The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-G-2025
ISPRS Geospatial Week 2025 "Photogrammetry & Remote Sensing for a Better Tomorrow…", 6–11 April 2025, Dubai, UAE

Implementation of a Smart Campus: 3D Database Modeling for University Management

Elaine Gomes Vieira de Jesus [1], Arivaldo Leao de Amorim [2], Mauro Jose Alixandrini Jr [3], Vivian de Oliveira Fernandes [3]

[1] Geosciences Institute, Federal University of Bahia, Salvador, Bahia, Brazil - elainegomes623@gmail.com
[2] Faculty of Architecture, Federal University of Bahia, Salvador, Bahia, Brazil – alamorim@ufba.br
[3] Polytechnic School of Engineering – Federal University of Bahia, Salvador, Bahia, Brazil – alixandrini@ufba.br, vivian.fernandes@ufba.br

KEY WORDS: 3D Database, Geometric and Semantic Modeling, 3DCityDB, CityGML, University Campus.

ABSTRACT:

This paper addresses the use of geometric and semantic modeling associated with 3D Geographic Information Systems (3D GIS), focusing on university campus management. The aim is to demonstrate the importance of database modeling and highlight the advantages these technologies offer to the academic community, contributing to the development of a smart campus. To achieve this goal, practical cases from universities in Brazil and abroad that have implemented smart campus technologies are presented, focusing on the Federal University of Bahia (UFBA) case. In this research, CityGML is used as the standard for creating geometric and semantic models, while 3DCityDB is employed to store the campus building models. Finally, the importance of storing data, such as space uses and functions, in a 3D database is discussed. This approach can assist university management in decision-making, providing a more transparent and more precise view of the needs and challenges of a university campus.

1. Introduction

This paper addresses the use of geometric and semantic modeling associated with 3D Geographic Information Systems (3D GIS), focusing on its application for university campus management. The research employs CityGML as the standard for creating models and 3DCityDB as a tool for storing campus building models.

The importance of 3D GIS is justified by its ability to integrate geometric data (shape, position, and dimensions) and semantic data (attributes and functions), providing a robust model that facilitates efficient decision-making. Additionally, 3D numerical models (geometric and semantic models) of cities represent real-world objects through four elements: geometric representations (shape), appearance, topology, and semantics.

In geometric modeling, it is necessary to define the Level of Detail (LOD), which expresses the accuracy and fidelity with which elements should be represented and the classes to be included (Redweik et al., 2007). The international standard for creating 3D numerical city models is CityGML, developed by the Open Geospatial Consortium (OGC).

The CityGML standard provides an open data model for storing and sharing data related to cities and their environments in spatial applications. It supports different levels of detail, from the city to the building scale. The 3D numerical city models created in the CityGML standard can be stored in 3DCityDB, a software for storing three-dimensional geographic data, enabling its use with database management systems such as Oracle and PostgreSQL.

The level of detail is crucial for obtaining precise and detailed information in 3D numerical city models, allowing planners to make more assertive decisions and facilitating management. This decision-making is relevant in urban planning or managing university campus infrastructure, where public resources are scarce and must be managed as effectively as possible.

In this context, Geographic Information Systems (GIS) can be used as a tool for spatial data analysis and data management on a university campus. For example, GIS can be used to solve problems such as identifying the appropriate capacity of classrooms based on the number of students (Ramlee et al., 2019). This is a common issue in many universities, including the Universiti Teknologi Malaysia, and can cause difficulties for students in planning their activities.

However, it is worth noting that, to date, it is uncommon for university campuses in Brazil to have Geographic Information Systems that enable access to and manipulation of data, even in two dimensions, let alone more complex spatial analyses. In other countries, some studies stand out in implementing these systems, including the third dimension (Bansal, 2011; Suwardhi et al., 2016; Pispidikis et al., 2018).

An interesting example is the study by Suwardhi et al. (2016), which addresses the construction of a three-dimensional Geographic Information System for the campus of the Bandung Institute of Technology (Indonesia). The authors emphasize the importance of the following steps for building this system: defining the system's objectives, choosing hardware and software, acquiring spatial data, processing and analyzing data, system analysis, layer management, queries and spatial analysis, and displaying and publishing information.

Furthermore, it is important to highlight some gaps related to 3D numerical city models. Most models focus only on buildings and do not include other CityGML modules, which limits more comprehensive analyses. Additionally, it is uncommon to find 3D numerical city models with varying levels of detail (LOD) in a single model. Finally, there is a lack of applications focused on university campus management based on geometric and semantic modeling in the CityGML standard, particularly regarding issues related to 3D GIS.

2. Models and Data Modeling

A data model is the foundation of a Geographic Information System (GIS) and consists of a set of constructs used to represent objects and processes in a computational environment. Four levels of abstraction are used to represent the real world in a computational environment, known as the paradigm of the four universes (Gomes e Velho, 1995).

The first universe involves the identification of real-world phenomena, such as buildings, streets, wells, lakes, and people. This universe encompasses aspects that individuals may or may not perceive or consider relevant for a particular application. The second universe, conceptual or mathematical, includes a mathematical definition of the entities to be represented. The third universe, representation, corresponds to the logical model, which associates the conceptual universe with geometric representations. Finally, the fourth universe is the implementation universe, associated with the physical model, where the model is implemented using programming languages.

Data modeling is an abstraction process that focuses on the essential elements of the observed reality, while discarding non-essential elements. The conceptual database modeling process involves describing the possible contents of the data and structures and rules applicable to them (Lisboa Filho et al., 2000).

Conceptual modeling is always based on some conceptual formalism, such as object orientation. For each conceptual formalism, there are various schema description languages. The formalism provides a set of concepts, elements, and rules used in modeling reality, while the description language provides a grammar for presenting the conceptual schema resulting from the modeling (Lisboa Filho et al., 2000).

Regarding 3D GIS, both the representation of objects and data modeling follow specific criteria, adopting the CityGML standard and the Unified Modeling Language (UML). 3D numerical modeling of cities involves geometric, semantic, and topological modeling. Geometric modeling aims to capture the shape of an object; semantic modeling assigns meaningful properties to the object, and topological modeling analyzes the relationships between them (Kim et al., 2020).

3. CityGML Standard

CityGML is an XML-based data standard for storing 3D numerical city models. It is implemented as an application of Geography Markup Language 3 (GML3), the international extensible standard for encoding spatial data issued by the Open Geospatial Consortium (OGC) and ISO TC211. This standard was developed by the Special Interest Group 3D (SIG3D), a working group that deals with issues related to the modeling, storage, visualization, and manipulation of 3D spatial data.

The first version of CityGML was released in 2008, with the second version following in 2012. Although version 3.0 of CityGML was released in 2021, this article opted to use version 2.0 due to a limitation of 3DCityDB, the software used for database modeling, which does not yet support modeling in the new version.

In version 2.0, CityGML supports different levels of detail, which can range from LOD0 to LOD4, as shown in Figure 1. In LOD0 (lowest level of detail), only the terrain surface is represented over large areas, at the city scale; in LOD1, buildings are represented by the extrusion of their external perimeter (footprint); in LOD2, exterior features of buildings, such as roof shapes and textures, may be included; in LOD3, the building scale is represented, with more detailed modeling of the exterior, including protrusions and other features; and in LOD4, the interior of buildings is represented, including internal divisions and their equipment, with rich detail and semantics.

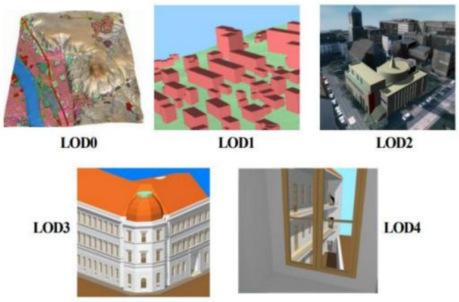

Figure 1. CityGML five levels of detail
Source: GRÖGER et al., 2012

CityGML 2.0 comprises 14 thematic modules**:** Core, Appearance, Bridge, Building, CityFurniture, CityObjectGroup, Generics, LandUse, Relief, Transportation, Tunnel, Vegetation, WaterBody, and TexturedSurface. In addition to the basic modules provided by the CityGML standard, extensions known as Application Domain Extensions (ADE) have been developed. These extensions can be of two types: those designed to support specific applications and generic extensions that complement CityGML without targeting a specific application.

An ADE extends the standard CityGML model created to meet specific objectives. It serves as a mechanism to enrich the data model with new classes and attributes while preserving the semantic structure of CityGML (Biljecki et al., 2018). An extension can be specified using an XML schema definition file or Unified Modeling Language (UML) diagrams.

Several studies have used the CityGML standard for 3D numerical city modeling. For example, Gröger and Plümer (2012) describe the construction of 3D numerical city models for European cities, such as in Germany, compatible with LOD2, and some models in LOD3, including Berlin, Cologne, Dresden, Dusseldorf, and Munich. In Asia, there are also 3D numerical city models in the CityGML standard, such as Istanbul (Turkey) in LOD1 and LOD2, Yokohama (Japan) in LOD2, and Doha (Qatar) in LOD3.

4. Database

Data in a database is physically stored and organized by Database Management Systems (DBMS), which are software systems designed to efficiently and effectively manage data storage and access. Queries to retrieve data are performed using a standardized query language called SQL (Structured Query Language), which provides a universal method for interacting with databases.

DBMS solutions exist for various applications, and it is essential to define conceptual models and schemas to structure data within them. In this context, 3DCityDB is a widely used tool for 3D numerical city modeling, primarily because it is free, open-source, and allows for the import, management, analysis, storage, visualization, and export of geometric and semantic models following the CityGML standard (Yao et al., 2018).

3DCityDB supports using Oracle and PostgreSQL DBMS with their spatial extensions, Oracle Spatial and PostGIS, respectively. It uses these spatial DBMSs as a database, adding a schema for numerical and semantic city models derived from CityGML and including all thematic modules of CityGML. Each element is stored in a table corresponding to the class belonging to the CityGML module, along with geometry, semantic information, and topological relationships connecting the elements (Kim et al., 2020).
Many projects are being developed using 3DCityDB. For example, the Campus RoadMap Project, discussed by Fliegner et al. (2016), aims to reduce energy consumption on a university campus. Additionally, Prandi et al. (2015) used 3DCityDB to develop and deploy a platform for storing, visualizing, and analyzing 3D numerical city models via the web.

5. Smart Campus and University Management

According to Liu and Shao (2016), the primary objective of building a smart campus is to enhance the quality of learning and the students' living environment, while establishing a comprehensive, intelligent, innovative, and open information service platform.

Fenghua et al. (2010) emphasize that GIS, as a management tool, can integrate spatial information with teaching, administration, and scientific research data within the campus. This integration provides an efficient communication channel, leading to significant changes in management while saving human and material resources. Additionally, images, videos, and other media can assist in management, planning, and decision-making. Thus, GIS plays a fundamental role in the digital structure of the campus.

Kahramana et al. (2013) introduce the concept of the Campus Information System (CIS), which is defined as an integrated system composed of hardware, software, data, and users, capable of collecting spatial and non-spatial data within the university and its subunits (academic and administrative areas). These data can be transferred, stored, queried, analyzed, and presented to decision-makers.

Managing and updating the different types of information necessary for campus spatial planning is a complex task. Planning new infrastructure and modernizing existing ones becomes challenging, as information is often scattered, outdated, available in different scales and formats, and, in many cases, not digitally accessible (Bansal, 2011). This reality is also observed in Brazilian universities, such as UFBA, which holds a large amount of data, some in digital format, such as survey maps produced in recent years. However, discrepancies exist regarding the location of features and the semantic data of academic units, which are not organized to facilitate information access and dissemination.

In Brazil, the use of GIS as a methodology for campus management has been addressed by authors such as Manzoli (2003), Tambani (2017), and Couto (2012), mainly in activities related to administration, maintenance, and the implementation of new facilities. Access to accurate and updated campus information can help management bodies administer physical assets more effectively, directing efforts to priority areas.

The proposal for creating a smart campus at UFBA is still in its early stages. Some studies have been conducted on using and integrating geospatial data and intelligent tools that support the future development of a smart campus at UFBA. Notable among these studies are Elias (2017), Jesus et al. (2018), Magalhães (2020), Silva (2021), Sacramento (2021), and Costa (2022).

Regarding systems involving 3D applications for universities, which encompass geometric and semantic data, it has been observed that university campus models generally vary in levels of detail, ranging from LOD1 (Chen et al., 2020) to LOD3 (Pispidikis et al., 2018). This suggests that models can be adapted to meet the specific needs of each university.

For facility management and university administration, the studies of Trisyanti et al. (2019), Suwardhi et al. (2016), Bansal (2011), and Pispidikis et al. (2018) stand out. These studies demonstrate the importance of using 3D numerical models to improve the efficiency and effectiveness of university management.

Concerning the availability of 3D numerical models on web platforms, the studies of Buyukdemircioglu and Kocaman (2018), Trisyanti et al. (2019), Kahramana et al. (2013), and Ramlee et al. (2019) can be considered as key references.

6. Metodology

The methodology proposed in this study consists of two main stages: defining the requirements for an intelligent university campus system and proposing specific use cases. Accordingly, the 3D database modeling was conducted for the entire Federação/Ondina campus of UFBA at LOD1 of CityGML and for a single building at LOD4. This selection was based on the functional requirements and the proposed use cases to demonstrate the system's potential.

The primary focus of this intelligent system is to enable analyses aimed at optimizing built spaces on campus. These analyses cover aspects such as physical structure, space usage, and function and identify locations susceptible to certain risks, such as those imposed by laboratories.

For the LOD4 modeling, the Escola Politécnica building was selected due to its complexity, as it is the largest building in the study area, with eight floors. It has a high circulation of people, including students, faculty, and administrative staff, and features unique characteristics, such as the presence of laboratories of various types. These laboratories allow for the simulation of scenarios involving potential safety risks.

6.1 Functional Requirements

Some requirements were broadly designed to encompass analyses of the entire university campus, while others aimed to address the internal aspects of the Escola Politécnica. These requirements are related to the actions that an intelligent system for a university campus could perform. The User-Centered Design (UCD) methodology was used to define the requirements for this system, as described below:

- Consult the capacity of classrooms and the availability of their equipment;
- Identify the courses allocated by schedule in each room of the university units;

- Identify the uses and functions of spaces in all campus buildings, particularly the spaces on one floor of the Escola Politécnica;
- Recognize areas susceptible to risks posed by laboratories.

6.2 System Use Cases

The use cases were developed based on the three main actors involved in the dynamics of a university campus: students, faculty members, and campus administrators. Each has a specific role and distinct needs within this context.

Students primarily engage in attending classes for the courses they are enrolled in. To do so, they need access to campus facilities and services such as classrooms, laboratories, libraries, and dining halls. On the other hand, faculty members are involved in teaching, research, and extension activities, which include preparing and delivering lectures, producing and reviewing academic papers, and advising students. As such, they require access to technological resources to support their professional activities.

Lastly, administrators operate on multiple fronts, focusing on infrastructure and services, security, and decision-making related primarily to academic and administrative factors. Regarding infrastructure and services, their role is to ensure that facilities are well-maintained and meet institutional needs.

To fulfill these requirements, use cases were developed specifically for managing the Escola Politécnica's physical structure, as illustrated in Figure 2. The use case diagram presents the relationships between the analyst, the system, and the users. The GIS analyst is responsible for designing a system that meets the needs of each user (students, faculty, and administrators). Additionally, the analyst must anticipate the possibility of users utilizing the system as a communication tool with the administration, allowing them to report essential and/or urgent events occurring on campus.

The system is responsible for enabling the consultation and analysis of information related to:

- **Spaces** (use and function)
- **Classrooms** (room name or number, size, student capacity, number of desks and chairs, available equipment, and scheduled courses)
- **Computer rooms** (machine specifications and available software)
- **Laboratories** (laboratory name, responsible faculty, contact information, and associated risks)
- **Security** (location of surveillance cameras, emergency exits, and collective protective equipment such as fire extinguishers)

Classroom-related information can be helpful for all three user groups. However, for students and faculty, the most relevant details include the location of their assigned classrooms, available equipment, and the locations of laboratories, libraries, and dining halls. On the other hand, administrators require more detailed information to support decision-making regarding university units' routine and exceptional needs.

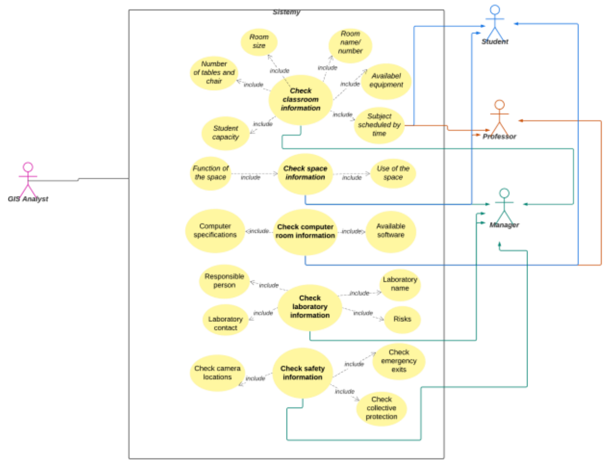

Figure 2. Use cases
Source: The authors, 2025

The manager can benefit from the analyses based on the use cases presented in Figure 2. For instance, it can be used to analyze students' movements, which can be visualized through the representation of routes between buildings or rooms within the same building. Another use case is related to the potential risk types associated with specific laboratories at UFBA, which can be assessed using buffers that indicate the area of influence of a specific risk.

Regarding safety, which should be prioritized for students, professors, and staff, it is essential to identify emergency exits, locate personal protective equipment (inside the buildings), and strategically position surveillance cameras to ensure the safety of individuals and property. These measures can reduce the risk of theft and enable monitoring of areas with a higher risk of fires and explosions within the buildings.

7. Results and Discussion

Initially, PgAdmin was used to create the database, and the PostGIS extension was employed to connect the database to 3DCityDB. Subsequently, it was possible to insert the file containing the geometric model in the desired Level of Detail (LOD) in CityGML format into 3DCityDB. A total of 136 features of the Building class, 140 of the Opening class, and 29 of the Room class were inserted into the database.

3DCityDB, in conjunction with the other mentioned software, ensures that the database meets the requirements of the CityGML standard. This standard creates tables automatically and establishes relationships between objects according to the conceptual model. During the database creation process, 66 tables were generated and automatically populated with values after the geometric and semantic models were inserted into the database.

In LOD1, the buildings were classified into education and administration. For function/use, they were assigned the following attributes: administrative, education and research, restaurant, library, hospital, or others (used for campus benches). Regarding the roof type (RoofType), all buildings were assigned a code corresponding to a flat roof.

In LOD4, the building elements were classified again into education and administration. For the function/use of the Room class, the spaces were assigned attributes such as kitchen, bathroom, stairs, cafeteria, balcony, conference room, entrance hall, reception, elevator, computer room, auditorium, library, classroom, laboratory, equipment room; or office, as shown in Figure 3. Additionally, attributes defined in the conceptual model, such as the number of chairs and tables, availability of computers, projectors, and air conditioning, were included. For the Building_Furniture class, elements were assigned attributes compatible with computer desks, air conditioners, tables, chairs, office chairs, televisions, computers, and cabinets, according to the code list.

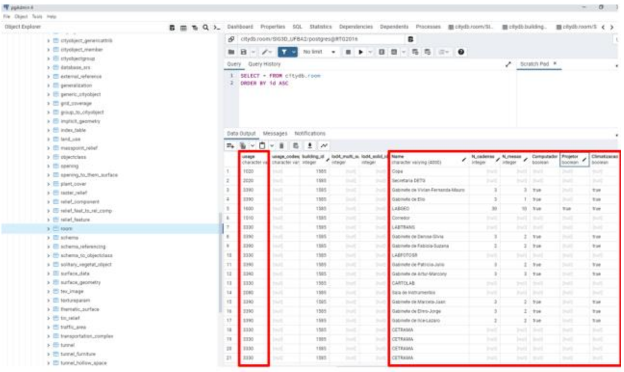

Figure 3. Room table with attribute insertion
Source: The authors, 2025

7.1 SQL Queries Performed on the Database

To demonstrate the potential of the database in executing SQL queries, three more tables were created in addition to the tables automatically created by the database. Some examples of queries are provided below:

a) Query 1 – Identify the Capacity of Classrooms and the Availability of Equipment

To perform this query, a table named `classroom` was created, which contains the following columns: `id`, `capacity` ,`air_conditioning` ,`computer` ,`n_chairs`, `n_tables` ,`name`, `projector`, `network`, and `size`. These columns were populated with data corresponding to three classrooms on the sixth floor (rooms 6.03.02, 6.03.03, and 6.03.04).

The query revealed that room 6.03.02 is more significant, with a capacity for 70 people but equipped with 60 chairs, while the other two rooms (6.03.03 and 6.03.04) have a capacity for 45 people and 40 chairs each. Regarding available equipment, none of the three rooms have air conditioning, but all are equipped with a computer, projector, and internet network (as shown in Figure 4).

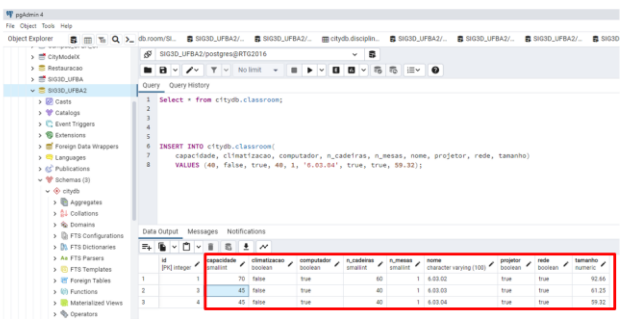

Figure 4. Consulting classroom information
Source: The authors, 2025

b) Query 2 – Identify Courses Allocated by Schedule in a Specific Classroom

To perform this SQL query, three tables were used. The first was the `classroom` table, already utilized in Query 1. The second table, named `disciplina` (course), includes the following columns: `id`, `cod` (code), and `nome` (name). The third table, named `alocacao_disciplina` (course allocation), contains the following columns: `id`, `disciplina_id` (course ID), `classroom_id` (classroom ID), `dia_semana` (day of the week), and `horario` (time). The `id` column served as the primary key in all three tables. The `disciplina_id` and `classroom_id` fields in the `alocacao_disciplina` table were used as foreign keys. The `alocacao_disciplina` table was an associative table to join the information. The importance of such tables lies primarily in the database's scalability, as courses may change classrooms depending on the semester, and this information can be updated in the future.

Figure 5 shows the result of the SQL query, which displays the names of the courses (Topografia and Geoprocessamento) and their respective codes (ENGA50 and ENGA52) allocated to room 6.03.02 on Monday and Tuesday. It can be observed that the course ENGA50 is scheduled from 8:00 to 10:00 on Monday and Tuesday in room 6.03.02, while ENGA52 is scheduled from 10:00 to 12:00 on Tuesday in the same room.

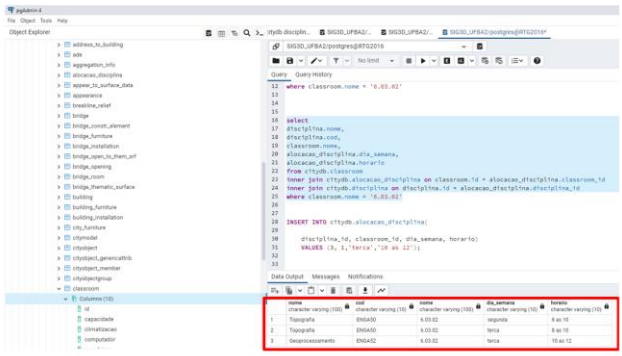

Figure 5. Consultation of subjects allocated to a room
Source: The authors, 2025

8. Conclusion

Based on the findings, several relevant issues have been identified, primarily related to the creation of tables and the establishment of relationships between them to meet user needs. This was demonstrated by creating the database, which generated 66 tables representing the classes and relationships corresponding to the CityGML modules. Additional tables can be created to fulfill the application's objectives, as in this case with the tables `classroom`, `disciplina`, and `alocacao_disciplina`. Creating these tables was relatively straightforward, performed via scripts, as was the insertion of values.

However, issues were identified with the semantic attributes associated with the geometric model. It was observed that when exporting the geometric and semantic model in CityGML format and importing it into 3DCityDB, some problems were reported in the command console. As a solution, the semantic data was manually inserted directly into PostgreSQL.

Another important issue concerns the volume of data for storage in 3DCityDB, as there are many relationships between objects defined by primary and foreign keys. To identify all the classes and relationships for each module, it is necessary to consult the 3DCityDB documentation.

Challenges were also encountered in obtaining data from the institution, primarily due to the lack of easily accessible information on the administrative units' websites. This significantly hinders acquiring the necessary attributes for insertion into the database, making it more time-consuming and labor-intensive.

Regarding space management at the university, the institution must control essential aspects such as the physical structure of the unit and optimize spaces to meet demands. However, in practice, this is often not done efficiently or effectively. In this context, this work aims to improve the decision-making process by demonstrating how queries performed on the database can facilitate the management of spaces on the university campus.

References

BANSAL, V. K. Use of geographic information systems in spatial planning: a case study of an institute *campus*. **Journal of Computing in Civil Engineering**. Fairfax, v. 28, n. 4, 2014. p. 1-12.

BILJECKI, F.; KUMAR, K.; NAGEL, C. CityGML Application Domain Extension (ADE): overview of developments. **Open Geospatial Data, Software and Standards,** New York, v. 3, n. 13, p. 1-17, August 2018.

BUYUKDEMIRCIOGLU, M.; KOCAMAN, S. A 3D campus application based on city models and WEBGL. *In:* SYMPOSIUM "GEOSPATIAL TECHNOLOGY – PIXEL TO PEOPLE", 5., 2018, Dehradun. **Proceedings** […]. Hannover: International Society for Photogrammetry and Remote Sensing, 2018. p. 161-165.

CHEN, K. W.; MEGGERS, F. Modelling the built environment in 3D to visualize data from different disciplines: The Princeton University Campus. **Journal of Digital Landscape Architecture**, Berlin, v. 5, n. 1, p. 227-234. May 2020.

COSTA, R. M. **Proposta de interface para mapa de *campus* universitário através do método reverso a partir de testes de usabilidade e avaliação heurística**. 2022. 160 f. Dissertação (Mestrado em Engenharia Civil) – Escola Politécnica, Universidade Federal da Bahia, Salvador, 2022. 160 f.

COUTO, R. A. S. **O uso de ferramentas de geoprocessamento para o gerenciamento de bens patrimoniais e prediais**. 2012. Dissertação (Mestrado em Arquitetura e Urbanismo) – Faculdade de Arquitetura e Urbanismo, Universidade de São Paulo, São Paulo, 2012.

Elias, E. N. N. **Atualização cartográfica através de imagens obtidas com o uso de Veiculo Aéreo não Tripulado (VANT) quadrotor**. 2017. Trabalho de Conclusão de Curso (Curso de Engenharia de Agrimensura e Cartográfica) – Escola Politécnica, Universidade Federal Bahia, Salvador, 2017. 154 p

FENGHUA, W.; JIUDONG, Y.; JUN, D.; DEQING, G. The design and implementation of the 3-D campus geographic information system. *In:* INTERNATIONAL CONFERENCE ON INFORMATION SCIENCE AND ENGINEERING, 2., 2010, Hangzhou. **Proceedings** […]. Piscataway: Institute of Electrical and Electronics Engineers (IEEE), 2010. p. 4136-4139.

FLIEGNER, C.; BRÜNTJEN, M.-A.; FRISCH, J.; VON TREECK, C. Database development with "3DCityGML"- and "EnergyAde"- schema für CityDistrict-simulation modelling. *In*: CENTRAL EUROPEAN SYMPOSIUM ON BUILDING PHYSICS, 3., 2016, Dresden. **Proceedings** […]. Dresden: Technische Universität Dresden, 2016. p. 235-241.

GRÖGER, G.; PLÜMER, L. CityGML – Interoperable semantic 3D city models. **Journal of Photogrammetry and Remote Sensing,** Hannover, v. 71, p. 12–33, July 2012.

GOMES, J. M.; VELHO, L. **Computação visual**: Imagens. Rio de Janeiro: Sociedade Brasileira de Matemática, 1995.

JESUS, E. G. V.; AMORIM, A. L.; GROETELAARS, N. J.; FERNANDES, V. O. Modeling cities for 3D_GIS purposes. *In*: SYMPOSIUM "3D SPATIAL INFORMATION SCIENCE – THE ENGINE OF CHANGE", 4., 2018, Delft. **Proceedings** […]. Hannover: International Society for Photogrammetry and Remote Sensing, 2018b. p. 135–142.

KAHRAMAN, I.; KARAS, I. R.; ALIZADEHASHARFI, B.; ABDUL-RAHMAN, A. A 3D campus information system – initial studies. *In*: 3D GEOINFO CONFERENCE, 8., 2013, Istanbul. **Proceedings** […]. Hannover: International Society for Photogrammetry and Remote Sensing, 2013. p. 35-39.

KIM, T.; CHO, W.; MATONO, A.; KIM, K. PinSout: automatic 3D indoor space construction from point clouds with deep learning. *In:* INTERNATIONAL CONFERENCE ON ADVANCES IN GEOGRAPHIC INFORMATION SYSTEMS, 28, 2020, Seattle. **Proceedings** […]. New York: Association for Computing Machinery, 2020. p. 211-214.

LIU, Y.; SHAO, L. Construction of Smart Campus Based on Situational Awareness in the Era of Big Data. *In*: International Conference on Computer Engineering and Information Systems, 2016, Shanghai (China). **Proceedings** […]. Dordrecht: Atlantis Press, 2016, p. 235–240.

LISBOA FILHO, J.; IOCHPE, C.; HASENACK, H.; WEBER, E. J. Modelagem conceitual de banco de dados geográficos: o estudo de caso do Projeto PADCT/CIAMB. *In:* CENTRO DE ECOLOGIA (org.). **Carvão e Meio ambiente.** Porto Alegre: Editora da Universidade Federal do Rio Grande do Sul, 2000. p. 440-458.

MAGALHÃES, I. A. **Organização dos dados geoespaciais de edificações universitárias para ambiente SIGWEB**: estudo de caso cursos Politécnica/UFBA e avaliação do MEC - avaliação de infraestrutura da Escola Politécnica da UFBA com base em critérios de avaliação de cursos do MEC. 2020. Dissertação (Mestrado em Engenharia Civil) – Escola Politécnica, Universidade Federal da Bahia, Salvador, 2020.

MANZOLI, A. **Proposta de um SIG para planejamento e gestão de *campus* universitário**. 2003. Dissertação (Mestrado em Engenharia Civil) – Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos, 2003.

PISPIDIKIS, I.; TSILIAKOU, E.; KITSAKIS, D.; ATHANASIOU, K.; KALOGIANNI, E.; LABROPOULOS, T.; DIMOPOULOU, E. Combining methodological tools for the optimum 3D modelling of NTUA campus. *In:* 3D GEOINFO CONFERENCE, 13., 2018, Delft. **Proceedings** […]. Hannover:

International Society for Photogrammetry and Remote Sensing, 2018. p. 57–63.

PRANDI, F.; DEVIGILI, F.; SOAVE, M.; DI STASO, U.; DE AMICIS, R. 3D web visualization of huge CityGML models. *In*: GEOSPATIAL WEEK, 1., 2015, La Grande Motte. **Proceedings** […]. Hannover: International Society for Photogrammetry and Remote Sensing, 2015. p. 601–605.

RAMLEE, S. S. S.; ABD RAZAK, N.; UJANG, U.; MOHD. SALLEH, S.; AZRI, S.; CHOON, T. L. Towards 3D smart campus via 3D city modelling. *In:* INTERNATIONAL CONFERENCE ON GEOMATICS AND GEOSPATIAL TECHNOLOGY, 6., 2019, Kuala Lumpur. **Proceedings** […]. Hannover: International Society for Photogrammetry and Remote Sensing, 2019. p. 523-526.

REDWEIK, P.; TEVES-COSTA, P.; VILAS-BOAS, I.; SANTOS, T. 3D city models as a visual support tool for the analysis of buildings seismic vulnerability: the case of Lisbon. 2017. **International Journal of Disaster Risk Science**, New York, v. 8, n. 3, p. 308-325, September 2017.

SACRAMENTO, I. C. C. **Proposta de sistema integrado IoT/GIS de baixo custo para apoio a gestão da segurança contra incêndios em campus universitário**. 2021. Tese (Doutorado em Engenharia Civil) - Escola Politécnica, Universidade Federal da Bahia, Salvador, 2021.

SILVA, D. S. S. **Banco de dados geográficos para gerenciamento da infraestrutura da Escola Politécnica da Universidade Federal da Bahia**. 2021. Trabalho de Conclusão de Curso (Bacharelado em Engenharia de Agrimensura e Cartográfica) – Escola Politécnica, Universidade Federal da Bahia, Salvador, 2020.

SUWARDHI, D.; TRISYANTI, S.W.; AINIYAH, N.; FAJRI, M.N.; HANAN, H.; VIRTRIANA, R.; EDMARANI, A. A. 3D surveying, modeling and geo-information system of the new campus of ITB-Indonesia. *In*: 3D GEOINFO CONFERENCE, 11., 2016, Athens. **Proceedings** […]. Hannover: International Society for Photogrammetry and Remote Sensing, 2016. p. 97–105.

TAMBANI, R. M. **O uso de sistema de informação geográfica na gestão de um *campus*:** estudo de caso**.** Universidade Estadual de Londrina. 2017. Trabalho de Conclusão de Curso (Bacharelado em Geografia). Departamento de Geociências, Universidade Estadual de Londrina, Londrina, 2017.

TRISYANTI, S.W.; SUWARDHI, D.; MURTIYOSO, A.; GRUSSENMEYER, P. Low cost web-application for management of 3D digital building and complex based on BIM and GIS. *In:* INTERNATIONAL WORKSHOP LOWCOST 3D – SENSORS, ALGORITHMS, APPLICATIONS, 6., 2019, Strasbourg. **Proceedings** […]. Hannover: International Society for Photogrammetry and Remote Sensing, 2019. p. 371-375.

YAO, Z.; NAGEL, C.; KUNDE, F.; HUDRA, G.; WILLKOMM, P.; DONAUBAUER, A.; ADOLPHI, T.; KOLBE, T. H. 3DCityDB - a 3D geodatabase solution for the management, analysis, and visualization of semantic 3D city models based on CityGML. **Open Geospatial Data, Software and Standards**, New York, v. 3, n. 5, p. 1-26, May 2018.