Ontology Based Integration of BIM and GIS for the Representation of Architectural, Structural and Functional Elements of Buildings

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Abstract

Building Information Modelling (BIM) and Geographic Information System (GIS) integration allows for analysis and visualization of geospatial characteristics and relationships of buildings and their surroundings for in a number of domains such as planning and management of built environments and disaster management. BIM provides detailed geometric and semantic data about a building and its elements. Moreover, it is a technology that enables 3D display of architectural, structural, and mechanical, electrical, and plumbing (MEP) projects in a local cartesian coordinate system. On the other hand, GIS employs global (geographic or projected) coordinate systems, thereby allowing for the integration, analysis, and visualization of various geospatial data. The development of BIM and GIS for different purposes brings about differences in spatial focus, geometric and semantic representations, level of detail, coordinate systems, and other aspects. In order to eliminate these differences and ensure integration, geometric transformation and semantic transfer are required. The semantic web represents a logical preference for semantic transfer, characterised by a natural ability to integrate information from disparate sources. In this study, the detailed geometric and semantic data of a building with structural, architectural, and MEP projects in BIM were integrated with the geospatial data in GIS using a semantic web approach. For this purpose, an ontology including concepts, relationships, and attributes was developed with the contribution of core ontologies from BIM and GIS. Semantic and geometric data values related to the building and its elements were transferred to this developed ontology, which was formatted in RDF format. Queries were made using SPARQL to analyse the transferred data. The results of these queries indicated that the semantic web is well suited for use in BIM and GIS integration.

1. Introduction

Building Information Modelling (BIM) and Geographic Information System (GIS) integration is a fundamental technique for a range of applications, including the development of smart cities and the creation of spatial digital twins. This integration necessitates the incorporation of BIM-generated building models into a GIS environment for analysis and visualization (Xia et al., 2022; Zhu and Wu, 2021). BIM is a methodology that focuses on the creation of detailed building models, which are comprised of a set of objects in a building and their associated digital definitions. These objects typically pertain to walls, floors, stairs, pipes, cables, electrical plugs, and other related elements. Each object within the model is represented by three-dimensional geometry, which reflects its physical appearance. Additionally, descriptive and classificatory data are included such as performance values, material types, expected lifetime, relationships with other elements in the model, dimensions, and manufacturer (Casini, 2022). GIS technology combines database operations such as querying and statistical analysis with the spatial analysis and visualization capabilities provided by maps. This integration enables a more comprehensive study of spatial phenomena and facilitates analyses that focus on locations, conditions, trends, patterns, and predictive models. These features make GIS an indispensable tool, enhancing the understanding and management of spatial data (Longley, 2008; Longley et al., 2015). Furthermore, spatial information is represented in GIS via an abstract model, which includes coordinates, spatial relationships between features, and additional non-spatial (thematic) characteristics (Liu et al., 2017). This integration contributes to the understanding of the effects of the environment on the building and the building on the environment at each stage of the building life cycle management. Thus, it becomes easier to make sustainable decisions in the feasibility, planning, construction, operation, and maintenance phases of the building life cycle, develop implementation schedules, determine the construction cost at a specific location, and analyse building performance (Bansal, 2021).

The integration of BIM and GIS is complicated by the differences between the two methodologies in terms of levels of detail, geometric representation methods, archiving methods, and semantic content (Vacca and Quaquero, 2020). There are many studies in the literature for this purpose. Although data transformation is usually performed from BIM to GIS, three different integrations can be performed as GIS to BIM, transferring BIM and GIS to a third system (Ma and Ren, 2017; Zhu and Wu, 2022). Industry foundation classes (IFC) are used for BIM data, while CityGML, CityJSON (Ohori et al., 2022), and shapefile format are used for 3D GIS data (Zhu and Wu, 2022). IFC is the primary open data schema created by buildingSMART for information exchange within the architecture, engineering, and construction (AEC) practice area (Herle et al., 2020). IFC includes relevant structures for various disciplines, uses, and processes related to the construction domain, semantic description, geometric representation, and relationships of typical building elements (Noardo et al., 2021). CityGML is an open standard data model and exchange format capable of storing 3D models of cities and their surroundings based on the geography markup language (GML) defined by the

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Open Geospatial Consortium (OGC) in extensible markup language (XML) format (Sani and Rahman, 2018). CityGML represents the geometric, semantic, and visual aspects of 3D city models. The focus is on the semantic description of all objects (features) relevant to applications of 3D city models (Gröger and Plümer, 2012). It defines a conceptual schema for entities in the urban area, such as buildings and their parts (building parts, walls, roofs, skylights, doors, windows, etc.), roads, railways, tunnels, bridges, water bodies, vegetation, and terrain (Yao et al., 2018).

The conversion between BIM and GIS needs to include semantic transfer as well as geometric transformation (Zhu and Wu, 2021). Geometry provides data about the shape, size and location of objects, while semantics provides data about properties such as class type, material and functions. Geometric transformation involves representation transformation, level of detail transformation and georeferencing. It has largely been resolved with software packages or toolsets such as the Feature Manipulation Engine (Adouane et al., 2020) and ArcGIS Data Interoperability Extension. Attribute extraction, semantic mapping and semantic web methods are used for semantic transfer. Attribute extraction refers to the extraction of the necessary attributes and their insertion into data formats that are usually not semantic. Semantic mapping is usually performed between data formats with defined classes, such as IFC and CityGML (Zhu and Wu, 2022). However, semantic transfer cannot be fully achieved with attribute extraction and semantic mapping. In this scope, semantic web is the technology used for representing, publishing, and displaying data on online platforms. The basic elements of the semantic web platform are query tools such as uniform resource identifier (URI), web ontology language (OWL), Resource Description Frame (RDF) and SPARQL (Malinverni et al., 2022). An ontology is a formal definition of the objects and relations of objects that enables the representation, sharing and management of knowledge. OWL expresses data in terms of classes and stores the relations and attributes of classes as RDF triples (subject, predicate, object) (Costin et al., 2023; Malinverni et al., 2022). For ontologies, a distinction can be made between ontologies that aim to cover a broad domain (e.g. ifcOWL for BIM data) and ontologies that contain only basic concepts (e.g. Building Topology Ontology - BOT). Basic concept ontologies have the advantage that they can be extended to specific domain ontologies when needed (Costa and Sicilia, 2022). Numerous tools, such as GeoSPARQL and BIMSPARQL, exist for the integration of geometric and spatial data (Wagner et al., 2023). The OGC introduced the GeoSPARQL protocol, as a SPARQL extension to facilitate querying of geographic RDF data (Zhang et al., 2015b). GeoSPARQL encompasses an RDF/OWL vocabulary to represent spatial information, a collection of functions for spatial calculations, and a series of rules for query transformation (Hart and Dolbear, 2013).

An integrated geospatial information model (IGIM) approach based on semantic web technologies and the RDF was used for the integration of BIM and GIS (Hor et al., 2016). Researchers have also developed various data exchange formats to support the interoperability of BIM and GIS. The IFG (IFC for GIS) data model and the buildingSMART Data Dictionary (bSDD) are examples of efforts to integrate BIM with other engineering application areas such as GIS. The aim of IFG is to enable the exchange of building and GIS data by importing or exporting a single data type. However, there are many heterogeneous classes for the representation of building and geographic information. Therefore, it makes more sense to implement a different interoperability format for both building and GIS classes (Karan et al., 2015). bSDD is an online service that hosts classifications and their properties, allowed values, units, and translations, as well as a data dictionary. bSDD allows linking all content within the database, providing a standardized workflow to guarantee data quality and information consistency (Costin et al., 2023). In this study, geometric and semantic data of a building in BIM and geospatial data in GIS are integrated with a semantic web approach. An ontology was developed to integrate the building project with geospatial data. The semantic data in BIM and GIS were transferred and analysed with concepts, relations and attributes.

2. Methodology

An ontology that merges BIM and GIS data has been created to facilitate the semantic integration of complex structural and spatial data, enabling meaningful querying of this integrated information. As shown in Figure 1, the fundamental workflow in this study can be summarized as follows: (1) creation of an ontology based on classes, relationships, and attributes in BIM and GIS, (2) definition of ontologies based on attribute values, (3) query and analysis of the ontology expressed in RDF format.

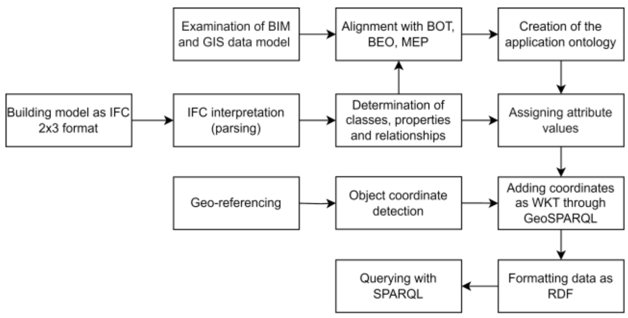

Figure 1. Workflow of the study

2.1 Creation of Application Ontology

To develop an ontology, it is necessary to identify concepts/classes, relationships, and attributes. In defining the concepts pertinent to BIM and GIS, it is essential to resolve various semantic discrepancies that exist between these systems. Such discrepancies often manifest as differing definitions for the same entity (e.g., a window is designated as “IfcWindow” in IFC, whereas in CityGML, it is merely termed “Window”) or a situation where one data format may recognize a component that is not acknowledged by the other (e.g., IFC specifies elements such as columns, beams, and stairs, which are not distinctly recognized in CityGML and are rather generalized under “BuildingInstallation”). Given the greater number of classes associated with buildings and their elements in BIM, semantic losses predominantly occur within the GIS framework. Nonetheless, integrating GIS concepts is vital for incorporating spatial data and facilitating environmental connectivity. In this context, it was leveraged from the BIM concepts described in the IfcOWL ontology and the GIS concepts described in CityGML and CityJSON. However, since BIM has more classes for building elements than GIS and the IfcOWL ontology is comprehensive and complex, core ontologies such as BOT (https://w3id.org/bot#), Building Element Ontology (BEO - https://pi.pauwel.be/voc/buildingelement), Building Product Ontology (BPO - https://w3id.org/bpo), Distribution Element Ontology (MEP - https://pi.pauwel.be/voc/distributionelement) were utilized. BOT describes the topological concepts of the building, BEO describes building elements, BPO describes the products in the building, and MEP describes the mechanical, electrical, and plumbing elements (Pauwels et al., 2022).

GIS concepts are designed to encompass data related to the structure, project, and surrounding environment, including land information, land use, topography, and transportation data, thus establishing a connection with the building environment. On the other hand, BIM concepts have been developed considering various domain. The "Building Element" structure has been categorized into "Structural Element", "Non-Structural Element", and "Functional Element". In both BIM and GIS, concepts that have same meanings (e.g., transforming the entities "IfcWall" in IFC and "WallSurface" in CityGML into classes such as "LoadBearingWall" and "Wall" based on whether the wall is load bearing) and distinct concepts (e.g., creating a "Stair" class in GIS where no equivalent "IfcStair" entity exists in CityGML) have been identified. Functional elements consist of MEP (Figure 2). Moreover, identifying rooms and floors containing building elements is crucial. Definitions of the identified concepts were established, and taxonomic (is-a) and partonomic (part-of) hierarchies were constructed. Common properties of concepts (e.g., ID, Name) and class specific properties (e.g., "OverallHeight" for door class and "StepHeight" for stair class) and data types (string, double, etc.) of these properties were defined (Figure 3). The ontology was designed in the open-source Protégé ontology editor (https://protege.stanford.edu).

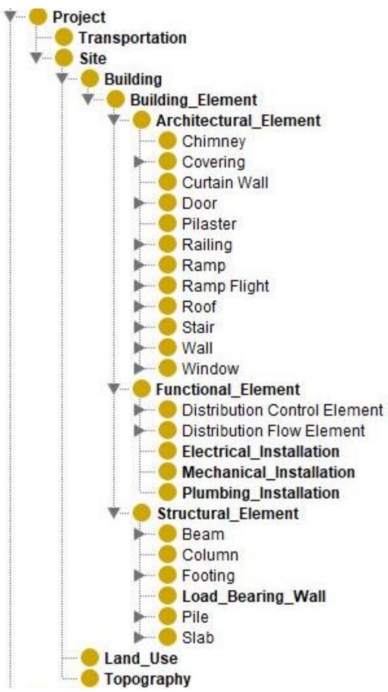

Figure 2. Basic concept/class hierarchies for BIM and GIS integration

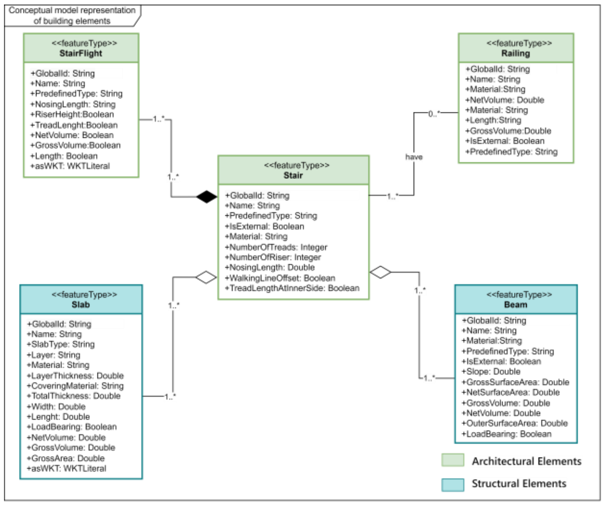

Figure 3. The relationship and attributes of the concept of "Stair"

2.2 Georeferencing and Geometric Data

Georeferencing is a technique originally designed to align maps or raster images with their corresponding geographic locations. It is crucial for integrating building models with other spatial data within a GIS framework (Zhu and Wu, 2021). The process of georeferencing involves adjusting the coordinates of an object to precisely locate it geographically (Diakite and Zlatanova, 2020). There are various georeferencing methods available in GIS, which are vital due to challenges associated with IFC standards (Zhu and Wu, 2022). Georeferenced BIM data can be seamlessly integrated with additional spatial datasets in GIS (Ingram, 2020). BIM and GIS deploy different coordinate systems uniquely. BIM uses a local coordinate system where objects are defined with 3D Cartesian coordinates. The coordinates of an object is often connected to another, facilitating model adjustments—for example, a window's local positioning system might be linked to a wall's system (Zhu et al., 2018). On the other hand, GIS primarily uses a geographic coordinate system, suitable for applications spanning large geographic areas, with each object possessing definitive coordinates in terms of latitude, longitude, and elevation (Deng et al., 2016; Zhu and Wu, 2022). While GIS can employ a local planar coordinate system, it generally relies on a geographic coordinate system (Zhu et al., 2018). It is advised to utilize equations (1) and (2) for transforming reference systems. Equation (1) is used to calculate the coordinates of object vertices in the local coordinate system (Wu and Hsieh, 2007), while equation (2) is employed to transition the coordinates from the local to the real-world system (Sani and Rahman, 2018; Wu and Hsieh, 2007).

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = D.\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} + \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_x & \sin\theta_x \\ 0 & -\sin\theta_x & \cos\theta_x \end{bmatrix} \begin{bmatrix} \cos\theta_y & 0 & -\sin\theta_y \\ 0 & 1 & 0 \\ \sin\theta_y & 0 & \cos\theta_y \end{bmatrix} \begin{bmatrix} \cos\theta_Z & \sin\theta_Z & 0 \\ -\sin\theta_Z & \cos\theta_Z & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} + \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{bmatrix} \quad (2)$$

where *D* is sweep distance, (Vx, Vy, Vz) denotes the direction vector of the sweep, θx, θy, θz are rotation angles around the x', y', and z' axes, respectively, to align the x, y, z coordinate, and (Δx, Δy, Δz) denotes the translation vector from the origin of the local coordinate system to the real-world coordinate system.

For geometry representation, well-known text (WKT), a text markup language for representing data with vector geometry, is recommended by the OGC. WKT is a less complex solution compared to GML. Furthermore, it provides more flexibility due to its support for multiple coordinate systems. It is widely used to efficiently store large amounts of geometric information in a database. It can also be semantically combined with coordinates to support GIS (Wagner et al., 2023).

2.3 Querying with SPARQL

SPARQL, a query language standardized by W3C, was used to query the ontology. SPARQL allows queries to be made from RDF data sources, which allows the representation of objects and the relationships between these objects. Therefore, the ontologies are exported in the RDF standard. SPARQL queries can search RDF graphs according to specific criteria, filter matching data and return the desired results. SPARQL queries exist in four principal forms: SELECT, ASK, DESCRIBE, and CONSTRUCT. Most forms of a SPARQL query begin with one of these keywords, which are applied to what is known as the basic graph pattern, a set of triple patterns. Similar to the RDF triple model, the SPARQL triple model also comprises these components. However, in SPARQL, one or more of these components can be a variable (Hart and Dolbear, 2013).

3. Experimental Study

3.1 Study Area and Data

In order to conduct an experimental study of BIM and GIS integration, static, architectural, and mechanical and electrical (MEP) project data of a building, freely offered by BIMcollab, were acquired in IFC 2x3 format (Figure 4). This building is composed of a foundation, a ground floor, two floors and a roof.

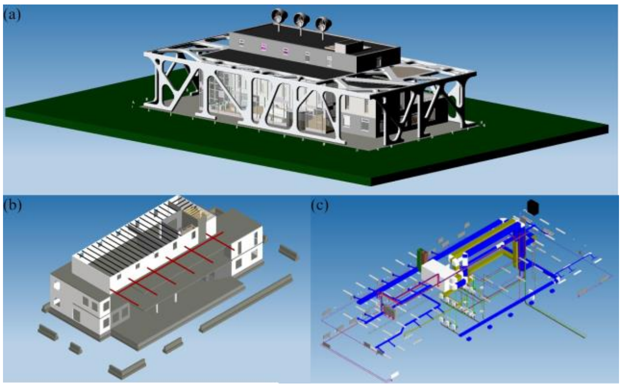

Figure 4. Building Model in IFC format: (a) architectural model, (b) static model, (c) MEP model

In the IFC files, objects in 3D solid models are represented using boundary representation (B-rep), swept solid (SS), or constructive solid geometry (CSG) techniques (Donkers et al., 2016; Zhu et al., 2019; Zhu and Wu, 2022). BIM is based on a hierarchical data model (Karan et al., 2015). In the IFC files, semantics are stored as a combination of entities, attributes, and relationships. The building model in IFC includes classes such as "IfcSite", "IfcProject", and "IfcBuilding", which are present in every building and contain general information about the project. "IfcElement" is the abstract superclass for entities that model physically existing objects. The relevant physical objects are structural elements ("IfcBuildingElement"), distribution elements ("IfcDistributionElement"), and geographic and civil elements ("IfcGeographicElement" and "IfcCivilElement"). Structural elements form the main parts of buildings. These elements include windows ("IfcWindow"), doors ("IfcDoor"), walls ("IfcWall"), floors ("IfcSlab"), stairs ("IfcStair"), and similar components. Distribution elements represent different types of service networks both within the building and around the construction site. Examples include pipes, cables, and ducts (Rajabifard et al., 2019) (Figure 5). However, there is also the "IfcBuildingElementProxy" class, which is commonly used for general purposes but does not provide this information. Similar subclasses exist in other parts of the standard for distribution elements (e.g., heating, cooling, ventilation, and plumbing). In IFC, relationships between entities are generally defined within an "is-a" hierarchy. However, some are organized within a "part-of" hierarchy. In terms of attributes, various semantic forms of information, such as materials, properties (key-value pairs), and even scheduling, can be associated with IFC elements (Ohori et al., 2022). Each object class not only possesses attributes related to identity data (e.g., GlobalId) but also attributes that express different characteristics of the objects.

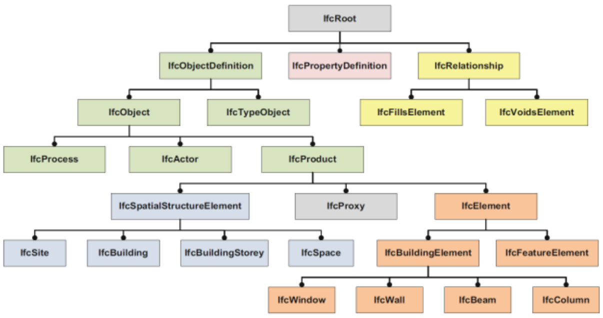

Figure 5. Part of the IFC class hierarchy (Borrmann et al., 2018)

3.2 IFC Interpretation and Attribute Value Assignment

In order for building information in IFC to be practically usable by applications, IFC files must first be appropriately interpreted or parsed. Text-based IFC files, whether in EXPRESS, JSON, or XML format, are readable by both humans and machines, but they are not suitable for practical use (for example, for querying and extracting information). Parsers are necessary to facilitate information querying and to organize building information in a more structured format (Zhu and Wu, 2022). EXPRESS-based IFC files are commonly parsed using parsers available in popular programming languages through tools like IfcOpenShell Python (Figure 6). The element classes related to the architectural, structural, and functional elements of the buildings in the IFC file, along with their attributes and values, have been exported in a table format (Figure 7). The attribute values of building elements were imported into BIM and GIS ontology as a table with rules.

```python
for object in objects:
     psets = Element.get_psets(object, psets_only=True)
     add_pset_attributes(psets)
     qtos = Element.get_psets(object, qtos_only=True)
     add_pset_attributes(qtos)
     object_id=object.id()
     objects_data.append({
        "ExpressId": object.id(),
        "GlobalId":object.GlobalId,
        "Class":object.is_a(),
        "PredefinedType":Element.get_predefined_type(object),
        "Name":object.Name,
        "Level":Element.get_container(object).Name
        if Element.get_container(object)
        else"",
        "ObjectType":Element.get_type(object).Name
        if Element.get_type(object)
        else "",
        "QuantitySets":qtos,
        "PropertySets":psets,
     })
return objects_data,list(pset_attributes)
```

Figure 6. Python code example of IFC file parsing

(a)

```
#39=IFCPROPERTYSINGLEVALUE('FireRating',$,IFCLABEL('60'),$);
#42=IFCLOCALPLACEMENT(#12626,#262543);
#88=IFCPROPERTYSINGLEVALUE('LoadBearing',$,IFCBOOLEAN(.F.),$);
#153=IFCWALL('00oZxkjymyIBhCBmXyRiqV',#1,'Separation wall (non LB)',
$,$,#254883,#270917,'00CA3EEE-B7CC-3C48-BACC-2F087C6ECD1F');
#72918=IFCCARTESIANPOINT((23625.0,15200.0,0.0));
#100756=IFCAXIS2PLACEMENT3D(#72918,#4,#12);
#100793=IFCSHAPEREPRESENTATION(#3,'Body','Brep',(#98152,#98153));
#333140=IFCPROPERTYSET('29ZW$PAZDmB2pS0Vk5pCwg',#1,'Pset_WallCommon',$,(#39,#88,#27));
```

(b)

GlobalId	Class	PredefinedType	Name	Level	ObjectType	GrossSideArea
00oZxkjymyIBhCBmXyRiqV	IfcWall	STANDARD	Separation wall (non LB)	01 First floor	Separation wall	59,9064
0Kx7WcQm__GO5WhM4zDFZ	IfcWall	STANDARD	Separation wall (non LB)	01 First floor	Separation wall	50,723652
1W3T6mmG9qJRxB$zh5oUqJ	IfcWall	STANDARD	Separation wall (non LB)	00 Ground floo	Separation wall	36,5636
3rhRuQuInHHBg4ntrur0$7	IfcWall	STANDARD	Separation wall (non LB)	01 First floor	Separation wall	36,5586
1_BpZg_JtqGRbcbvB0MGtM	IfcWall	STANDARD	Separation wall (non LB)	00 Ground floo	Separation wall	23,49135225

Figure 7. The outcome of (a) parsing of the IFC-SPF data and (b) transferring it in a tabular format

3.3 Adding Geometric Data and Querying

The geometric data were imported in Well-Known Text (WKT) format using "geo:wktLiteral" in the GeoSPARQL (http://www.opengis.net/ont/geosparql) ontology (Figure 8). The building elements were transferred in 3D. The developed ontology was formatted as an RDF file (Figure 9). Queries and analyses were performed in Python using the SPARQLWrapper and RDFlib libraries (Figure 10).

Figure 8. Display of the building in WKT format in QGIS

```xml
rdf:about="http://www.semanticweb.org/ozlem/ontologies/2024/3/geobim#2IM6ysT2_ZGQexw96wknxY">
    <rdf:type rdf:resource="https://pi.pauwel.be/voc/buildingelement#Window"/>
    <geobim:Area rdf:datatype="http://www.w3.org/2001/XMLSchema#double">2.74129545422
    </geobim:Area>
    <geobim:Depth rdf:datatype="http://www.w3.org/2001/XMLSchema#double">340.0
    </geobim:Depth>
    <geobim:FireResistance>30 minutes fire resistant</geobim:FireResistance>
    <geobim:GlobalId>2IM6ysT2_ZGQexw96wknxY
    </geobim:GlobalId>
    <geobim:GrossArea rdf:datatype="http://www.w3.org/2001/XMLSchema#double">2.74129545422
    </geobim:GrossArea>
    <geobim:Height rdf:datatype="http://www.w3.org/2001/XMLSchema#double">1827.53030281
    </geobim:Height>
    <geobim:IsExternal rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">true
    </geobim:IsExternal>
    <geobim:Level>00 Ground floor</geobim:Level>
    <geobim:Name>Type A</geobim:Name>
    <geobim:ObjectType>R1 21</geobim:ObjectType>
    <geobim:Perimeter rdf:datatype="http://www.w3.org/2001/XMLSchema#double">n/a
    </geobim:Perimeter>
    <geobim:Volume rdf:datatype="http://www.w3.org/2001/XMLSchema#double">0.0745085102159
    </geobim:Volume>
    <geobim:Width rdf:datatype="http://www.w3.org/2001/XMLSchema#double">1500.0
    </geobim:Width>
</owl:NamedIndividual>
```

Figure 9. Representation of the wall and its properties in RDF format

```
query = """
PREFIX geobim: <http://www.semanticweb.org/ozlem/ontologies/2024/3/geobim#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>

SELECT ?window
WHERE {
  ?window rdf:type <https://pi.pauwel.be/voc/buildingelement#Window> .
  ?window geobim:Level "01 First floor" .
  ?window geobim:Name "Type B" .
}
"""
```

Figure 10. SPARQL query example

4. Results and Discussion

Since BIM and GIS are created for different purposes, their integration poses various challenges. Semantic web is successful in integrating data due to its structure. The objective of this study was to achieve the integration by developing an ontology, which represents one of the fundamental concepts of semantic web technology. Ontology includes concepts, relationships, attributes, and various constraints. In this study, a common ontology was created to integrate BIM and GIS. This ontology was created based on structural, architectural and functional elements of buildings in order to facilitate the querying of objects according to the requirements in different application areas. In particular, GIS provides a broader perspective with its ability to associate multiple datasets thanks to georeferencing. For example, in terms of disaster management, multi-dimensional data of buildings may be analysed along with physical and socio-economic geospatial data, and geoscientific data. In addition, this ontology is intended to be used in the facility management phase of the building life cycle. Therefore, this ontology facilitates rapid and accurate access to information about the building and its elements, including geo-referenced coordinate data, within facility management processes. This method ensures the efficient retrieval of necessary data when addressing specific challenges or requirements throughout the building lifecycle. For these purposes, the ontology was aligned with various BIM and GIS ontologies. Common and distinct concepts pertaining to BIM and GIS were identified. Then, taxonomic and partonomic relationships and appropriate attributes were determined. Following that, an experimental study was carried out for the suitability of the developed ontology. In this context, the objects and attribute values in the IFC file containing geometric and semantic data of the study area were added to the ontology. Geo-referenced geometry data were also added to the objects in the ontology. These ontologies formatted in RDF were queried with SPARQL. As a result of these queries, the desired data could be accessed. Semantic web enabled the transfer and querying of all semantic data required for BIM and GIS integration. Geometrically, multiple polygons of the objects were transferred as WKT.

When creating ontologies, it is important to determine the purpose and the meaning of the concepts. Every concept may not be relevant to the specified objective. In the absence of a clear definition of these concepts, it will be difficult to use them effectively and potentially lead to confusion. Consequently, the use of core ontologies serves to avoid confusion.

Although ontologies are created for general use, the attributes to be transferred for each application may vary according to the project. Thanks to the flexible structure of ontologies, relevant concepts, attributes, relationships, and rules can be added and removed as desired. Such a framework eliminates the need for mandatory classes and relationships as observed in the data formats used in BIM and GIS integration.

BIM and GIS data were combined thanks to Semantic web for the integration. At the same time, it facilitates display, sharing, and analysis of data by assisting in the comprehension of the relationships and connections between data. It can also be used to analyse large amounts of data. Semantic web standards provide a framework that facilitates data exchange and integration. These standards increase data compatibility between BIM and GIS applications and enable different systems to communicate with each other.

5. Conclusion

The integration of BIM and GIS has been realised and examined using semantic web technologies. The semantic web has successfully enabled the thorough implementation of semantic transfer. This study will make the use of the semantic web more understandable for the applications that require BIM and GIS integration. In practice, it is important for the building model used in the experimental study to consist of static, architectural and MEP projects to examine its relationships with different core ontologies. Furthermore, incorporating MEP projects into the workflow ensures the coordinated formation of systems throughout the building's life cycle, starting with construction planning. This coordination helps prevent clashes between systems and enables easier connections to external networks. Additionally, knowing the exact locations of these installations' eases problem identification and resolution for facility management.

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