GEOMATICS AND ENVIRONMENTAL ENGINEERING • Volume 17 • Number 1 • 2023

https://doi.org/10.7494/geom.2023.17.1.19

Andrzej Szymon Borkowski[1], Łukasz Kochański[2], Michał Wyszomirski[3]

A Case Study on Building Information (BIM) and Land Information (LIM) Models Including Geospatial Data

Abstract: Landscape information modeling (LIM) is a new trend in spatial projects made using BIM technology. Elements of land development are, not only in the opinion of the authors, just as essential as the element of a building object. In turn, GIS data can be used to model larger areas based on combined data from GIS and BIM models. The lack of the strict integration of BIM and GIS (ISO/TR 23262:2021 covers GIS/BIM interoperability, ISO 19166 is in preparation) prevents the modeling of land development objects, both existing and planned, in many cases. The modeling process using the current and known BIM tools and processes were presented to efficiently develop a model of a building object with its surroundings. Modeling took place using best practices that are collected and used in the Polish reality. The work presents an object-oriented approach to modeling elements of spatial development with the preservation of the so-called occupational hygiene. By applying the above principles, it is possible to develop a "good" LIM model that fits the current trends and developments in BIM.

Keywords: BIM, LIM, GIS, integration data

Received: 13 May 2022; accepted: 27 September 2022

[1] Warsaw University of Technology, Faculty of Geodesy and Cartography, Warsaw, Poland, email: andrzej.borkowski@pw.edu.pl, https://orcid.org/0000-0002-7013-670X
[2] Warsaw University of Technology, Faculty of Geodesy and Cartography, Warsaw, Poland, email: lukasz.kochanski2.stud@pw.edu.pl, https://orcid.org/0000-0002-6861-029X
[3] Warsaw University of Technology, Faculty of Geodesy and Cartography, Warsaw, Poland, email: michal.wyszomirski@pw.edu.pl, https://orcid.org/0000-0002-5407-0536

1. Introduction

BIM (building information modeling), one of the latest trends in construction, is quickly becoming a fundamental approach to the digital integration of data and information in the design, implementation, and management of building facilities. However, in current BIM projects and integrated design and construction practices, landscape design and land development (LIM) is underestimated and has failed to take advantage of the benefits that BIM provides to the industry at various scales [1]. The advantages and benefits have already been observed from various perspectives, not only those of designers, but also investors, general contractors and subcontractors. This strengthens and accelerates the dialogue between different team members. Benefits of a Landscape Information Model would be (a) formalization of knowledge in landscape design; (b) information model to support multiple participants in landscape design; (c) improved information exchange between landscape design, architecture, and urban design [2]. The subject of BIM/GIS integration has been an area of scientific research for over a decade. In recent years, several proposals and research results have been presented (i.e., [3, 4]). An interesting classification of the process of the integration of BIM and GIS into five types was presented in [5], the first three of which refer to integration at the data level. The first method is a conversion of BIM data into GIS based on the conversion of the IFC model into the CityGML model. As a result, BIM and GIS data are stored in the CityGML model and managed from the level of GIS software. This solution is often used by authors and users of GIS systems who require detailed data concerning a given building. This issue has been discussed in numerous papers (e.g., [4, 6–15]). The second is a conversion of GIS data into BIM based on the conversion of the CityGML model into the IFC model. As a result, BIM and GIS data are stored according to the IFC model and managed from the level of BIM software. This solution is mostly used in cases when architects or people who manage a building using BIM software require data concerning the surroundings of a building [16, 17]. The third integration method at the data level is the unified data model. Solutions in this category concentrate on developing a separate unified model to combine BIM and GIS data for selected analyses and particular applications [18–20]. Moreover, the unified building model has been proposed to provide a two-directional conversion of BIM-GIS data [21–23]. The next two approaches to integrate BIM and GIS data are at the application level. First is a method of integrating BIM and GIS at the application server level. Solutions in this category offer a new concept of approaching the integration of BIM and GIS by introducing new IT (Information Technology) tools and extending existing applications so that it is possible to operate BIM and GIS data jointly. This is usually realized through the GIS application server [24]. The second method is integration at the level of the client application. Solutions in this category depend on the transformations of BIM and GIS data downloaded by independent client applications such as GIS or FM (facility management) [25–28].

This type of classification was analyzed from a slightly different, although generally similar, perspective in [29]. The authors proposed a division into three integration modes: "BIM leads and GIS supports", "GIS leads and BIM supports", and "BIM and GIS are equally involved". In recent years, more and more research has indicated an interest in the use of combined BIM and GIS data (e.g., [30–33]). A very different approach was presented in [34] where the authors proposed the contextual linking of data from different domains.

Interoperability is fundamental for the accurate interpretation and use of data within systems and tools, as well as for the re-use and exchange of data [35]. However, most of the research is focused on importing BIM data in GIS applications and vice versa. LIM uses integrated GIS and BIM data. As long as there is no comprehensive solution integrating BIM and GIS, simple methods should be considered in order to build a complete LIM model but with the desired effect. The process of importing GIS data to BIM is simple, it is not a comprehensive data integration solution, but it provides quick results. It can be used when the model is built in a BIM environment, and it is temporarily required to enrich it with spatial data from the GIS system.

The aim of the research carried out by the authors is to verify the process of integrating BIM and GIS data that allows practitioners to easily create building models enriched with spatial data of the immediate surroundings of the building in order to build a comprehensive LIM model.

2. Materials and Methods

The model used in the research covers the area of a housing estate consisting of six buildings and its immediate surroundings. The input data was CAD drawings of the construction documentation (Fig. 1).

It was performed in the Autodesk Revit software, using reverse engineering methods by modeling objects based on spatial data, as well as by importing these data. The construction design and spatial data containing information about the surroundings of the buildings were used to model the objects in the research area.

The design documentation consisted of projections, sections, elevations, and a land development plan. These sources contain information on the geometry and materials of building elements and objects in the area covered by the project.

Data on the surroundings of buildings have been obtained from many sources and contain an extensive range of information. The following data sources were used to create the landscape information model:

- base map in scale 1:500 containing, among other elements, information about the neighboring buildings, the existing communication system, and infrastructure;
- soil and agricultural maps, where the areas of complexes of agricultural use of soils are marked;

- a numerical model of land cover which is a point cloud representing the ground surface with objects protruding above it, such as buildings and trees;
- a numerical terrain model containing information about the terrain surface and points to represent the surface beneath the objects above it is interpolated;
- orthophoto map where the distribution of small architecture objects, trees, and shrubs is clearly visible, thanks to which the locations of landscape objects have adequately been designated.

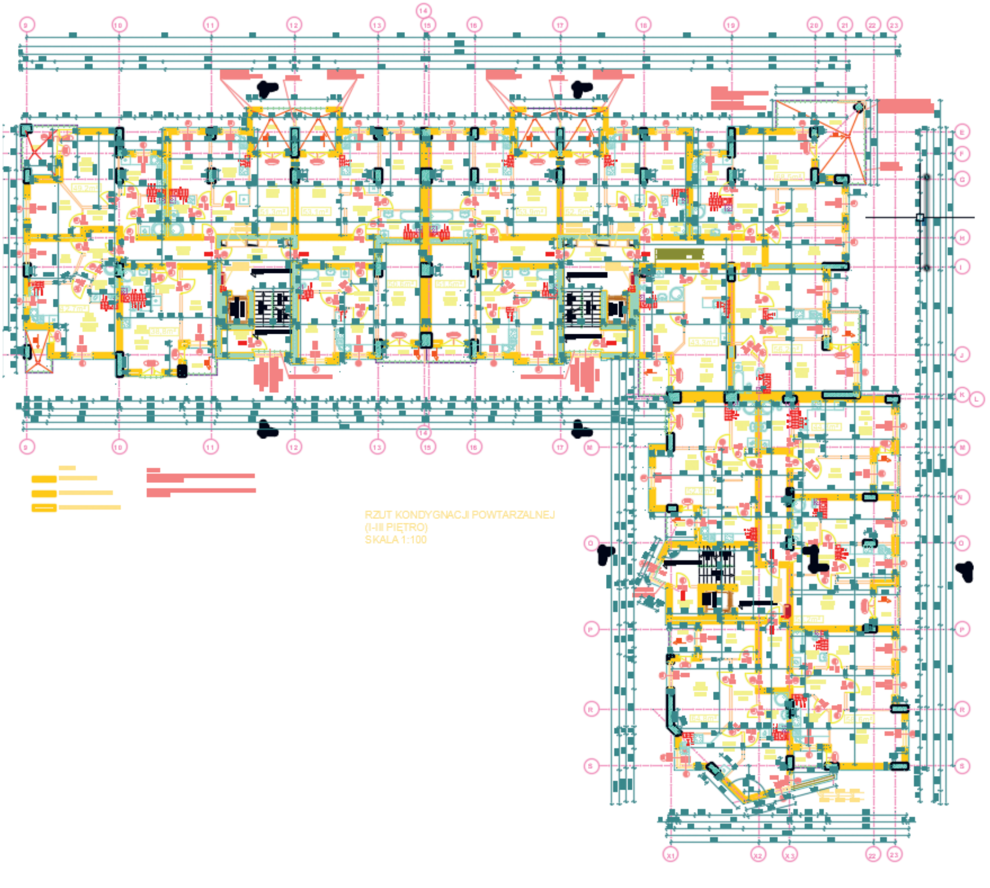

Fig. 1. Example CAD data

Photographs were taken in the research area during field visits before each modeling stage to obtain data unavailable from the above-mentioned spatial data. These were information about the surface materials and geometry of objects, as well as possible contradictions between the previously mentioned data and reality.

The list of data sources concerning the building design and its surroundings is presented in Table 1.

Table 1. List of data sources used in the test model

Data	Source	Precision	Format	Description	Data-specific quantity
Building projects	Property developer	scale: 1:100	DWG or PDF	Vector floor plan, section and elevation drawings of buildings	23 DWG drawings and 10 PDF drawings of floor plans, sections and elevations
Land development plan	Property developer	scale: 1:500	DWG	Vector drawing representing land development plan of the estate	1 vector drawing representing land development plan of the estate
Base map	Department of Geodesy and Cartography of Town Hall in Ostrołęka	scale: 1:500	DXF	Vector base map of the estate and surrounding	1 vector base map of the estate and surrounding
Soil and agricultural map	Department of Geodesy and Cartography of Town Hall in Ostrołęka	scale: 1:2000	Printout on A3 sheet, scanned and saved as a PNG file	Sheet covering the area of almost 25 ha	1 A3 printout
Digital land cover model	geoportal.gov.pl	point network 0.5 m × 0.5 m	XYZ	Point cloud covering the area of almost 486 ha	2 point clouds covering the area of almost 486 ha
Digital terrain model	geoportal.gov.pl	point network 0.5 m × 0.5 m	XYZ	Point cloud covering the area of almost 486 ha	2 point clouds covering the area of almost 486 ha
Ortophotomap	geoportal.gov.pl	pixel size 10 cm ×10 cm	TIF	Raster layer covering the area of almost 486 ha	2 raster layers covering the area of almost 486 ha
Photos	own collection	–	JPG	Photos of objects located in the area of the estate	301 photos

The scheme of input data presenting use of building source data and environment source data is shown in the Figure 2.

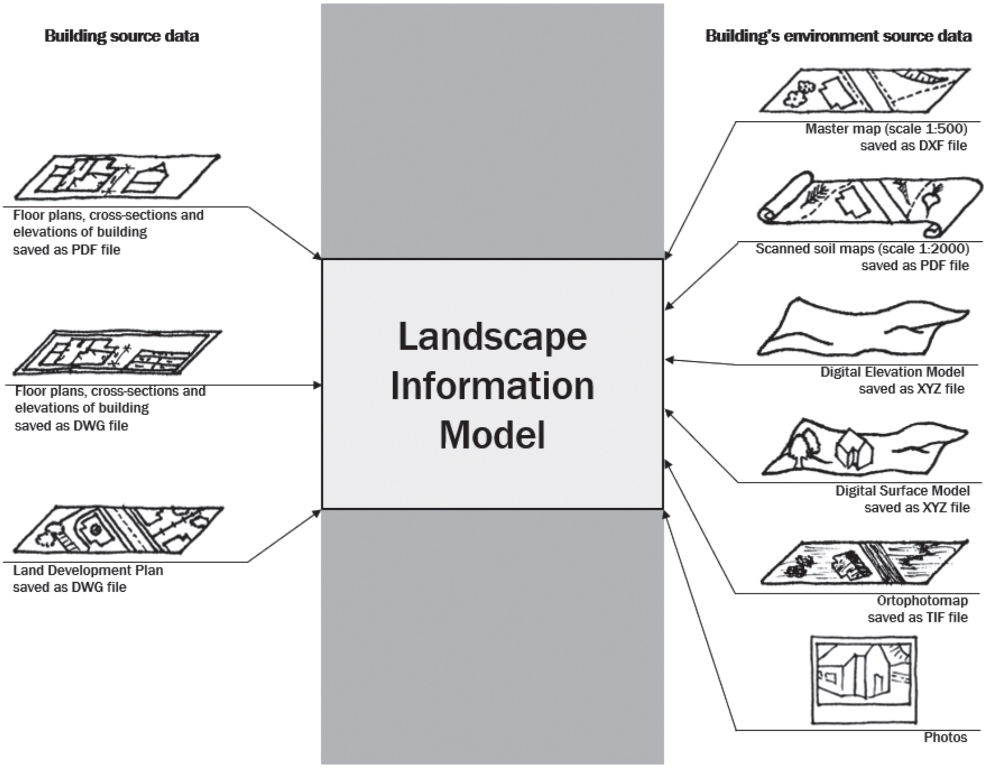

Fig. 2. Scheme of input data to the LIM model

The model building process began with the creation of BIM models of all buildings based on their architectural and construction designs. After loading the projections, sections, and elevation views to the design, appropriate levels and grids of the structure were determined on their basis, and then the modeling of structural elements, partition walls, and elements of the door and window joinery was started (Fig. 3). Each object was given dimensions and materials in accordance with the design and then compared with photos and possible measurements in the field, and in the event of differences, the parameters were edited to be consistent with reality.

Subsequently, a collective model was prepared, in which, on the basis of the base map (rotated by an angle, which was then entered as the "angle to true north"), the BIM models of buildings were combined, giving them the appropriate height and the geographical location of the project was assigned to the project. The absolute heights were read from the DEM (Digital Elevation Model) and the location was determined from geographical coordinates (in Poland, the 2000 zone VII EPSG:2178 system applies for large-scale studies). Subsequently, landscape modeling was started by creating a terrain surface by importing the coordinates of the points from the DEM. The data had to be prepared in advance by selecting points from the area of the investment and its surroundings and then reformatted into a text file that can be loaded into the Autodesk Revit software. At this point, it should be emphasized that s BIM applications do not always offer the possibility of importing GIS data. In many cases, it is necessary to use a plug-in (e.g. the PlaceMaker plug-in for SketchUp). After the terrain surface was created, the soil and agricultural raster map was properly located in the coordinate system of the project, and the terrain was divided based on its contours, giving its parts the names of appropriate soil types. The last step in creating the land surface was to model sidewalks and parking lots based on the contours from the main map and the heights of the DSM (Digital Surface Model) points contained in the inserted cloud.

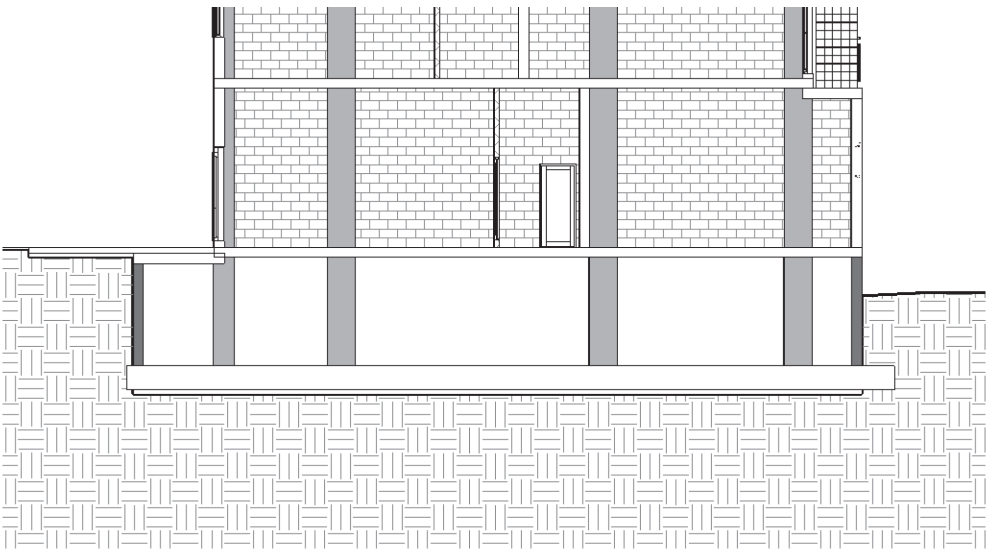

Fig. 3. Ground section

Modeling of landscape objects began with the insertion of a land development design and an orthophoto map. On the basis of these materials and the base map, locations were assigned to individual objects. The exact shape and materials of the objects were determined on the basis of measurements and photos taken in the field. Some of the families were downloaded from available resources on the internet, while some were modelled in the Family Editor available in Autodesk Revit.

Landscape objects were divided into four collections:
1) vegetation – objects with the appearance of plants, containing information about a given species;
2) loadable families – families of small architecture objects loaded into the project (e.g., benches, lanterns, litter bins);
3) system families – buildings or small architecture objects modeled with the elements obtained from the template models (e.g., walls, handrails);
4) combined projects – small architecture objects which, due to their complexity, have been constructed and combined into a common project (e.g., garbage cans).

The last stage of model building was the creation of objects in the immediate vicinity of the investment, including roads, trees, and buildings with a low level of detail. The roads were separated from the previously created terrain model on the basis of an orthophoto map, and then they were given appropriate materials. On the basis of the same study, trees were inserted that do not show the exact location and number of objects that are actually in the area but occupy a similar space. The buildings were created with the use of conceptual blocks – initially at a low level of detail (at this point it should be emphasized that the level of information is more important than the level of detail-geometry). They were made on the basis of the basic map from which the outline of each object was read and the DSM, on the basis of which the shapes of the roofs were modeled (Fig. 4).

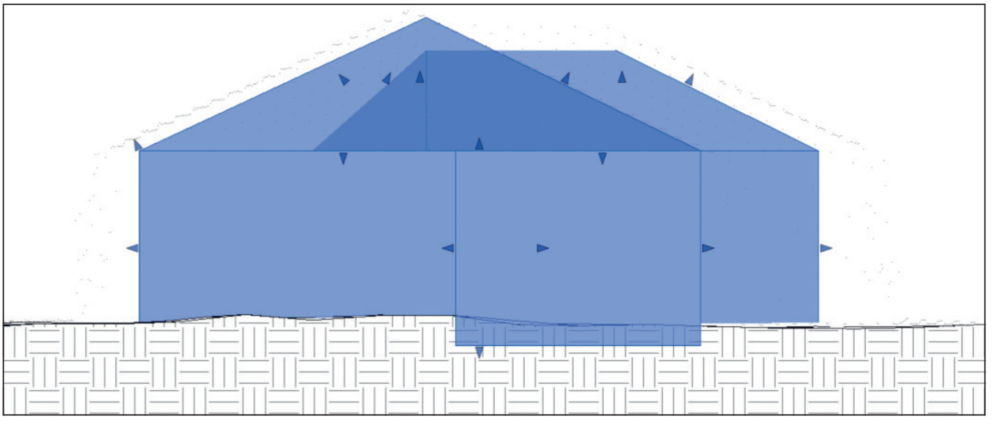

Fig. 4. Mass modeling based on the point cloud

3. Results

As a result of the process described above, three-dimensional BIM models of the buildings and a LIM model were obtained, including terrain, vegetation, and small architecture objects (Fig. 5). This was made at the level of detail corresponding to

LOD 300 (AIA classification) and allows the generation of documentation in floor and terrain projections, sections, and 3D visualization. In addition, simulations supporting decision-making, such as artificial lighting analysis and shading analysis, can be carried out on the created model.

a) b)

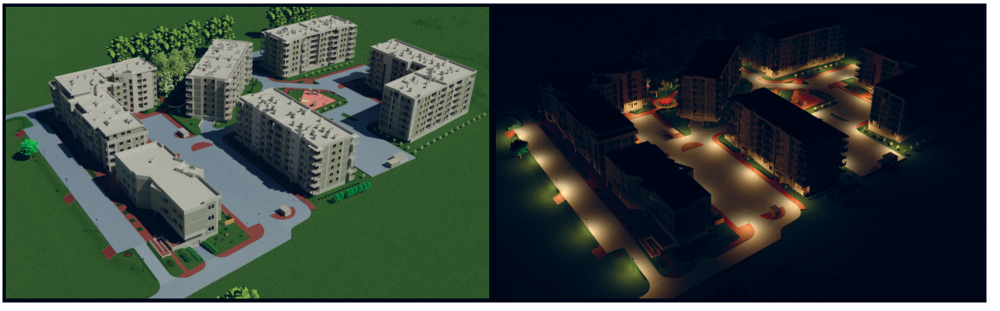

Fig. 5. 3D visualization of the BIM model:
a) standard visualization; b) visualization with an artificial light setting

The investment environment modeled in lower detail (Fig. 6) makes the investment model a natural continuation in space. The terrain surface represents actual topography and similar materials. The surrounding buildings correspond in detail to the LoD2 level. The model of the development's surroundings helps to shape the height of buildings, greenery, or technical infrastructure. Windows, doors or building elements (overhangs, stairs, etc.) are of secondary importance in the development environment.

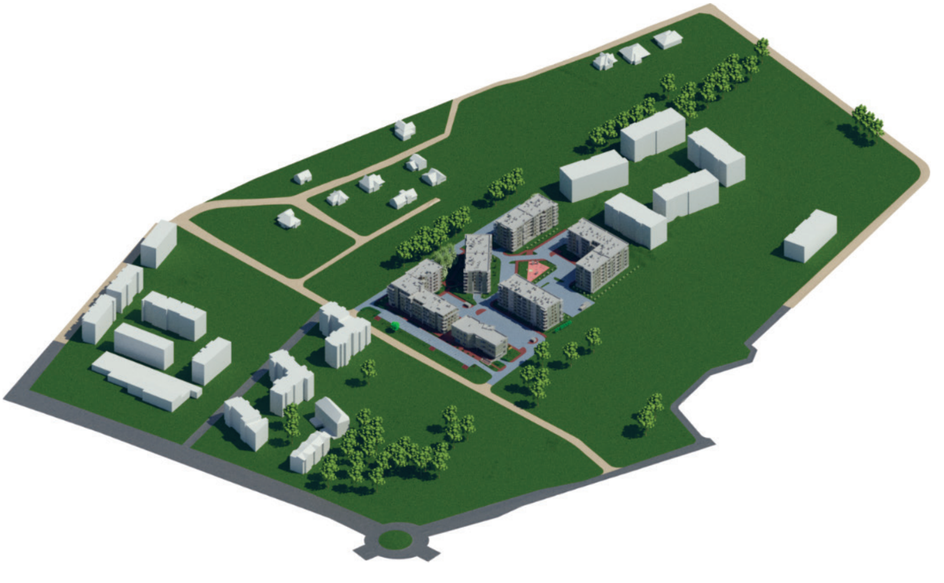

Fig. 6. View of the investment with the surrounding

The informational terrain model, which can supply significant content for the BIM model, consists of two main parts. The first is information and knowledge about the location, i.e., information about the land or the physical or legal condition of the land. The second part is information and knowledge about landscape objects, which are divided into "soft" such as plants, and "hard" such as infrastructure elements (Figs. 7–10).

Fig. 7. A photograph of a lantern

Fig. 8. View of the lantern in the model

Fig. 9. A photograph of vegetation

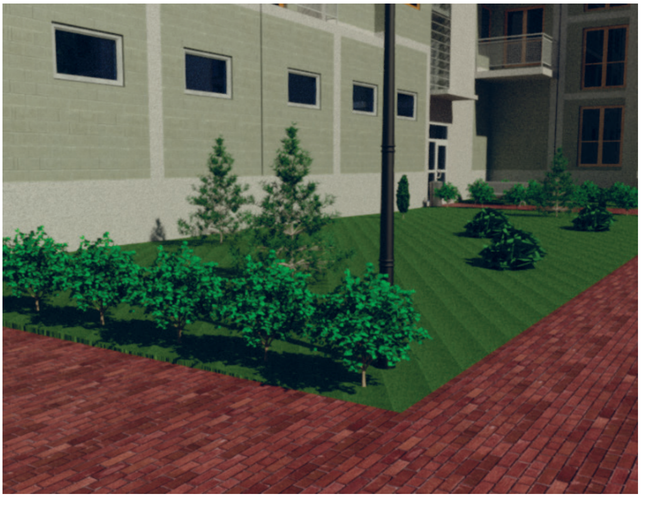

Fig. 10. View of the vegetation in the model

Topographic objects constituting an important content of the discussed project, such as the area of land, trees, shrubs, landscape architecture and infrastructure elements, reflect the actual number and location of objects in the research area. This can be seen in the control visualizations (Figs. 8, 10) juxtaposed with the photos taken during the field visits (Figs. 7, 9). Some objects, such as lanterns, are not only a geometric representation of the elements of the development but also have their own properties that allow for example, the simulation of artificial lighting (Fig. 5b).

4. Discussion

The described process is simple and not automated. It is not a comprehensive solution to the problem of BIM-GIS integration. However, it makes it possible to quickly develop a building model along with its surroundings. BIM applications increasingly provide tools for importing GIS data or support formats related to GIS data. Due to the ease of developing such a model, one can expect that many BIM models could be enriched with GIS data in a similar way.

Data on the surroundings of buildings are stored in the GIS system. They were also imported into the BIM model. The process of building a BIM model is time-consuming and requires a high level of BIM modelling skills, and after its completion, the data on the environment could be updated in the GIS system. The paradox, therefore, is as follows: a BIM model is an up-to-date building model and a valuable source of data about it that can be used to update data in the GIS system. However, the data about the environment contained in the BIM model are valuable, for example, for the purpose of model presentation, but in the case of BIM-GIS data integration, it is necessary to develop detailed procedures for data verification and selection.

Powering GIS systems with BIM models brings undeniable benefits. Similarly, BIM models need adequate and reliable spatial information. In the case of LIM, it is even more important, because the location in space (absolute ordinate, angle to true north) or location in a specific mapped or geographic coordinate system is necessary to design elements of small architecture or greenery. The more data from GIS databases are placed in the LIM model, the better it is from the point of view of the designer, but also the industry cooperation of a landscape architect, e.g., with a geologist, soil expert, or urban planner. The presented case study confirms the need for further research towards GIS-BIM integration – a database approach as well as an application collaboration.

5. Conclusion

In summary, landscape information modeling (LIM) is an essential component of any BIM model. GIS data facilitate their correct design thanks to reliable spatial information. The experience to date shows that the export-import on the BIM-GIS line is not always bi-directional and often requires either an intermediate application or a plug-in. The lack of the tight integration of BIM and GIS is a constant problem, both in the design community and in the scientific community. Work on the integration of GIS and BIM data should be continued, and the effects should have a positive impact on the development of LIM.

Author Contributions

Author 1: conceptualization, methodology, validation, formal analysis, resources, data curation, writing – original draft preparation, writing – review and editing, supervision, project administration, funding acquisition.

Author 2: conceptualization, resources, software, visualization, validation, writing – original draft preparation.

Author 3: conceptualization, methodology, validation, writing – original draft preparation, writing – review and editing, supervision.

References

[1] Borkowski A.S., Wyszomirski M.: *Landscape information modelling: an important aspect of BIM modelling, examples of cubature, infrastructure, and planning projects*. Geomatics, Landmanagement and Landscape, no. 1, 2021, pp. 7–22. https://doi.org/10.15576/GLL/2021.1.7.

[2] Zajíčková V., Achten H.: *Landscape Information Model: Plants as the components for information modelling*. [in:] Stouffs R., Sariyildiz S. (eds.), *eCAADe 2013: Computation and Performance. Volume 2: Proceedings of the 31st International Conference on Education and research in Computer Aided Architectural Design in Europe: 18–20 September 2013, Delft, The Netherlands,* eCAADe, Faculty of Architecture, Delft University of Technology, pp. 515–523.

[3] Isikdag U., Underwood J., Aouad G.: *An investigation into the applicability of building information models in geospatial environment in support of site selection and fire response management processes*. Advanced Engineering Informatics, vol. 22(4), 2008, pp. 504–519. https://doi.org/10.1016/j.aei.2008.06.001.

[4] Isikdag U., Zlatanova S.: *Towards defining a framework for automatic generation of buildings in CityGML using building information models*. [in:] Lee J., Zlatanova S. (eds.), *3D Geo-Information Sciences*, Springer, Berlin, Heidelberg 2009, pp. 79–96. https://doi.org/10.1007/978-3-540-87395-2_6.

[5] Fosu R., Suprabhas K., Rathore Z., Cory C.: *Integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) – a literature review and future needs*. [in:] *Proceedings of the 32nd International Conference of CIB W78, Eindhoven, The Netherlands, 27–29 October*, pp. 196–204.

[6] Zhu J., Wang X., Wang P., Wu Z., Kim M.J.: *Integration of BIM and GIS: Geometry from IFC to shapefile using open-source technology*. Automation in Construction, vol. 102, pp. 105–119, 2019. https://doi.org/10.1016/j.autcon.2019.02.014.

[7] Rafiee A., Dias E., Fruijtier S., Scholten H.: *From BIM to Geo-analysis: View Coverage and Shadow Analysis by BIM/GIS Integration*. Procedia Environmental Sciences, vol. 22, pp. 397–402, 2014. https://doi.org/10.1016/j.proenv.2014.11.037.

[8] Amirebrahimi S., Rajabifard A., Mendis P., Ngo T.: *A data model for integrating GIS and BIM for assessment and 3D visualisation of flood damage to building*. [in:] Veenendaal B., Kealy A. (eds.), *Research@Locate'15: Proceedings of Research@ Locate 15 in conjunction with Locate 15: Brisbane, Australia, March 10–12, 2015*, 2015, pp. 78–89.

[9] Amirebrahimi S., Rajabifard A., Mendis P., Ngo T.: *A framework for a microscale flood damage assessment and visualization for a building using BIM-GIS integration*. International Journal of Digital Earth, vol. 9(4), 2016, pp. 363–386. https://doi.org/10.1080/17538947.2015.1034201.

[10] Hjelseth E., Thiis T.: *Use of BIM and GIS to enable climatic adaptations of buildings*. [in:] Zarli A., Scherer R. (eds.), *eWork and eBusiness in Architecture, Engineering and Construction: ECPPM 2008*, CRC Press, 2008, pp. 409–418.

[11] Stouffs R.: *A Triple Graph Grammar Approach to Mapping IFC Models into CityGML Building Models*. [in:] Fukuda T., Huang W., Janssen P., Crolla K., Alhadidi S. (eds.), *Learning, Prototyping and Adapting: Proceedings of the 23rd International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA 2018). Volume 2*, Association for Computer-Aided Architectural Design Research in Asia (CAADRIA). Honk Kong 2018, pp. 41–50 https://doi.org/10.52842/conf.caadria.2018.2.041.

[12] Olsson P.-O., Axelsson J., Hooper M., Harrie L.: *Automation of Building Permission by Integration of BIM and Geospatial Data*. ISPRS International Journal of Geo-Information, vol. 7(8), 2018, 307. https://doi.org/10.3390/ijgi7080307.

[13] Jusuf S.K., Mousseau B., Godfroid G., Soh J.H.V.: *Path to an Integrated Modelling between IFC and CityGML for Neighborhood Scale Modelling*. Urban Science, vol. 1(3), 2017, 25. https://doi.org/10.3390/urbansci1030025.

[14] Colucci E., De Ruvo V., Lingua A., Matrone F., Rizzo G.: *HBIM-GIS Integration: From IFC to CityGML Standard for Damaged Cultural Heritage in a Multiscale 3D GIS*. Applied Sciences, vol. 10(4), 2020, 1256. https://doi.org/10.3390/app10041356.

[15] Matrone F., Colucci E., De Ruvo V., Lingua A., Spanò A.: *HBIM in a semantic 3D GIS database*. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XLII-2-W11, 2019, pp. 857–865. https://doi.org/10.5194/isprs-archives-XLII-2-W11-857-2019.

[16] Nagel C., Stadler A., Kolbe T.H.: *Conceptual Requirements for the Automatic Reconstruction of Building Information Models from Uninterpreted 3D Models*. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Science, vol. XXXVIII-3-4/C3, 2009, pp. 46–79.

[17] Chen L.-C., Wu C.-H., Shen T.-S., Chou C.-C.: *The application of geometric network models and building information models in geospatial environments for fire-fighting simulations*. Computers, Environment and Urban Systems, vol. 45, 2014, pp. 1–12. https://doi.org/10.1016/j.compenvurbsys.2014.01.003.

[18] Isikdag U., Zlatanova S.: *A SWOT analysis on the implementation of Building Information Models within the geospatial environment*. [in:] Krek A., Rumor M., Zlatanova S., Fendel E.M. (eds.), *Urban and Regional Data Management: UDMS 2009 Annual*, CRC Press, 2009. https://doi.org/10.1201/9780203869352-5.

[19] Hagedorn B., Trapp M., Glander T., Döllner J.: *Towards an Indoor Level-of-Detail Model for Route Visualization*. [in:] *MDM '09: Proceedings of the 2009 Tenth International Conference on Mobile Data Management: Systems, Services and Middleware*, IEEE, 2009, pp. 692–697. https://doi.org/10.1109/MDM.2009.118.

[20] Hor A.-H., Sohn G., Claudio P., Jadidi M., Afnan A.: *A Semantic Graph Database for BIM-GIS Integrated Information Model for an Intelligent Urban Mobility Web Application*. The ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. IV-4, 2018, pp. 89–96. https://doi.org/10.5194/isprs-annals-IV-4-89-2018.

[21] El-Mekawy M., Östman A.: *Semantic Mapping: An Ontology Engineering Method for Integrating Building Models*. [in:] *3rd ISDE Digital Earth Summit, 12–14 June, 2010, Nessebar, Bulgaria*, 2010.

[22] El-Mekawy M., Östman A., Shahzad K.: *Towards Interoperating CityGML and IFC Building Models: A Unified Model Based Approach*. [in:] *5th International 3D GeoInfo Conference*, Springer, Berlin 2010. http://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-52033 [access: 17.02.2020].

[23] El-Mekawy M., Östman A., Hijazi I.: *A Unified Building Model for 3D Urban GIS*. ISPRS International Journal of Geo-Information, vol. 1(2), 2012, pp. 120–145. https://doi.org/10.3390/ijgi1020120.

[24] de Laat R., van Berlo L.: *Integration of BIM and GIS: The development of the CityGML GeoBIM extension*. [in:] Kolbe T., König G., Nagel C. (eds.), *Advances in 3D Geo-Information Sciences*, Lecture Notes in Geoinformation and Cartography, Springer, Berlin, Heidelberg 2011, pp. 211–225. https://doi.org/10.1007/978-3-642-12670-3_13.

[25] Döllner J., Hagedorn B.: *Integrating urban GIS, CAD and BIM data by service-based virtual 3D city models*. [in:] Rumor M., Coors V., Fendel E.M., Zlatanova S. (eds.), *Urban and Regional Data Management: UDMS 2007 Annual*, CRC Press, 2007, pp. 157–170.

[26] Lapierre A., Cote P.-M.: *Using Open Web Services for urban data management: A testbed resulting from an OGC initiative for offering standard CAD/GIS/BIM services*. [in:] Rumor M., Coors V., Fendel E.M., Zlatanova S. (eds.), *Urban and Regional Data Management: UDMS 2007 Annual*, CRC Press, 2007, pp. 381–393.

[27] Karan E.P., Irizarry J.: *Extending BIM interoperability to preconstruction operations using geospatial analyses and semantic web services*. Automation in Construction, vol. 53, 2015, pp. 1–12. https://doi.org/10.1016/j.autcon.2015.02.012.

[28] Deng Y., Cheng J.C.P., Anumba C.: *Mapping between BIM and 3D GIS in different levels of detail using schema mediation and instance comparison*. Automation in Construction, vol. 67, 2016, pp. 1–21. https://doi.org/10.1016/j.autcon.2016.03.006.

[29] Wang H., Pan Y., Luo X.: *Integration of BIM and GIS in sustainable built environment: A review and bibliometric analysis*. Automation in Construction, vol. 103, 2019, pp. 41–52. https://doi.org/10.1016/j.autcon.2019.03.005.

[30] Tobiáš P.: *BIM, GIS and semantic models of cultural heritage buildings*. Geoinformatics FCE CTU, vol. 15(2), 2016, pp. 27–42. https://doi.org/10.14311/gi.15.2.3.

[31] Zhao L., Liu Z.-S., Mbachu J.: *An Integrated BIM-GIS Method for Planning of Water Distribution System*. ISPRS International Journal of Geo-Information, vol. 8(8), 2019, 331. https://doi.org/10.3390/ijgi8080331.

[32] Ismail M.H., Ishak S.S.M., Osman M.: *Role of BIM+GIS checker for improvement of technology deployment in infrastructure projects*. IOP Conference Series: Materials Science and Engineering, vol. 512, 2019, 012038. https://doi.org/10.1088/1757-899X/512/1/012038.

[33] Rahman S.A.F.S.A., Maulud K.N.A.: *Approaching BIM-GIS Integration for 3D Evacuation Planning Requirement Using Multipatch Geometry Data Format*. IOP Conference Series: Earth and Environmental Science, vol. 38, 20195, 012033. https://doi.org/10.1088/1755-1315/385/1/012033.

[34] Beck S.F., Abualdenien J., Hijazi I.H., Borrmann A., Kolbe T.H.: *Analyzing Contextual Linking of Heterogeneous Information Models from the Domains BIM and UIM*. ISPRS International Journal of Geo-Information, vol. 10(12), 2021, 807. https://doi.org/10.3390/ijgi10120807.

[35] Noardo F., Harrie L., Ohori Arroyo K., Biljecki F., Ellul C., Krijnen T., Eriksson H. et al.: *Tools for BIM-GIS Integration (IFC Georeferencing and Conversions): Results from the GeoBIM Benchmark 2019*. ISPRS International Journal of Geo-Information, vol. 9(9), 2020, 502. https://doi.org/10.3390/ijgi9090502.