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INTEGRATION AND WEB-BASED PRESENTATION OF 3D CITY MODELS AND BIM DATA: THE CASE OF THE KÖYCEĞİZ CAMPUS

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ABSTRACT:

Smart cities increase the quality of life of people living in cities with the help of technology. They are the living spaces where practices that minimize the adverse effects of city life are implemented. The ever-growing and complex structure of cities has increased the need to include advanced information and communication technologies in management processes. In addition, the creation and use of three-dimensional (3D) city models in different areas are becoming widespread. 3D city models can be used for spatial analysis and visualization in various applications such as urban and telecommunications planning, disaster management, real-time simulations for educational purposes, and facility management. New concepts and techniques such as 3D GIS and virtual geographic environments are still under development in this context. In addition, Building Information Modelling (BIM) processes are of great importance for the construction of buildings, from manufacturing to operation and management, to the theme of smart cities.

In this study, three-dimensional (3D) city models produced by terrestrial and aerial photogrammetry, BIM, and campus infrastructure projects produced by the theme of smart cities were presented on the web. Evaluations were made on the comparison and integration of the mentioned systems.

1. INTRODUCTION

Smart cities are living spaces where practices that increase the quality of life of people living in cities with the help of technology and minimize the negative effects of city life are implemented. In addition, they are urban structures built on an integrated information organization that has an advanced City Information System, where citizens can benefit from all services via fixed or mobile systems and provide information returns in every field. Smart cities offer real-time information and solve the problems of the city. Today, “Smart City” solutions aiming to solve the problems of cities and increase the quality of life of those living in cities gain importance and are rapidly being implemented in many cities worldwide. It implemented intelligent city solutions in such a way as to enable decision-making based on real-time information and integrated with the information technologies infrastructure systems of cities such as City Information System (CIS) and Geographic Information System (GIS). With the developing technology, it is seen that CIS has developed into 3D and continues with 3D City Models. The most important data generation method for 3D Urban Models is photogrammetric methods based on LIDAR and UAV technology. In recent years, the use of laser scanning systems (lidar systems) has been increasing rapidly in 3D modeling studies, detection of deformation areas, restoration, and survey work.

Building information modeling (BIM) is a numerical representation of a facility's physical and functional characteristics. BIM serves as a shared source of useful information for a facility, providing a reliable foundation throughout its lifecycle from its inception. In the context of facilities management, GIS is used by owners and managers to manage facilities of different scales. GIS data is expected to answer many different questions that require location, time, and descriptive information, such as the following:

- What is the average area per employee by department (m^2)?
- Where are the fire extinguishers that need to be inspected next month?
- How many toilet cubicles are there for the disabled, and what is the distance from the furthest room?
- What rental areas can serve as cafeterias in the next six months?
- Which valves must be closed to disable the main pipe, and which buildings will it affect? (Akkaya et al., 2011).

To answer these questions, it is necessary to compile all the natural and artificial details found underground, on the ground, and inside the building in the same database (Przybyla, 2010). The main reason facility owners and managers need GIS is to make their buildings smarter. Making the long-term operation and maintenance of buildings sustainable requires retrofitting existing buildings or designing and constructing new ones. A smart building is a building managed with data and information systems that help to build planners and managers make faster and more accurate decisions through analysis, visualization, and reporting (Young, 2010).

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2. 3D CITY MODELING

3D city models, which are the foundation for 3D GIS; comprise computerized 3D representations of spatial data such as land surface, buildings, roads, trees, and other earth objects. The essential components of a 3D city model are digital terrain models, building models, street object models, and models of green areas (Döllner et al., 2006). Different names such as "Virtual City", "Cybertown", "Cybercity," and "Digital City" are used for 3D city models (Sadek et al., 2002). 3D city models, especially in recent years, have focused on obtaining a view as close to physical reality as possible and creating photorealistic views of urban objects (Döllner et al., 2006). Many applications, such as urban planning, facility management, and personal navigation programs, require hosting semantic information about urban objects as well as geometry models (Mao, 2011). During the production of 3D city models, if only presentation-oriented models are produced and thematic/semantic or topological information is neglected, these models can only be used for visualization. However, they cannot be used for thematic queries, analyses, and spatial information (Döllner et al., 2006).

CityGML proposes five different levels of detail LoD for 3D city models, as shown in Figure 1 (Kolbe et al., 2005). These levels of detail start from the zero level and explain how detailed the objects will be displayed in the city model.
The coarsest level LOD0 is essentially a two-and-a-half-dimensional Digital Terrain Model, over which an aerial image or a map may be draped. LOD1 is the well-known blocks model comprising prismatic buildings with flat roofs. In contrast, a building in LOD2 has differentiated roof structures and thematically differentiated surfaces. Vegetation objects may also be represented. LOD3 denotes architectural models with detailed wall and roof structures, balconies, bays, and projections. High-resolution textures can be mapped onto these structures. In addition, detailed vegetation and transportation objects are components of a LOD3 model. LOD4 completes a LOD3 model by adding interior structures for 3D objects. For example, buildings are composed of rooms, interior doors, stairs, and furniture (Kolbe et al., 2005).

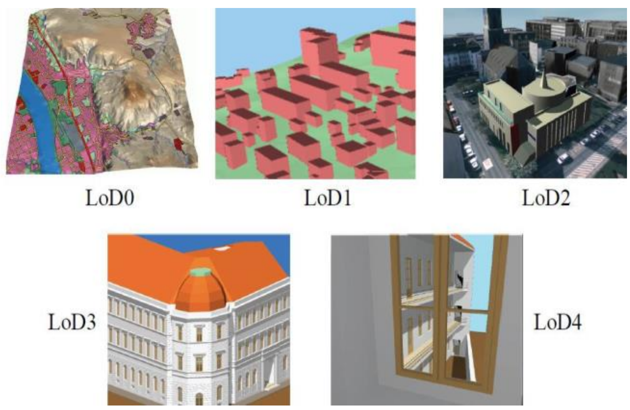

Figure 1. LoD representation defined by CityGML (Kolbe et al., 2005).

3. BIM

The Building Information Modelling process is unique, based on a sharable, digital-based, integrated, and multi-operable Building Information Model. Thus, the Building Information Model, as the definition of Building Information Modelling, as the process and conformity that provides information management, is the backbone of the Building Information Modelling process, semantically enriched 3D model(s) (Underwood, Işıkdağ, 2010).

BIM provides us with the virtual accessibility of a real facility throughout its entire life cycle (Volk et al., 2014). BIM can be used throughout the entire asset cycle of the building, from the design process to the building operation. It is possible to collect this usage under four main headings. These are:

- Use in the Design Process
- Use in Environmental Analysis
- Use in Building Construction Process
- Use in Building Operation

IAI (International Alliance for Interoperability), which would later change its name to BuildingSmart, defines, disseminates, and, publishes Industry Foundation Classes (IFCs) that will form the basis for the exchange of information between different disciplines and technical applications throughout a building's existence cycle, as a basis for BIM. IFC, which was recognized by ISO in 2013 and started the certification process; It is published as an open and international standard in 2018 (ISO 16739-1:2018).

The LOD specification leverages the basic LOD definitions developed by the American Institute of Architects (AIA) for the "G202-2013 Building Information Modelling Protocol Form". LOD are definitions developed to solve a few fundamental problems in projects developed using BIM. In general, the starting point of these problems is that other stakeholders, other than the person who produced the project, who want to look at the project and get information from it, make wrong inferences about that project and often have to grapple with detailed information that will not work (Figure 2).

Figure 2. Relationship between LOD and degree of representativeness.

4. INTEGRATION OF GIS-BIM

Until recent years, GIS researchers did not pay much attention to indoor applications. This is because the data is not spatial in nature. That is, they do not have a relative or geographical location. There are no direct definitions of building interiors in the directives on spatial data infrastructures. As a result, the integration of GIS applications with BIM and other CAD-based planning, design, and construction applications has remained mainly in the dimension of data transfer, focusing on the inside of the building boundary in CAD and BIM and outside in GIS.

CityGML and IFC are quite different in many ways. The main difference arises from the modeling approaches used to produce 3D models in GIS and BIM and computer-aided architectural design (CAD). In GIS, 3D objects are derived from surface observations (metric measurements) of topographic features based on sensor-specific extraction methods. Thus, details are defined by their observed surfaces by applying the cumulative modeling principle. On the other hand, the BIM model expresses how the 3D object is created, uses the generative modeling approach, and focuses on the built environment rather than topography. Therefore, BIM models consist of volumetric and parametric primitives that represent the structural components of buildings. Figure 3 illustrates the effects of both modeling approaches (Nagel et al., 2009).

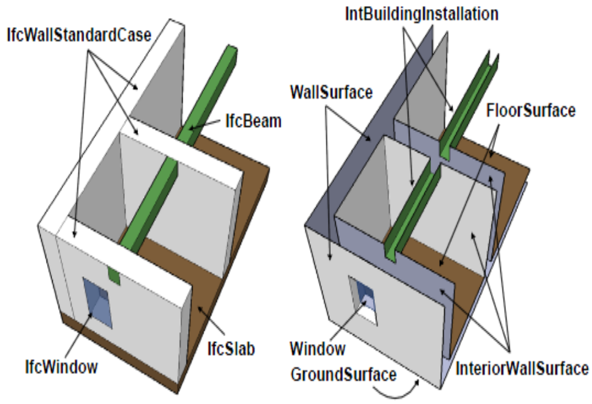

Figure 3. Snapshot of a building storey modeled in IFC (left side) and CityGML (right side) (Nagel et al., 2009).

5. METHODOLOGY

In this study, 3D models of a building were created with real measurement and metric values in a way to provide input to a geographic information system that will also include interior spaces. Thus, a model that can be used in terms of building elements, architectural equipment, and facility management and is open to development has been obtained. Within the application's scope, the Faculty of Social and Human Sciences building located in the Köycegiz Campus of Necmettin Erbakan University in Konya was used as the test area (Figure 4).

Figure 4. Working Area.

In this study, 3D models of a building were created with real measurement and metric values in a way to provide input to a geographic information system that will also include interior spaces. Thus, a model that can be used in terms of building elements, architectural equipment, and facility management and is open to development has been obtained. The building was modeled in 3D with two different methods. The first is the BIM model created at the LOD 300 level by modeling CAD data. CAD data were obtained in March 2020. CAD drawings are quite complex structures. Additional operations such as cleaning, layering, and redrawing are required to model CAD drawings. After these additional operations are done, they are transferred to the BIM software, and the modeling process is completed with the following operations:

- Build Up a Framework for a BIM Object
- Add Architectural and Design Elements
- Choose Materials and Textures
- Create the Environment

This model is also called CAD to BIM model. The CAD to BIM model is shown in Figure 5.

Figure 5. CAD to BIM Model.

The other is the LoD 4 level photogrammetric model obtained by Terrestrial Laser Scanning (TLS) and Unmanned Aerial Vehicle (UAV) methods. In other words, it is the Scan to BIM model.

Scan to BIM data is obtained by using data from two different disciplines. It will help to create LoD 3 level data with aerial photogrammetry data obtained by Unmanned Aerial Vehicle. The data obtained by the terrestrial photogrammetry method, which is required for LoD 2 and LoD 3 Levels, was produced with the DJI Phantom 4 RTK device with approximately 11 million points in August 2019. In addition, in May 2021, the orthophoto image of the entire campus was produced with the same device to be used as a base in GIS studies (Figures 6/a and 6/b).

Figure 6/a. SBIF UAV Data. **Figure 6/b.** Campus Orthophoto.

DJI Phantom 4 RTK is one of the most suitable solutions for 3D model production with a 1 mm resolution image acquisition capability. The built-in RTK module integrated into the Phantom 4 RTK provides real-time and centimeter-level positioning data with image data. It enables the production of high-quality orthophoto, digital elevation model, point cloud data with coordinated photo acquisition.

Another data is the terrestrial LIDAR data required for LoD 3 and LoD 4 Levels, and it was produced with the Zeb-Revo Hand Held Laser Scanner device in 6 sessions in August 2020 to consist of 216 million points (Figure 7).

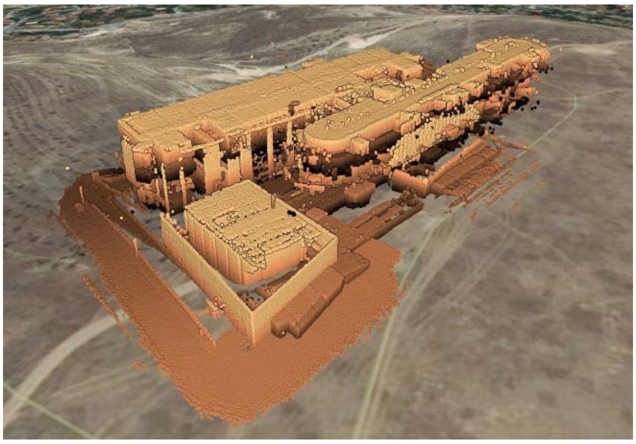

Figure 7. SBIF LIDAR Point Cloud.

Zeb-Revo, a handheld LiDAR scanner, is a time-of-flight measuring device with an IMU integrated positioning system without the need for satellite navigation systems. The scanner determines all the details around it with a simultaneous location and mapping (SLAM) algorithm (Geo-SLAM, 2019). The SLAM algorithm identifies the objects around the scanner as static, and according to this assumption, the points are connected, and the whole point cloud is obtained (Sammartano and Spanò, 2018).

Digitization was performed from the scan data, and all floor plans were digitized and produced in a 2D CAD environment to make the data more meaningful. Likewise, the floor plan of the attic was obtained in the CAD environment with the aerial photogrammetry data obtained by the UAV. Later, these floor plans were rendered in 3D, and the Scan to BIM model of the entire building was created by combining all floor plans and the attic plan, as seen in Figure 8.

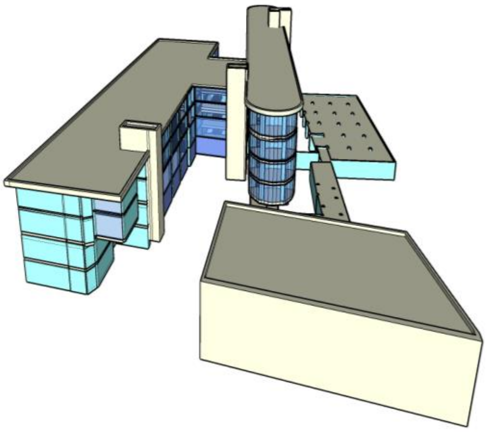

Figure 8. Scan to BIM Model.

We have two different models and an orthophoto to use as a base. There is much theoretical knowledge about GIS-YBM integration. However, there are many software and applications for different purposes and forms in practice and transfer BIM models to GIS software. The first challenge is the conversion problem from IFC to CityGML. The FME application is the only software to meet all these requirements in this context. The other problem is the 3D GIS data presentation part. Cesium, Locus, Novaprint, and WorldWind are the most famous 3D presentation engines.

This study has decided to use the Cesium engine for presentation since its capabilities are understood to be better. The model used in GIS-BIM integration has been revealed and summarized in Figure 9.

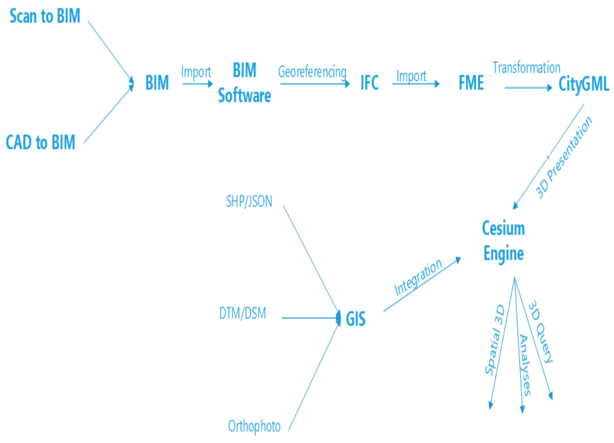

Figure 9. GIS/BIM Integration Model.

By the model for GIS-BIM Integration, BIM data is first geo-referenced with BIM Software and then converted to IFC format. Later. BIM data, for which IFC transformation was performed, was opened with the FME application, and CityGML transformations were performed using the predefined FME workbench (Figure 10). After the necessary transformations have been made, there is no longer any obstacle to presenting the data in a 3D GIS infrastructure and making analysis.

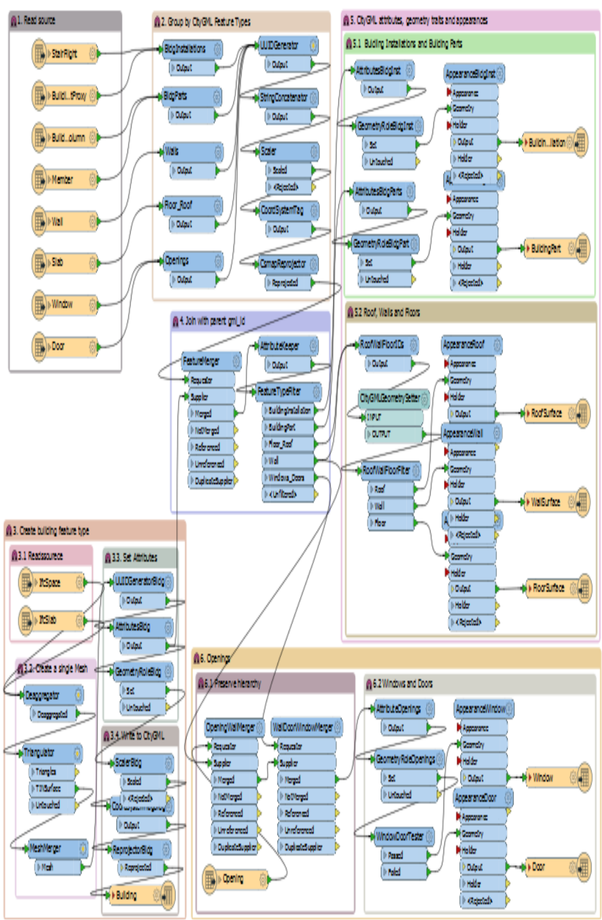

Figure 10. IFC to CityGML Transformation FME Workbench (Safe, 2020).

6. RESULTS

When creating 3D city model applications, the developer should consider the technical features and capabilities of the platform according to the application. These can be related to the support for 3D geoinformation (i.e., geographical coordinate systems and APIs), visualization capabilities (e.g., real-time rendering, support for VR/AR), the flexibility of use (e.g., web use, openness, the level of interactivity), data integration and management (e.g., integration of semantics, sensor data or other meaningful data types) and support for 3D data assets (e.g., mesh models, point clouds, CityGML, BIM models, etc.). In this context, web-based platforms have become popular among 3D applications in recent years. Web-based solutions attract much attention as they are applications that can be easily accessed by a wide range of users and can be run without additional licensed software downloads. The development of web-based 3D presentations has enabled a rapid transition from 3D desktop applications to browsers. This expansion required the standardization of 3D GIS applications and bringing common solutions to data formats. CesiumJS, GeoServer, or 3DCityDB are the most widely used open-source solutions.

In this study, it was decided to present the data in the Cesium engine. The presentation was made through the Cesium Ion application; the web portal offered free of charge by Cesium itself. Cesium ion is a robust, scalable, and secure platform for 3D geospatial data. Cesium engine usually presents data in its own unique format, 3D TILES, and web presentation cannot be made without converting to this format. Although the FME application enables the conversion from CityGML to 3d TILES, Cesium Ion can take the data in its own formats and tile it within itself without the need for this. Cesium Ion recognizes many CAD, BIM, and GIS formats (Table 1).

Format	3D Tiles	Terrain	Imagery	glTF	Native
Zip Archive (.zip)	✓	✓	✓	✓	
glTF (.gltf, .glb)	✓			✓	
Filmbox (.fbx)	✓			✓	
CityGML (.citygml, .xml, .gml)	✓				
CZML (.czml)					✓
GeoJSON (.json, .geojson, .topojson)					✓
KML (.kml, .kmz)	✓				✓
LASer (.las, .laz)	✓				
COLLADA (.dae)	✓			✓	
Wavefront OBJ (.obj)	✓			✓	
Floating Point Raster (.flt)		✓	✓		
Arc/Info ASCII Grid (.asc)		✓	✓		
Source Map (.src)		✓	✓		
GeoTIFF (.tiff, .tif)		✓	✓		
Erdas Imagine (.img)		✓	✓		
USGS ASCII DEM and CDED (.dem)		✓	✓		
JPEG (.jpg, .jpeg)			✓		
PNG (.png)			✓		
Cesium Terrain Database (.terraindb)		✓			

Table 1. Cesium supported data formats (Cesium, 2022).

In this context, we uploaded our orthophoto, CAD to BIM, and Scan to BIM models produced to the Cesium Ion cloud. The Cesium engine itself completed the necessary TILES processes and made it ready for presentation. Thus, the optimized data is ready for presentation in the Cesium story section.

Figure 11. Orthophoto integration.

As a result, CAD to BIM and Scan to BIM model, which can also be seen in figures 12 and 13, was loaded on cesium ion and displayed at its real point in the world. Cesium Ion; It has been tested to perform GIS-BIM integration perfectly. It is used as an orthophoto GIS base and added to both models as a subbase of data (Figure 11).

Figure 12. CAD to BIM in Cesium Ion.

Figure 13. CAD to BIM in Cesium Ion.

7. CONCLUSION

With the integration of BIM specializes in building, the smallest component of a city, and as much detail on building and GIS, which is specialized in the city as a whole and has much detail in general, but does not deal with the details of the small components themselves, a significant step will be taken for the smart city concept. Because while reaching the most detailed levels of the buildings and creating their digital twins, virtual cities integrated with the whole city will be constructed in their real location in the world. In addition, with disciplines such as artificial intelligence and machine learning, which are essential elements of technological developments, analysis and management studies for smart cities can be done quickly.
The increasing complexity of cities and the effective management of constructions and facilities have revealed the need for geographic information systems to include indoor models and building geometries. For this purpose, a 3D modeling and visualization study aimed at GIS integration is presented. There are very few automatic transformation studies on GIS integration of indoor models called LoD4 in the concept of CityGML. As in this study, there are mostly semi-automatic conversion studies. The next step will be to provide fully automatic integration between IFC and CityGML.

As a result, A study was conducted on the GIS integration of BIM models produced in a building with two different methods and its web-based presentation. It was clearly seen that the data could be integrated with each other. With this study, photogrammetric models have been seen to be an essential data production technique for BIM as well as being efficiently used in 3D Urban Models / 3D Cadastre studies, and BIM models are now moving towards being the most important data source for 3D city models.

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