrated into Autodesk ReCap and linked into Revit as references (RCP/RCS). Based on these data, with concurrent interpretation of orthophotos and aerial imagery – the key building components were manually recreated: walls, roofs, and window and door openings, and, where supported by the data, selected ancillary elements (e.g., balconies, dormers). The resulting geometry was then enriched with semantic information, including the types of material used, roof coverings, insulation data, and an assessment of technical condition. These attributes were derived from imagery and from geospatial databases (BDOT500, EGiB) and assigned to model elements as object parameters in Revit. Although this study relied exclusively on manual attribution, the workflow allows optional semi-automation (e.g., via Dynamo/pyRevit scripts or plug-ins for CSV/XLSX import) for larger datasets.

The integration of geometry and semantics produced complete BIM models of the three analysed single-family buildings, subsequently exported to IFC. The resulting IFC models constitute a coherent database of spatial and technical information that can be directly linked with GIS layers for spatial verification, visualisation, and analysis. The developed models provide a multifunctional tool for property management: they allow for visualisation of assets and components, generation of material/technical schedules and operational documentation, execution of simulations (e.g., energy, insolation/shading), assessment of technical condition, and planning of maintenance activities. Combining BIM with GIS further facilitates advanced spatial analyses – from single assets to portfolios – supporting decision-making across the building life cycle.

3D modelling in the BIM environment

For the purpose of this study, three-dimensional BIM models of three residential buildings were generated in Revit 2025 (Autodesk). Their geometries were based on an ALS point cloud (LIDAR) from the National Geodetic and Cartographic Resources. The actual dimensions and characteristics of the buildings were sourced from QGIS integrated with the land and building register layer data. Next, the authors applied the required grid and assigned heights to individual storeys (Figure 4).

Non-geometric information about the buildings was obtained from aerial photographs, geospatial databases, and BIM object families and types appropriate for given components and objects in the model (Figure 5). Roofs, walls, doors, and some windows were identified using the Revit library. Their materials and colours were modified. Also, some windows were reshaped at the BIM family level. Some other windows were taken from the BIM Object database (BIMobject, 2025) and modified. The authors employed two sources of window objects to test the available resources and better adapt them to the buildings.

When identifying materials, families, types, and object model components, one can use BIM libraries where objects are described using technical parameters (Figure 6).

3 Results: 3D model, visualisation, and building database

The authors generated 3D models of three residential buildings, integrating BIM, GIS, and open-access geospatial data. The results are presented in Figure 7.

The models (Figure 7) can be used: for a detailed analysis of building geometry, to identify critical structural components, and to assist property management. The present approach facilitated representing actual characteristics of the objects and their visualisation as 3D models. Geometric accuracy and the level of detail of the developed BIM models are directly determined by the quality of the geospatial input. In this study, airborne laser scanning (ALS, LiDAR) data with a density of 12 points per square metre was used, with a vertical error of $\pm$10 cm and an average planimetric error of approximately $\pm$25 cm. Orthophotos and oblique imagery with a ground sampling distance of 5 cm allowed for precise identification of building components and selected material and technical features. Geospatial databases available from the National Geodetic and Cartographic Resources (PZGiK) provide situational accuracy up to $\pm$10 cm for objects belonging to the highest class of detail. As a result, the models attained a level of detail consistent with CityGML LOD3 (detailed exterior geometry including window and door openings, without interior modelling); in BIM terms, this is largely equivalent to LOD 300–350. Identification of small features (e.g., dormers, chimneys, selected balconies/roof windows) was jointly verified using the ALS point cloud together with the imagery. The results were verified by comparing geometric attributes from two sources: the reference cadastre (EGiB) obtained from the National Geodetic and Cartographic Resources (PZGiK), and the 3D BIM models created in Autodesk Revit. The analysis focused on building footprint area and front-elevation (frontage) lengths. A summary of the validation results is provided in Table 2.

3D building models derived from airborne laser scanning (ALS) point clouds achieve accuracy that reflects the quality and characteristics of the input data. The relevant literature indicates that, for point densities of about 12 pts/m^2, typical geometric accuracy is in the order of ~10 cm RMSE. The relatively uniform, spatially coherent error structure of LiDAR across a project area supports stable geometric reconstruction; at this sampling level, building shells and roof planes can be reliably captured, enabling models that meet CityGML LOD2–LOD3 requirements. These expectations align with our validation results reported in Table 2, which show high agreement between the BIM models and the reference datasets. In the context of property and asset management, this decimetre-level fidelity is sufficient for footprint-based metrics, frontage assessments and condition-related analyses that do not require interior modelling. Open ALS datasets provided by the National Geodetic and Cartographic Resources (PZGiK) make the workflow widely deployable; the same procedure can be extended with additional attributes and data sources to support broader typologies and portfolio-scale applications.

The structural characteristics of the buildings are summarised in Table 3. The list includes such components as: roofs, doors and windows, walls as well as such additional components as balconies and terraces. The data were obtained from a diversity of resources, including aerial photographs, LiDAR point clouds, orthophotos, and open-access spatial databases. Table 3 also includes information on the buildings' condition and data sources. The materials and their properties were identified with BIM libraries and geospatial information resources.

Information used in property control can be classified into several groups: surveying information (property cadastre, utilities register, property ordinal numbering register, master map), legal information (land and mortgage register, protected heritage register, State Treasury and its divisions), planning information (local zoning plans, municipal masterplans, zoning approvals, and building permits), and market information (property price registers, property valuation tables, property valuation maps, property sale offers) (Siejka, 2017; Cienciała et al., 2023). The type and condition of the primary structural components are pivotal for property management and valuation as they affect the value directly (Peng and Zhang, 2019; Gdakowicz and Putek-Szeląg, 2020; Ho et al., 2020; Lu, 2018). Property valuation is critical for sale, purchase, and investment decisions. Buildings in good condition do not require repair expenses and reach higher prices. Conversely, buildings needing

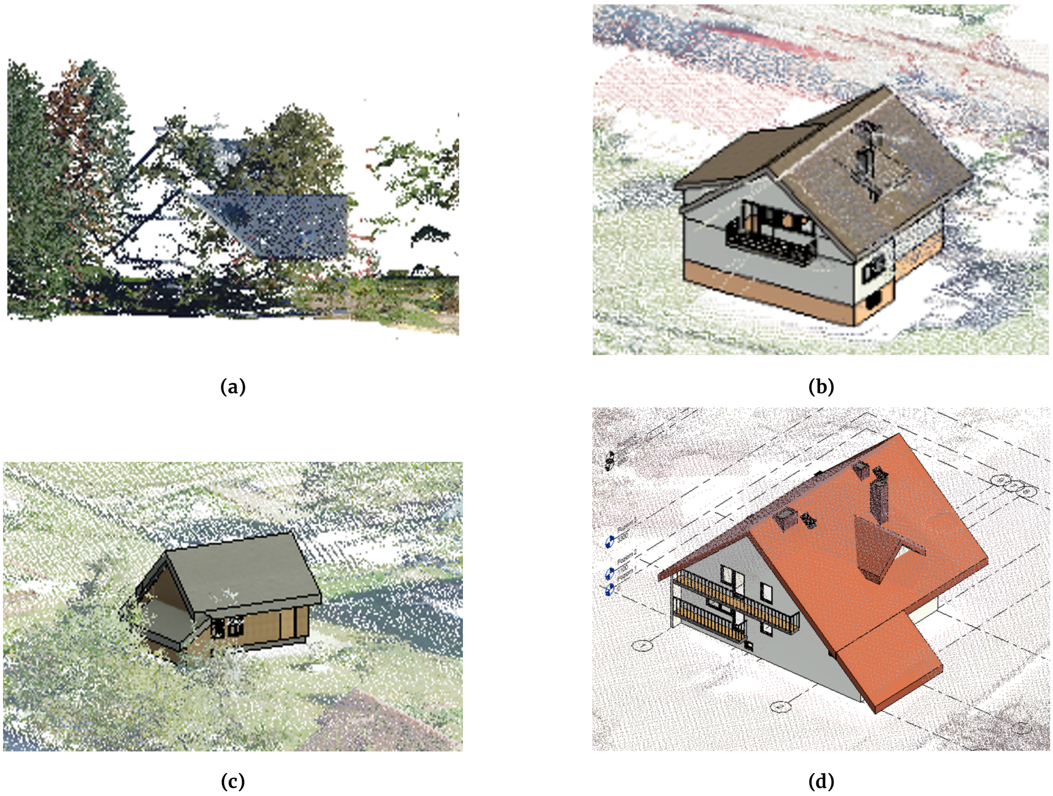
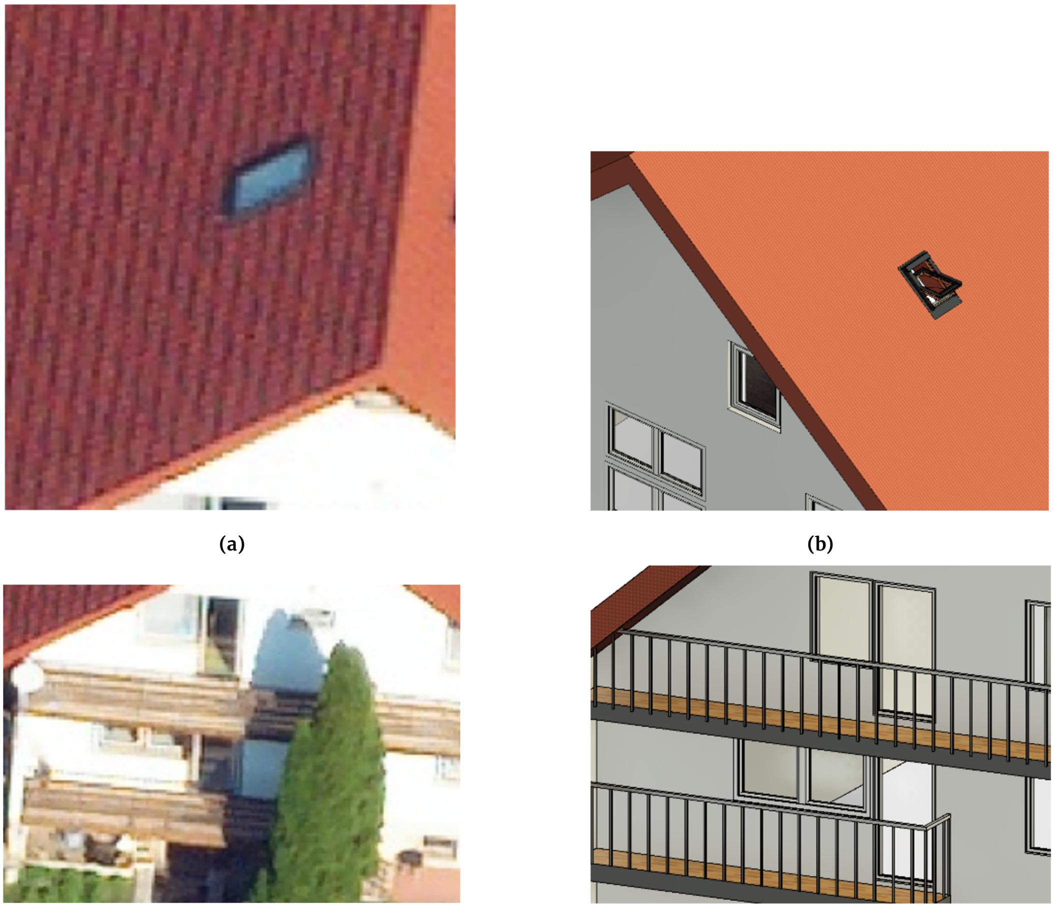


Figure 4. LiDAR point cloud as a source of 3D modelling data: (a) point cloud cross-section; (b) modelling of building No. 1; (c) modelling of building No. 2; (d) modelling of building No. 3

Table 2. Geometric validation of BIM models: footprint-area agreement and frontage-length discrepancies

Building / Object	**Footprint area**		**Area agreement** (%)	**Frontage length**		**Difference** (m)
	QGIS area – EGiB (m^2)	**Revit area – BIM model** (m^2)		**Frontage – EGiB** (m)	**Frontage – BIM model** (m)	
1	92.84	91.75	**98.8**	6.41	6.40	0,01
				0.96	1.00	0.04
				3.69	3.70	0.01
				10.35	10.40	0.05
				6.60	6.50	0.10
				1.53	1.50	0.03
				3.50	3.50	0.00
				7.84	7.80	0.04
				Mean length error:		**0.04**
2	36.05	35.28	**97.9**	7.42	7.35	0.07
				4.87	4.80	0.07
				7.41	7.35	0.06
				4.85	4.80	0.05
				Mean length error:		**0.06**
3	117.45	117.66	**99.8**	10.66	10.60	0.06
				11.02	11.10	0.08
				10.66	10.60	0.06
				11.02	11.10	0.08
				Mean length error:		**0.07**



(a) (b) (c) (d)

Figure 5. Identifying and determining non-geometric information: (a,c) identification of objects in aerial photographs; (b,d) generation of identified objects

Type Properties

Family: Pava_Double_Window_Fixed_Mullion_Koncept

Type: Pava_Double_Window_Fixed_Mullion_Koncept

Type Parameters

Parameter	Value
Constraints	
Default height of the window sill	400.0
Construction	
Construction Type	Double window
Wall Closure	By host
Left sash area	1.000 m^2
Right sash area	1.000 m^2
Sash area maximum	2.250 m^2
Window area	2.000 m^2
Window area maximum	14.377 m^2
Materials and Finishes	
Frame material	White
Glass material	Glass
Handle material	White
Dimensions	
Height	1000.0
Right side width	1000.0
Rough Height	1000.0
Rough Width	2000.0

Sort by:

(a)

Type Properties

Family: LOD100-Windows_Roof-Windows_FAKRO_Centre-pivot-window-FTP-V-U30-APZX-FSC

Type: FTP-V U30 APZX FSC - 01 - 55x78

Type Parameters

Parameter	Value
Resistance to wind load	Class C4/B4
Resistance to snow load	4H-17-4
Load-bearing capacity of safety device	Threshold value (350 N)
Reaction to fire	Npd
Water tightness	Class 9A
Solar factor g	0.530000
Light transmittance	0.760000
Harmonised technical specification	EN 14351-1:2006+A2:2016
Effective glazing area [m^2]	0.220 m^2
Opening method	Pivot
Operation mode	Automatic
Roof angle	15-90°
Material	Pine
Colour	Natural - Pine
Window perimeter [mm]	2656.0
Glass perimeter [mm]	2106.0
Internal frame area [m^2]	0.320 m^2
Frame area [m^2]	0.209 m^2
Other	
Obj Type	1.0

Sort by:

(b)

Figure 6. Assigning non-geometric information: (a) object parametrisation; (b) identification of physical and technical properties based on BIM libraries

Figure 7. Outputs of 3D modelling and visualisation: (a) object No. 1 – model; (b) object No. 1 – visualisation; (c) object No. 2 – model; (d) object No. 2 – visualisation; (e) object No. 3 – model; (f) object No. 3 – visualisation;

Table 3a. Building characteristics

Structural component		Building 1	Building 2	Building 3
roof	**type**: flat, lean-to, gable, multi-plane	gable	gable	gable
	source of the information	(oblique) aerial photography, LiDAR, orthophoto	(oblique) aerial photography, LiDAR, orthophoto	(oblique) aerial photography, LiDAR, orthophoto
	material type: metal tiles	steel decking	asbestos cement sheets	ceramic-coated steel roofing tiles
	source of the information	(oblique) aerial photography, orthophoto	(oblique) aerial photography, orthophoto	(oblique) aerial photography, orthophoto
	roof windows presence	no	no	yes (number: 4)
	source of the information	(oblique) aerial photography, LiDAR, orthophoto	(oblique) aerial photography, LiDAR, orthophoto	(oblique) aerial photography, LiDAR, orthophoto
	condition: missing material / damage (over 10 cm)	no visible missing material or damage	no visible missing material or damage	no visible missing material or damage
	source of the information	(oblique) aerial photography, orthophoto	(oblique) aerial photography, orthophoto	(oblique) aerial photography, orthophoto
building	**Footprint area** [m2]	93	36	117
	source of the information	DTO (BDOT), LandBR (EGiB)	DTO (BDOT), LandBR (EGib)	DTO (BDOT), LandBR (EGiB)
windows and doors	**condition**: missing material / damage (over 10 cm)	no visible missing material or damage	no visible missing material or damage	no visible missing material or damage
	source of the information	(oblique) aerial photography	(oblique) aerial photography	(oblique) aerial photography
balconies and terraces	**material type**: concrete, glazed tiles, wood / other	glazed tiles	not applicable	glazed tiles
	source of the information	(oblique) aerial photography	–	(oblique) aerial photography
	condition: missing material / damage (over 10 cm)	no visible missing material or damage	not applicable	no visible missing material or damage
	source of the information	(oblique) aerial photography	–	(oblique) aerial photography
	location: facade with damage	western, northern	not applicable	southern
	source of the information	(oblique) aerial photography, LiDAR, orthophoto	–	(oblique) aerial photography, LiDAR orthophoto
railing	**present**: no / yes	yes	no	yes
	source of the information	(oblique) aerial photography, LiDAR	(oblique) aerial photography, LiDAR	(oblique) aerial photography, LiDAR
	condition: missing material / damage (unless not visible)	no visible missing material or damage	not applicable	no visible missing material or damage
	source of the information	(oblique) aerial photography	–	(oblique) aerial photography
facade	**external wall insulation**: no / yes	yes	no	yes
	source of the information	(oblique) aerial photography, LiDAR	(oblique) aerial photography, LiDAR	(oblique) aerial photography, LiDAR
	material type: topcoat, concrete render, brick, natural stone	Masonry, styrofoam insulation, decorative render	wood	Masonry, styrofoam insulation, decorative render
	source of the information	(oblique) aerial photography, LiDAR	(oblique) aerial photography, LiDAR	(oblique) aerial photography, LiDAR
	condition: missing material / damage (over 10 cm)	no visible missing material or damage	missing material and damage found missing material in the western wall, replaced with a different material	no visible missing material or damage
	source of the information	(oblique) aerial photography	(oblique) aerial photography	(oblique) aerial photography

where: LandBR – the land and building register database (EGiB), DTO – database of topographic objects (BDOT), LiDAR – ALS point cloud

Table 3b. Building characteristics (cont.)

Structural component		Building 1	2	3
number of storeys	**number**	inconsistency LandBR: 1, Aerial photography: 2 (storeys + basement)	1	2
	source of the information	LandBR / (oblique) aerial photography, LiDAR	LandBR / (oblique) aerial photography, LiDAR	LandBR / (oblique) aerial photography, LiDAR
driveways, pavements	**present**: no / yes	yes	no	yes
	source of the information	(oblique) aerial photography, orthophoto, LiDAR, map	(oblique) aerial photography, orthophoto, LiDAR, map	(oblique) aerial photography, orthophoto, LiDAR, map
	material type: paving blocks, concrete	concrete	not applicable	paving blocks
	source of the information	(oblique) aerial photography, orthophoto	–	(oblique) aerial photography, orthophoto
	condition: missing material / damage (over 10 cm)	no visible missing material or damage	not applicable	no visible missing material or damage
	source of the information	(oblique) aerial photography, orthophoto	–	(oblique) aerial photography, orthophoto

where: LandBR – the land and building register database (EGiB), DTO – database of topographic objects (BDOT), LiDAR – ALS point cloud

overhauls, such as structural repairs, are valued lower. Valuation covers the current condition and potential future costs of repairs, retrofits, or conversions (Ho et al., 2020; Copiello et al., 2021).

Three-dimensional building models (Figure 7) are highly relevant to structural analysis. Visualisations precisely represent the geometry, the foundation for any technical analyses. The combination of BIM and GIS yielded a complete reproduction in three dimensions, which is critical for analyses and management. The structural analysis (Table 3) demonstrated a diversity of components and materials used in the buildings. Geospatial data and 3D visualisations provided details of the types of roofs, wall materials, condition of doors and windows, and presence of additional elements like balconies or driveways. The study confirmed that when supported by GIS and BIM, freely available geospatial data can yield detailed characteristics of buildings. Buildings designed and built with quality materials retain higher value in the long term, even if they need repairs. Property valuation can also include the predicted building lifespan, which is relevant to long-term investment decision-making. High technical standards of a building that combine aesthetics, functionality, and recent technology (energy efficiency, new systems, etc.) improve a property's appearance and value. Well-maintained buildings are valued higher than those needing thorough upgrades (Olaussen et al., 2021). The building's condition significantly affects property value by influencing user safety, functionality, maintenance costs, durability, or potential lease or sale profits. Valuation is not a derivative of location or property area only. It also involves a meticulous analysis of the types of materials used in structural and fit-out components as well as their condition.

The present results and literature review confirm that the proposed methodology of 3D building modelling founded on the constructive collaboration of BIM, GIS, and open-access geospatial data is an effective tool supporting property management. Three-dimensional models of various levels of detail (LOD) from such data sources as LiDAR or orthophotos are useful in spatial planning, structural health monitoring, and environmental analyses (Klapa, 2022; Wang et al., 2019; Biljecki et al., 2016). Analyses suggest a range of applicability of 3D BIM models to integrate geospatial, geometric, and semantic data into a single environment to support building management decision-making. Moreover, integrating BIM and GIS can yield precise 3D models useful for building and infrastructure life cycle management. As demonstrated by Pärn et al. (2017); Kurwi et al. (2017); Ryzhakova et al. (2022), this approach can help optimise schedules and costs, supports structural health monitoring, and helps make decisions based on valid and precise data. The employment of open-access geospatial databases adds to the versatility of the method and indeed to its potential for use in diverse 3D modelling and property management contexts. Digital twins of buildings integrated with BIM and GIS play a crucial role in structural health monitoring, maintenance planning, and environmental analysis. As Marmo et al. (2019); Khajavi et al. (2019); Stojanovic et al. (2018) pointed out, this approach can integrate diverse types of data for real-time change monitoring. The results have confirmed that 3D models augmented with semantics and technical data improve property management effectiveness, which is critical for sustainable development and building life cycle optimisation.

4 Conclusions

Open-access geospatial databases like map services, geoservers, cadastral data, and topographic databases are central for 3D modelling. The data add information layers and spatial context to the models, thus improving their effectiveness and utility in property and spatial infrastructure management. Integrating BIM and GIS is an effective technique for building detailed and multi-faceted 3D models to be used for property valuation, structural health monitoring, and maintenance planning. Moreover, such integrated models facilitate visualising and analysing complex spatial systems, which is particularly relevant when large groups of structures are managed. Management is improved thanks to the precise reproduction of critical structural components such as: roofs, walls, balconies, windows, and doors. When the information is stored as a model, generating, updating, and verifying the content of building databases is easy.

Open-access data, such as LiDAR and photogrammetry, cartographic documents, and topographic and cadastral databases ensure sufficient precision for 3D single-family building modelling. The tests have demonstrated that the data can be successfully integrated with BIM and GIS to generate detailed models with additional context, such as cadastral and topographic data. This method can be particularly useful for property management in regions where precise data are not readily available. However, it is crucial to consider data accuracy limitations and implement appropriate data processing and validating methods. The present study has demonstrated that 3D models support property life cycle management from design to use to demolition. They enable engineers to plan maintenance precisely , monitor material consumption, and optimise service costs. Additionally, the models can be employed to simulate investment scenarios, such as upgrade or conversion projects. This makes 3D models indispensable in today's sustainable property management ecosystems. These aspects demonstrate that insights into the technology and condition of principal structural components of buildings are crucial for effective property management, affecting safety and comfort of use, operating costs, and property value. Open-access geospatial data offer a quick way to obtain reliable and valid building data, which elevates property management effectiveness, proper valuation, and property sale security.

Using a deliberately heterogeneous sample of three buildings (geometry, structure, materials) within a single area allowed for an effective verification of the correctness and usefulness of the proposed methodology while controlling for non-object-related variables. This case selection focused on the technical details of BIM–GIS integration and on the quality of the resulting models. Although the number of analysed cases entails some degree of generalization, the study confirms that the methodology is adequate and sufficient for generating high-quality BIM models for property management. The workflow is open and scalable – additional datasets and object attributes can be incorporated, and the same procedures can be applied to analyses conducted locally as well as at much broader scales. Geometric validation (comparison against EGiB/QGIS reference data) confirmed very high agreement of the BIM models – values were virtually identical, with only marginal differences within the uncertainty bounds of the source data (see Table 2).

One of the key advantages of the proposed approach is the minimization of data-acquisition costs by relying on open source data – ALS (LiDAR), orthophotos, aerial images, and public geospatial databases. The quality and parameters of these data are maintained within the National Geodetic and Cartographic Resources (PZGiK), ensuring reliability without incurring acquisition costs. Compared with commercial spatial-data acquisition methods (e.g., commissioned laser scanning or photogrammetry), the proposed solution offers a clear economic benefit: costs shift from acquisition to processing and modelling, facilitating larger-scale deployments and routine updates. Consequently, the methodology is particularly attractive for public administration and real-estate stakeholders, enabling more comprehensive projects and spatial analyses at regional and national scales without additional financial barriers.

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