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3D SPATIAL DATA FOR BUILDING MANAGEMENT CASE STUDY

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Abstract. As the concept of the Metaverse develops, there is more and more discussion about the integration of digital data in various industries. Metaverse as a concept covers the use of various types of technologies and solutions in the virtual environment. This paper presents the application prototype of 3D spatial data in the building management cycle. New buildings and existing buildings contain different types of information: archive information, 3D geometric information, sensor information, etc. The building is not a stand-alone structure, but the plot of land on which it is located or the territory adjacent to it, which contains engineering communications and transport access possibilities, is attached to it. Building construction processes use BIM technologies and the 3D geometric models included in it, the application of which is not always effectively used after the building is built. The article discusses the acquisition, processing, and application of 3D data for the creation, monitoring and use of 3D geometrical models to analyse the life of the building. The article also discusses the issue of updating data during the life of the building and the application of the digital twin concept, applying future scenarios with the help of simulation. The aim of this work is to use 3D technologies, BIM and 3D models with building management.

Keywords: laser scanning, photogrammetry, BIM, virtual reality, augmented reality, GIS, computer graphics, IOT, digital twin, metaversa.

Introduction

With the development of technologies and rapid digitization of the construction industry, the term digital twin is increasingly encountered. Therefore, it is important to understand the meaning of the concept of digital twin, how they are divided, what is the evolution and application of digital twin technology. Now, it is difficult to define a specific and unified explanation for the digital twin, which could be applied to all industries and sciences in which this concept appears (Piromalis & Kantaros, 2022). In each industry, the use of the digital twin and the understanding of it may differ slightly, but the common thing in all industries is that it is a digital model that represents a physical thing, object, or system, such as a building, aircraft, ship, city, etc.

Digital twin technology has been continuously evolving since 2002, when the digital twin concept was first defined. Gartner's three-stage digital twin technology evolution model is widely used in the world, in which the existing world is duplicated in the first stage, controlled in the second stage, and optimized in the third stage (Jeong et al., 2022; Schwarz & Wang, 2022; Piromalis & Kantaros, 2022). In most of the existing studies, after duplicating one product or system in a virtual environment, it can optimize based on duplicate model simulation results. Since each system in the real world is specific and complex, a single system of a digital twin cannot provide an overall optimal solution (Schluse & Rossmann, 2016).

The building's digital twin is able to provide us with real-time data about the spaces in the building, such as temperature, C02 level, based on data from various sources, sensors. Also, the digital twin of the building gives the opportunity to create simulations such as, for example, the simulation of energy consumption, in which energy consumption is observed both for the moment and at the same time provides the opportunity to

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predict what it could be and what it should be (Tomin et al., 2020). The digital twin of the building is one of the basic components for the 3D geometric model of the building, which is obtained from spatial 3D data (Segovia & Gracia, 2022). Various methods and technologies are used to collect spatial data, dividing them by environment: outdoor and indoor data. The following technologies are used to acquire outdoor and indoor 3D data (Mohammadi et al., 2021):

- 3D laser scanners,
- Drones,
- Existing databases and geographic information systems,
- Existing 3D model of the building,
- Sensor data,
- Existing Building Information Model (BIM),
- Sensor data.

GIS and BIM can be used throughout the life cycle of a building, including building management and maintenance, and territory management. The information contained in the BIM model facilitates the planning of repairs and maintenance of the existing structure, reducing costs and the speed of response to emergencies. On the other hand, the GIS system allows to effectively maintain the management of the territory adjacent to the building, using GIS functions, which allows both the analysis of management costs per unit, as well as the monitoring and integration of the territory together with the BIM model (Zhu et al., 2022).

The work explores the integration of spatial data and BIM models of small areas in building management processes, covering data collection, creation of 3D models and data transfer to the GIS system. 3D laser scanner and photogrammetry technologies provide 3D data collection in the form of 3D point cloud and reality model. The 360 images obtained by both drones and laser scanners also allow managing the territory in the form of a virtual tour by combining them with database information from management models (Zhu et al., 2022; Celeste et al., 2022).

Virtual reality and augmented reality technologies make it possible to present 3D models and textual data, using the possibilities provided by 5G technology – to transmit data quickly to any device in time and space. Metaverse concepts offers to address and use 5G technologies, enabling the transformation of large volumes of data to the user's equipment (Yang et al., 2022). The study uses Unreal ENGINE, which allows large amounts of data to be collected and simulated in a virtual environment, making the digital twin dynamic.

One part of the research covers the integration of outdoor underground information in the construction management system and displaying it in a 3D environment (Sepasgozar et al., 2023).

By spatially managing the building life process and connect with the information surrounding it. It is possible to achieve both effective maintenance of spatial data and economically manage the building and provide a safe environment for the employees or residents in the environment.

1. The case study, materials, methods

1.1. Case study

The object of the study is the student campus of the Riga Technical University in Riga, which is located close to the center of Riga on an island covered by the Daugava River. The territory is ~20 h large, on which there are both buildings with various functions and adjacent territory, which are subject to management and maintenance. At the time of the research, several buildings were in the process of new construction or renovation in the territory. The construction process gives the opportunity to collect information on various stages of construction, as well as to obtain detailed geometry bases for the creation of a 3D BIM model (El-Omari & Moselhi, 2008). Figure 1 show campus of the Riga Technical university in 3D model.

3D spatial data about the Riga Technical university was obtained using photogrammetry and 3D laser scanning method, preparing the main data sets in 3D point cloud format and 3D model in 3MX and obj format (El-Omari & Moselhi, 2008). All data connected to Latvia Coordinate system and Latvia Height system. Figure 2 describe the main process from data collection to integration in GIS system. GIS technologies form ESRI and Bentley Context Capture, Bentley OpenBuildings Designer from Bentley Systems was used as main software for creating 3D models from point clouds and images, and integration in GIS platforms as Arcgis Online and Arcgis Enterprise Portal.

Figure 1. Territory of the Riga technical university

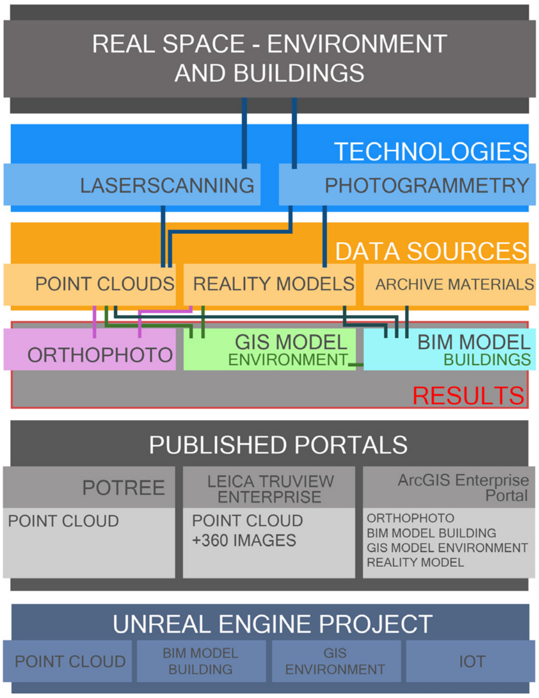

Figure 2. General workflow of the prototype

1.2. Data Acquisition and processing

The one aim of the research is to create a prototype in a GIS system and UNREAL ENGINE by combining and analysing different types of spatial data: point clouds, reality models, BIM models and sensor data. The data collection process is carried out in different environments – outdoor and indoor, and in the construction stage. As the last step in the research, perform data analysis and visualization through a GIS system and integration on VR/AR equipment (Xu et al., 2023; Lin et al., 2018).

The BIM model is one of the most important elements in the overall digital management of the building. It contains both the 3D model of the building, which reflects the location of the building's structures and rooms, their areas, as well as accompanying documents about the assets required for building management. Real estate does not consist only of buildings, but also of undeveloped land (parking lots, footpaths, green territory and infrastructures (lighting, water supply, etc.). Property management and administration includes regular cleaning of the area, surveying of building structures and maintenance of equipment. In addition to these there is also the daily hygienic and aesthetic maintenance of premises and structures. Each of the above-mentioned maintenance activities of the territory or structure requires a regular calculation of financial flows, which can be applied to unit costs (area, equipment, structure). By maintaining a regular database, it is possible to predict the necessary annual, monthly, or daily survey or management activities. Likewise, the asset model (ventilation, water pipes, equipment, etc.), which are BIM components, which contain the parameters and guarantees of the active parts, allow timely planning and organization of maintenance, guarantee or quality requirements. Sensors, construction management system (BMS), etc. shows the regular accumulation of water, allows monitoring of climate and air quality indicators, applied to a specific room or place. An up-to-date BIM model makes it possible to announce larger renovation works or ongoing maintenance works or equipment replacement faster, because all the necessary data is already available (Thomson & Boehm, 2015). Figure 3 give information about feature classification for BIM 3D model.

Figure 3. General workflow from data collection to 3D parametrical model

By digitizing the processes, the BIM model is given a second data life, which allows these data or its components to be used not only in the construction maintenance cycle, but also by providing full-fledged visual information data combined with databases to be used in VR/AR systems, which become an assistant in property management and allow simulating events from the sensors (Salem et al., 2020).

The application of GIS technologies allows simultaneous management of both spatial environmental data and building data and combining them with databases. GIS makes it possible to quickly update the information needed in management from current data, such as areas of roads and car places, changes in vegetation, reconstruction, and use of premises, monitoring data of crops, etc.

Integrate 3D point clouds and photogrammetrical results, to use GIS applications detecting the main features roads, vegetation, infrastructure objects. Data are analyzed and visualized dashboards and thematic maps, the results are published on the ArcGis Enterprise portal (Jing et al., 2019; Bovkir & Aydinoglu, 2021). Figure 4 shows the main stages of creating a GIS model.

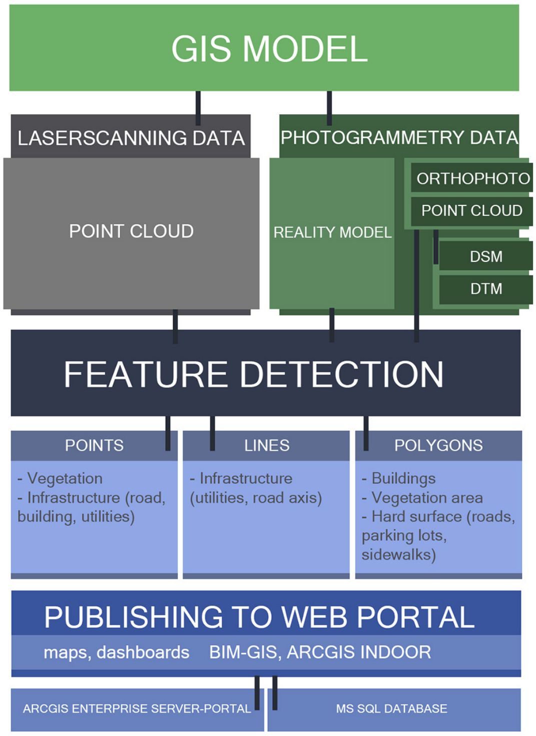

Figure 4. The main stages of creating a GIS model

3D point clouds for the exterior and indoor were collected to use 3D laser scanning technologies, collecting data for both existing buildings and those under construction, obtaining a point cloud set with 3 mm accuracy and 3–5 mm resolution. Data processing was performed with Cyclone Register and Cyclone, providing data publication on the Leica Truview Enterprise portal (Russhakim et al., 2019).

The photogrammetry method was used to obtain an orthophoto and a homogeneous 3D model of the area. By acquiring data in a short period of time, it is possible to exclude the influence of solar reflection and vegetation variability on the orthophoto and 3D model, which provides both geometric and visual information. To obtain good quality images from photogrammetry, flights were made at different heights: 50 m and 30 m, which provided 2 cm/pix resolution both at building and ground level. The buildings were flown separately at different heights, obtaining facade images with a resolution of up to 1 cm/pix. The objects in the construction process were flown in several periods, ensuring the gradual collection of information about the constructive elements of the building, reaching an average resolution of 1 cm/pix. The image shows the changes in the building during construction using the photogrammetry method. Photogrammetry data processing was performed in Bentley context capture, creating a 3D model. In the process of creating the model, trees and bushes were separated. Trees and bushes were separated in the 3D modeling process with Blender and Autodesk MeshMixer software's. Increasing the geometric accuracy of buildings, point clouds of building facades from ground laser scanning data were added in the process of processing photogrammetric results. The result is a point cloud e57 format, a reality model in 3MX format. The accuracy of the results is 2 cm/pix resolution from the ground and 5 mm accuracy in the plane and 2 mm in the vertical position. For the building are 1 cm/pix resolution.

Virtual and augmented reality technologies make it possible to use 3D models for various purposes, both by providing the representation of existing spatial data and by using them for simulations, such as animating CO_2 sensor indicators, getting to know the territory virtually, or developing various autonomous mobility technologies using digital twin components. To place 3D objects in VR and AR equipment, it is necessary to understand the mutual migration of graphical objects between technologies and the transfer requirements of big data using 5G technologies. Figure 5 give detailed information the main stages of data integration using Unreal Engine.

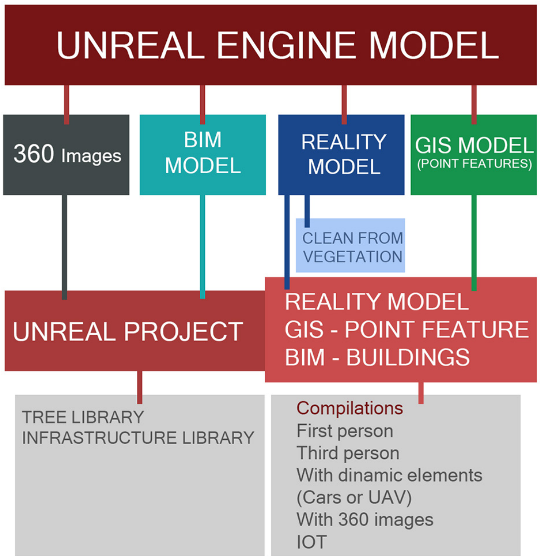

Figure 5. Workflow for Unreal Engine project

1.3. Results

The main results of the study are a Digital twin model, including a reality model, a point cloud, photographs and 360 images. The all data are prepared in WGS – 84 coordinate system.

The results from scanning works are the Latvia coordinate system EPSR3059 segmented for modelling purposes to make it easier to build a 3D BIM model (building, environment). Point cloud is cleaned and unified. Figure 6 shows a part of the point clouds of campus. The amount of the data is ~1300 scan positions and ~800 Gb per building, 3 mm accuracy and 2 mm space between points. One building contains average 10 billion points after unifying the clouds.

Photogrammetrical results are presented the reality model in 3MX format, mesh as obj and point cloud in e57 format (Mora et al., 2020). Amount of the data are ~5000 images with 24 Mpix resolutions used to to create model campus and ~2000 images separate for every building. Images taken from different altitude levels: main campus model from 50 m and building taken from 5–30 m from ground level. The flight trajectory presented in Figure 7.

The 3D modelling results are BIM model and 3D mesh model for buildings. 3D BIM model results presents the building outside – facade, roof and inside information – floor, rooms, public area divided for main objects described.

When creating a BIM model, the emphasis is placed on the creation of objects that cover the process of managing and managing the property, which is necessary for the performance of daily work and the monitoring of annual processes. When creating the BIM model, the LOD300 level has been chosen as the goal of detail, which ensures the acquisition of the main geometric parameters of the building and ensures the retrieval of the main volumes and possibility to connect attribute information (Latiffi et al., 2015; Grytting et al., 2017). The BIM model is created with aim of integrating into VR/AR equipment and GIS system, with the possibility to create simulations, data visualization and analysis. It is always possible to increase the level of detail of a BIM model by using point clouds and reality models obtained during the construction process and containing structural information. Figure 8 visualise simple BIM 3D model of the building.

As GIS systems develop, it becomes possible to use datasets and BIM models as a component of GIS. The 3D GIS model is built using ESRI technologies, which allows for the development of the integration of different data

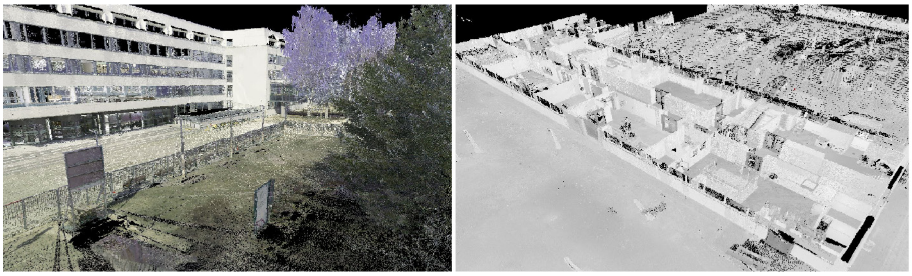

Figure 6. Part of the campus in pointcloud

Figure 7. Context Capture view

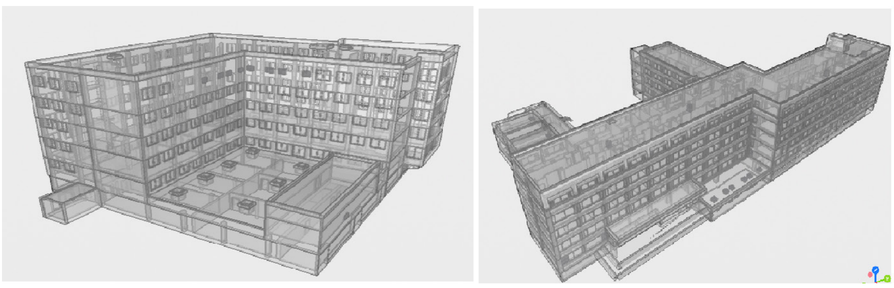

Figure 8. 3D BIM model of the building

sets together and the analysis of these data. GIS system content full environmental elements, underground utilities and building BIM model. GIS and BIM model can be updated and continued for next level of detail to integrate new assets and higher precision of the base data. Figure 9 represent full GIS model with underground and buildings in Arcgis Enterprise portal. GIS technologies allow for spatial analysis and acquisition of volumes, creating dynamic thematic maps that respond to real-time changes, bringing the spatial model to life as a digital twin (Kim, 2016). Figure 10 show analyse possibilities to use instrument panel – dashboard.

By simulating processes in a digital twin, Unreal Engine technological solutions provide an opportunity to understand quality and safety processes in construction and the surrounding area. Unreal Engine project has integrated BIM model using IFC format, reality model to use OBJ format – divide by tiles and point features to use fbx format. In the process of creating the project, landfill elements were also separated and integrated from the GIS model. The visual appearance is also very important for the Unreal project, which allows to bring the virtual environment very close to the real environment. An object-oriented programming approach was used for the simulation of the processes, which allows to effectively display the processes in the environment. Figure 11 illustrate Unreal Engine design process.

Figure 9. 3D GIS view in Arcgis Enterpise portal

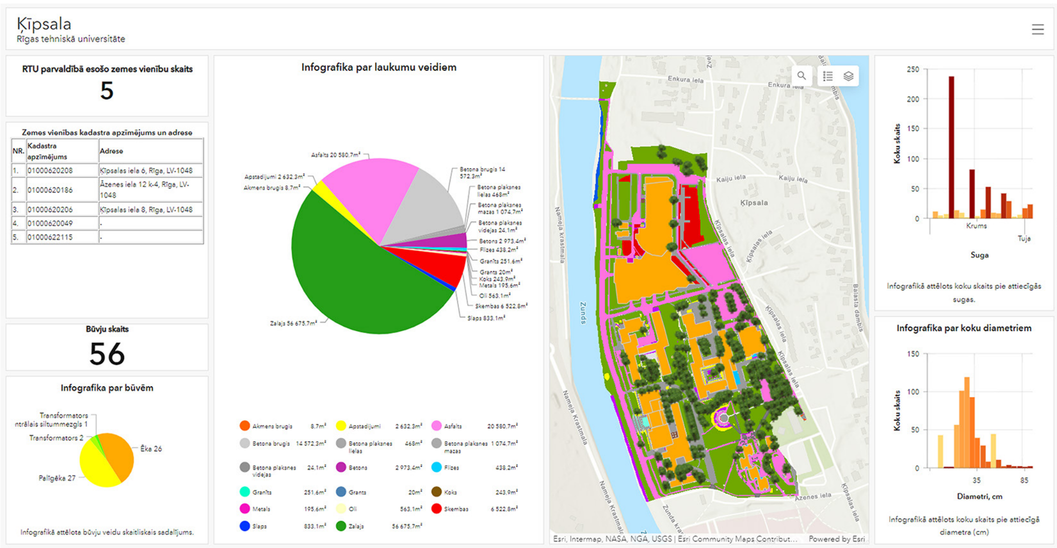

Figure 10. Dashboard view of the analyze spatial data

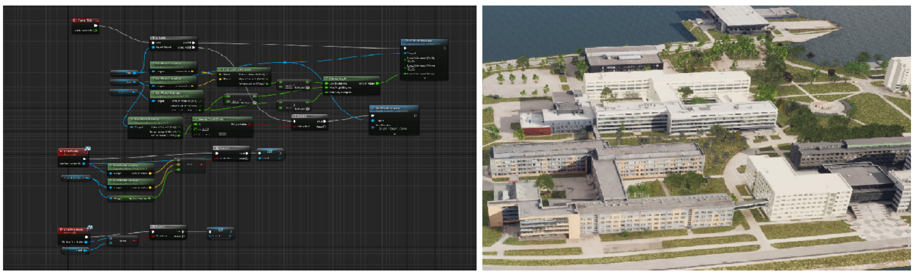

Figure 11. Unreal Engine design view

Conclusions

The research covers the application of spatial data: point clouds and reality models and their management in information systems. With the digitization of territory and construction management, spatial data is one of the data sets that help to understand the management areas and predict the necessary works. By integrating management information in the digital twin and visualizing the data and analysing it in the GIS system, it is possible to track the flow of work performed. On the other hand, looking at the building information, the BIM model is mostly unchanged for a long time after construction and is not widely used if we do not integrate it into a digital twin. The building's digital twin with sensor data allows you to see current information and simulate events that have occurred or may occur. The building's digital twin also allows for the integration of daily service or management data for equipment that is necessary for the building's functionality. By qualitatively and sustainably collecting infrastructure data in 3D datasets, it is possible to immediately use current data when predicting renovation or reconstruction works. Regularly collecting and updating current information about a separate area in the form of a digital twin, it is possible to integrate the data into the city's digital twin by describing the metadata information in advance.

Next step of the digital twin is developing data transform to user applications, to use XR devices. These transformation algorithms including 5G technologies to show all data in right place and time.

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Contribution

Conceptualization, J.S.V., E.T., M.K. and I.E.; methodology, M.K., I.E, L.G., K.G. and V.V.; software, V.V., I.K, R.S., L.G.; validation, J.S.V., E.T., M.K. and L.G..; formal analysis, M.K. and I.E.; investigation M.K. and I.E.; resources, M.K. and I.E.; data curation, V.V. and M.K.; writing – original draft preparation, M.K.., V.V.; visualization, M.K and V.V.; supervision, J.S.V., E.T., M.K. and I.E..; funding acquisition, M.K and I.E. All authors have read and agreed to the published version of the manuscript.

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