THE IFC FILE FORMAT AS A MEANS OF INTEGRATING BIM AND GIS: THE CASE OF THE MANAGEMENT AND MAINTENANCE OF UNDERGROUND NETWORKS

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ABSTRACT:

The construction sector is undergoing an important digital revolution. The integration between Building Information Modeling (BIM) and Geographical Information System (GIS) is a key component of this revolution and is increasingly discussed. Although benefits are already recognised, several challenges still remain. The purpose of this paper is to present the method proposed by the GEOBIMM project to overcome the existing barriers towards the integration between BIM and GIS domains and to present the first results applied to the maintenance of underground networks. The results are a set of guidelines essential for the integration of BIM files in GIS platforms within the GEOBIMM domain, to ensure: the appropriate geometric description of the elements; the correct georeferencing; the geospatial semantic and topological interoperability between the two systems; the appropriate definition of the information parameters. These pillars are further used to develop a guideline for planners and construction companies supporting them in developing compliant BIM models.

1. INTRODUCTION

In recent years the construction sector has undergone important transformations and innovations in digital revolution. The starting point of this revolution is Building Information Modeling (BIM). BIM is a process for creating and managing information on a construction project across its whole lifecycle (NBS, 2019). BIM plays an important role due to its growing prevalence among practitioners. However, a low acceptance by public bodies is generally recognised despite of the increasing legal obligation to use it in public projects (Matt et al., 2018).

Nevertheless, public bodies, in particular those working at local level (i.e. Municipalities), have an extensive long-time experience in using methods and systems very similar to BIM in their main characteristics. One of these is the Geographical Information System (GIS), the most common information management system used to manage geographical information. The scope of GIS is to represent and analyse cities and landscape, which are the context of planned construction (Biljecki et al., 2015). Moreover, it is based on geometrical objects, the virtual representation of real entities, and related semantics, a list of alphanumeric information that describe the object beyond its geometric dimension. These characteristics reveals the similarity between GIS and BIM.

The need to make the sector more efficient has encouraged the integration of BIM and GIS, later defined as GeoBIM. The GeoBIM domain is increasingly studied and discussed (Liu et al., 2017; Fosu et al., 2015; Arroyo Ohori et al., 2018; Sun et al., 2019; Noardo et al., 2020b). However, although this integration is beginning to yield significant benefits, the recognition of these benefits is still difficult to be acknowledge by the final user (i.e. technical professionals of the Municipality). One of the reasons is a lack of practical tools and suitable interoperable file formats that easily implement both the two domains solving the issues highlighted by Noardo (Noardo et al., 2020a).

The purpose of this paper is to describe the method proposed by the GEOBIMM project to overcome the existing barriers towards the integration between BIM and GIS domains and to present the first results obtained. The GEOBIMM project aims at responding to the real needs of public bodies in digitising their processes in a BIM perspective, exploiting, and enhancing the information management systems already in use and consolidated (GIS). The BIM-GIS integration is applied to the maintenance of underground networks (water supply network, black and white sewage system) by a public organization that works at city level. One of the outcomes of the GEOBIMM project is a guideline for planners and construction companies supporting them in developing BIM models compliant with open-BIM standards (i.e. IFC) and with the GIS-based Facility Management (FM) system in use within the public organization.

The paper firstly provides and overview on the state of the art of the digital transformation required by public organizations and of the current opportunities and challenges in BIM-GIS integration for FM of underground networks (Section 2). In addition, the GEOBIMM project is presented (Section 3). Section 4 describes the research methodology adopted within the GEOBIMM project to integrate BIM in GIS for the maintenance of underground networks. Section 5 reports the findings, which are discussed, followed by conclusions and future work, in Section 6.

2. STATE OF THE ART

2.1 Digital transformation in public organizations

In the last decade, European governments have developed strategies to support their construction market in facing the digital transformation. In Italy, the issue of BIM was introduced in the Code of Contracts (D.lgs 50/2016) heralding its gradual compulsory use in public tenders. To date, the use of BIM appears to be a rapidly growing trend in the public works sector.

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The digital revolution, declared mandatory by the government, will, in a short time, have an increasingly significant impact on both public organizations and companies operating in the construction sector. In this context, public organizations play a key role: on the one hand, they have to face, themselves, new working methods and technologies; on the other hand, they are the promoters of a digital and innovative culture towards companies and professionals.

The scenario that emerges highlights the direction that all the actors involved in the construction process will pursue and the review of the current processes, in the face of the change, is the first step of path to digitalization (Ullah et al., 2020). In this sense, public organizations have to review their current FM processes, as they will inevitably move towards a digitised management of their real estate assets. This means that an optimal and conscious management of all the activities that concern the FM sector will no longer be able to ignore the use of new digital tools, and public organizations will have to gradually internalise this change and equip themselves.

2.2 Combining BIM and GIS: opportunities and challenges

The integration between GIS and BIM can be beneficial to better streamline processes of urban development and management and for applications related to infrastructural works, including underground works (Liu et al., 2017): GIS supports in understanding how to plan infrastructures from urban to regional and national land context while BIM supports the design and construction processes of those infrastructures. Therefore, BIM and GIS integration provides georeferenced 2D/3D objects that can be used in infrastructure planning, design and maintenance, with a more efficient workflows and consistent data. GeoBIM applications provide complete and up-to-date data about facilities and related equipment for a more efficient monitoring and management of information across the whole lifecycle, putting data at the centre and connecting different workflows. Moreover, it has advantages in 3D visualisation, data logic and spatial analysis, environmental and operational management to improve efficiency and quality (Noardo et al., 2020b).
However, technical challenges still remain, related to the differences between how BIM (architecture/limited domain) and geoinformation (geography/wider extension) represent the world and the objects: the scale of representation and the coordinate systems, the levels of detail and geometric representation, the exchange file formats, methods for accessing and for the storage of information as well as semantic mismatches and topological issues (Ellul et al., 2018).

2.3 BIM and GIS for FM of underground networks.

In underground networks development and management multiple parties participate in the working chain with respective software and data formats, but often the data processing and conversion during data sharing may cause the loss of data and misunderstanding in construction and maintenance operations (Sharafat et al., 2021). Moreover, with its complex distribution in both horizontal and vertical dimensions, the underground networks need to consider not only their specific attributions, such as materials, depth, size, and connection, but also the interaction with other objects, as road or surface building.

In these last years both BIM and GIS technologies have been used to describe such kind of facilities. With the BIM technology, the topographic data, geometric and alphanumeric information can be seamlessly integrated into a comprehensive 3D digital model with significant advantages in data transcription, visualisation, collaboration (M. Chen, 2017) and interoperability of data, thanks also to the use of the IFC file format. The Industry Foundation Classes (IFC) is the international standard file format for data exchange intended to facilitate the interoperability in construction industry and in BIM-based projects. It guarantees the transfer of not only geometric characteristics but also relevant information about the physical and relational properties of BIM objects. However, currently, in the field of infrastructure works, there are still limitations in adopting the IFC format since it does not contain specific classes for infrastructural objects such as roads or rails (Floros et al., 2020).
On the other side GIS is an established platform for managing and presenting spatially referenced information and it is used to display the position of objects at city level. It presents spatial information in large scale and focuses on providing the position and displaying the spatial relationship. GIS is an information system in which “information is derived from the interpretation of data which are symbolic representations of features” (Maguire, 1991). With numerous nodes and lines sometimes the 2D visualisation of GIS systems is difficult to understand, as in the case of an underground piping networks where many objects with the same x, y coordinates are represented, causing misunderstanding in the construction filed. Steps forward have been done with the 3D city model and its CityGLM file format, a specific implementation of the Geographic Markup Language (GML). However, also this file format has still limits related to the representation, the level of detail of the geometric and semantic descriptions, with a basic support for metadata, and the lack of explicit definition of the semantic of the geographic features (Amirebrahimi et al., 2015).
The integration between BIM and 3D GIS domains and related open standards, IFC and CityGML, have been investigated in many research works (Kumar et al., 2019) but the two domains still remain disconnected because of the differences in the modelling approaches, concerning first the geometry, semantics, the level of detail and the gap of information richness and editing functions between BIM and GIS platforms (Cheng et al., 2015; Garramone et al., 2020). BIM models in fact are much more detailed and semantically rich than GIS models, and attempting to convert these formats may cause often losing information: so the integration of BIM and GIS should focus on reusing the available data to build up a shared database readable by both the systems.

Moreover, also the proper geo-referencing of BIM models plays a critical role in the BIM-GIS integration issue. The knowledge of precise location of underground networks is crucial to properly maintaining the existing networks or to plan new ones (Preciados Royano et al, 2019; Vishnu et al, 2018). Unfortunately, very often this information in IFC file is quite rough, related to the possibility to use IFC entity IfcSite (Diakité, 2018). IFCSite provides information about the local coordinate system defined within the BIM authoring design software and does not allow to make a strict link to the real world by dealing with the more precise cartesian coordinate systems.
Underground networks play a critical role in the urban and territorial space since their design, construction and maintenance requires accurate planning and implementation, but still there are not suitable unique digital tools for managing both planning and maintenance operations with a proper geometric accuracy and informative level for those kinds of facilities. The need to overcome the actual limits in FM platform is more urgent than ever.

3. THE GEOBIMM PROJECT

The GEOBIMM project has three main objectives:

1. To make the process of managing a public work more efficient by reducing the execution time of technical processes for a faster, more transparent and more aware public administration.
2. To support public administrations in facing the ongoing digital revolution by providing innovative software applications that can be integrated with the information management systems already in use.
3. To demonstrate the positive impact on the daily work of designers and companies working with public administrations.

These objectives will be achieved through the technological development of the GEOBIMM4FM app, a BIM-GIS software application for the Facility Management of underground networks.

The core of this application is an innovative interface that supports the connection between BIM and GIS data, promoting an integrated approach to the digital management of the underground networks. It allows to manage, analyse and visualise data according to a geo-referenced hierarchical scale, from territorial to punctual and vice versa, in order to obtain a holistic and efficient control along the whole life cycle of a facility.

This paper focuses on the methodology adopted and the first results obtained working on the BIM-GIS integration for the development of the GEOBIMM4FM software application.

3.1 GEOBIMM4FM

Within the GEOBIMM4FM software application, through to the conversion of IFC entities into GIS features, BIM models can be visualised in their geographical context and queried according to a certain organizational structure pre-defined by the end user, the public organization. BIM models will automatically populate the database of each underground network and of its – punctual and linear – components.
Performing the automatic population of the database from a BIM model requires firstly the identification of all the geometrical and alphanumerical information needed to maintain each component, then the development of the BIM model, that must contain the information previously identified and finally the mapping of each component into its GIS feature classes to have the topographical representation of the underground networks. The database will then be updated when changes will affect the underground network and, thus, the BIM model.

The scientific contents of the project are coordinated by a research institute expert in BIM implementation and in coordinating research projects, in collaboration with five companies: a software-house experts in GIS; a start-up company expert in combining data from different sources into up-to-date knowledge graphs; a public organization in charge of maintaining the underground networks; a construction company specialized in underground works.

4. METHODOLOGY

This section describes the methodology adopted for the integration of IFC files into GIS platforms to visualise, in 3D, the underground network geometries, to represent them within their geographical context, and to provide data, useful for the management of their maintenance activities, into the GEOBIMM4FM software application.
The current research is performed using Revit as BIM authoring software, to develop the BIM models of the underground networks; IFC as the open-format standard for exchanging BIM data and 3D spatial information; Workspaces as GIS-based Facility Management system; Ontop as the system for integrating and managing data from different data sources.

The first step was the geometrical development of the 3D models with an appropriate level of detail, according to the needs of the final user. Afterwards, alphanumeric information enriched the BIM models and, further, visualised in 3D through the IFC standard. The BIM models, exported in IFC format from the BIM authoring software, facilitate the interoperability with the other systems used to develop the GEOBIMM4FM app. Since the conversion from BIM standard (IFC) to GIS standard (CityGML) and vice versa is not always accurate, a third-party platform is used to manage different data sources, so the IFC file worked as database to enrich the Ontop system. Here, IFC entities were converted into semantically consistent features of a georeferenced database in order to become readable by the GIS-based FM system, Workspaces. The integration of BIM and GIS is given by the semantic and ontological mapping of the IFC entities and the verification of topological rules: the last are used to analyse in detail the spatial and semantic aspects of geometric data and to identify conflicts between each element of the underground networks and its surroundings. A proper georeferencing of the IFC file enables the integration between the BIM models of the underground networks and their surroundings (Andrianesi et al., 2020).

4.1 Case study

The study area is a district of a city located in the North of Italy, where the public organization headquarter will find place.
Within this area, the following data were collected:

- the point clouds of the area above the ground, in the proximity of the new headquarter.
- the GPS station surveys of the underground networks already existing in the area: the black and white sewage system, with its manholes and drains, and the water supply network, with its flow controllers. The survey focused only on those elements of the network available without adopting invasive actions.
- other existing information and data regarding the abovementioned elements – those that would have required invasive actions – were collected searching in documents (i.e. 2D/3D CAD files, reports, previous surveys) available at the current and the previous public organization responsible for their maintenance.

All the raw data collected were converted into vector-graphics format (.dwg) and then into the BIM model: the subsequent information and semantic enrichment leads to their integration and visualization within the GIS systems.

4.2 Research Design

So far, BIM and GIS are individual disciplines, each with its own language, but "the I of Information" is the basis for a consistent integration. Using the principles of interoperability, semantics and topological consistency, the main challenge was to ensure the correct information flow between the different systems and databases involved along the process.
According to the aforementioned considerations, the Industry Foundation Classes (IFC) has been chosen as the data exchange

format, and the BIM-GIS integration through the IFC has been investigated in order to gain also an advanced and a bi-directional flow between the two systems: even once imported in the FM system the IFC informative parameters can be updated, depending on the needs of the end user.
The general framework of the GEOBIMM project is shown in Figure 1 and described in detail as follows.

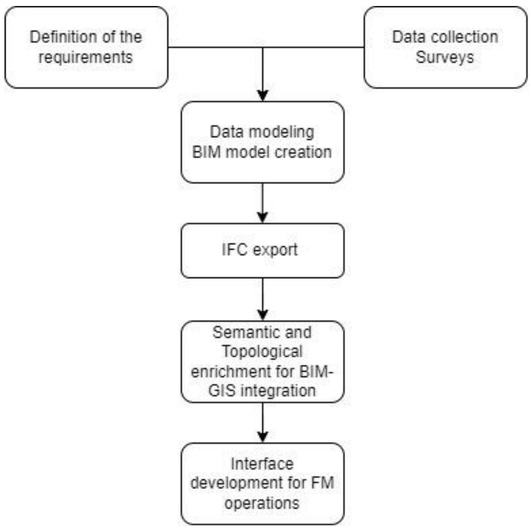

Figure 1. Framework for the GEOBIMM project.

4.2.1 Definition of the requirements: The underground networks are made up of linear and punctual elements that have different technical characteristics and operational and maintenance specifications. The organisational structure of the elements divided by network type has been defined by the final user based on its own maintenance service plans.
The BIM for FM workflow starts with the definition of the information requirements for each element, essentially the data and information deliverables to fulfil their specific maintenance service managed by the GIS-based FM software. The list of information requirements is the result of the process of determining what information is needed for achieving FM demands and, thus, what parameters have to be created within and provided by the BIM models.

DREINAGE SYSTEM				DREINAGE SYSTEM	
GROUP	PARAMETER	DESCRIPTION		BIM MODEL INDICATIONS (IfcFlowController)	
2.2.2	SUMP PIT	TIPOLOGY OF THE DATA	ORIGIN OF THE DATA	PROPERTY SET DENOMINATION	VALUES
00_IDENTIFICATION	Network Type	Text	From Model	00_ID_Network Type	2
00_IDENTIFICATION	Network Element	Text	From Model	00_ID_Network Element	2.2
00_IDENTIFICATION	Network technological Component	Text	From Model	00_ID_Network technological Component	2.2.2
00_IDENTIFICATION	Description	Text	From Model	00_ID_Description	Pozzetto_Acque_Nere_GEOBIMM: Pozzetto_Eccentrico
00_IDENTIFICATION	Object identification		From Model	00_ID_Object identification	xxx
00_IDENTIFICATION	Name of managing institution	Text	From Model	00_ID_Name of managing institution	xxx
00_IDENTIFICATION	Laying/installation date	Text	From Model	00_ID_Laying/installation date	xx.xx.xxxx
00_IDENTIFICATION	Sump Pit Model	Text	From Model	00_ID_Sump Pit Model	Cast-in-place/Prefabricated
01_LOCALIZATION	Type of infrastructure crossed	Number	From Model	01_LOC_Type of infrastructure crossed	(-) / road / pavement / bicycle path / parking area / flowerbed / private land / other
01_LOCALIZATION	Bottom Elevation in the sump pit	Length	From Model	01_LOC_Bottom Elevation in the sump pit	(m) (height from pit lid to water flow level inside the pit)
01_LOCALIZATION	Coordinate x-y	Text	From Model	01_LOC_Coordinate x-y	geographical coordinate X - geographical coordinate Y
02_TECHNICAL CHARACTERISTICS	Access type	Text	From Model	02_CAR_Access type	ladder / vertical inspection ladder / step / not present
02_TECHNICAL CHARACTERISTICS	Sump pit Material	Text	From Model	02_CAR_Sump pit Material	xxx
02_TECHNICAL CHARACTERISTICS	Cover Material	Text	From Model	02_CAR_Cover Material	xxx
02_TECHNICAL CHARACTERISTICS	Aeration	Yes/No	From Model	02_CAR_Aeration	Yes/ No
02_TECHNICAL CHARACTERISTICS	State of Preservation	Text	From Model	02_CAR_State of Preservation	(-) / Insufficient / Fair / Good / Excellent
02_TECHNICAL CHARACTERISTICS	Cover State of Preservation	Text	From Model	02_CAR_Cover State of Preservation	(-) / Insufficient / Fair / Good / Excellent
02_TECHNICAL CHARACTERISTICS	State of Preservation date	Text	From Model	02_CAR_ State of Preservation date	xx.xx.xxxx
02_TECHNICAL CHARACTERISTICS	State of Preservation Notes	Text	From Model	02_CAR_ State of Preservation Notes	xxx
02_TECHNICAL CHARACTERISTICS	Presence of grafts/connections	Yes/No	From Model	02_CAR_Presence of grafts/connections	Yes/ No
02_TECHNICAL CHARACTERISTICS	Number of grafts/connections present	Number	From Model	02_CAR_Number of grafts/connections present	
03_GEOMETRIC CHARACTERISTICS	Section shape	Text	From Model	03_GEOM_Section shape	rectangular/circular - size/diameter
03_GEOMETRIC CHARACTERISTICS	Cover section	Text	From Model	03_GEOM_Cover section	xxx
03_GEOMETRIC CHARACTERISTICS	Neck length	Length	From Model	03_GEOM_Neck length	(m)
04_DOCUMENTATION	Video inspections	URL	Documents	04_DOC_Video inspections	link to video
04_DOCUMENTATION	Floor plan/section drawings	URL	Documents	04_DOC_Floor plan/section drawings	link to document
04_DOCUMENTATION	Photographic documentation (inside the sump pit)	URL	Documents	04_DOC_Photographic documentation (inside the sump pit)	link to document
05_SURVEY	Survey Tool used	Text	From Model	05_RIL_Survey Tool used	GPS/TS/meter/drone/photos/...
05_SURVEY	Survey Date	Text	From Model	05_RIL_Survey Date	xx.xx.xxxx
05_SURVEY	Data Reliability	Text	From Model	05_RIL_Data Reliability	(1) o (2 + note) o (3)
06_MAINTENANCE	Cleaning execution date		Maintenance operations database		
06_MAINTENANCE	N. Hours needed for cleaning		Maintenance operations database		
06_MAINTENANCE	Cleaning frequency (half-yearly / yearly)		Maintenance operations database		
06_MAINTENANCE	Date of last cleaning		Maintenance operations database		

Figure 2. List of the information requirements (e.g. Sump Pit of the Sewer System).

This phase of the project produced an excel table where all the information requirements are listed, categorized in different thematic groups (Identification, Localisation, Technical Characteristics, Geometrical Characteristics, Documentation and Survey), tagged according to their typology (text, number, measure, Yes/No) and according to the source that can provide that information (GIS system, BIM model, .pdf document, etc.). The table also informs on how each information requirements must be named within a BIM model and indications of the rules for assigning the value to each parameter, so that these parameters are uniquely detectable both within authoring software and in the IFC file. An extract of the excel table is showed in Figure 2.

4.2.2 Data collection and data modelling: The collection of photographic and geometric data concerning visible surfaces of the subsurface networks' components is achieved through different surveying methods, such as laser scanner and GPS, and requires skilled workers. The generation of the BIM 3D model results from information derived from 2D as-built drawings combined with surveying data on elements heights.
The modelling of the underground network systems includes several steps. The CAD drawings of the piping systems and related flow accessories, resulting from the survey, are used as a base to generate a 3D model of the network systems with a high level of geometrical detail. The 3D modelling process consists in: a) the modelling of 3D objects representative of each type of elements of the subsurface networks; b) checking and integrating the parameters and information required from the public organization and provided by the topographic survey; c) placing elements of the underground networks in accordance with the local survey. Finally, a review of the completeness of required information is recommended in order to be able to proceed with the export of the IFC. Therefore, the geometric and alphanumeric information about the underground network systems is stored in the IFC file, used for the integration and database population process for the GIS-based FM system.
The result of this phase of the project is a collection of BIM models concerning the underground networks and a BIM library of the underground networks elements.

4.2.3 Semantic and geometric description in GIS and BIM integration: The object-oriented approach and the semantic data models used by BIM technology together with relations to other construction components (neighbourhood, groupings, etc.) provide a strong characterization to all the components of a facility model. The IFC format preserves several topological relationships from a GIS point of view and it consists of several relations among piping networks, pipe segments, and pipe connections (nodes): in fact the IFC spatial structure of the underground network systems includes IfcFlowSegment, IfcFlowFitting, IfcFlowController, IfcFlowTerminal and various connections between them defined by the connectivity relationship IfcRelConnects, through ports (IfcPort). Geometry of the modelled components refers to the physical features (dimension and location as geographical coordinates) of a subsurface network within a given area, whereas topology describes spatial relationships and constraints (Zhao et al., 2019).
Given the complexity of pipe network deployment, topological rules are fundamental in GIS platforms to check for any conflicts between the model objects and its surroundings since they help to detect objects that have spatial relationships with each other to provide a consistent 2D and 3D visualisation. Topological information is qualitative and it is expressed by topological relations, such as containment, adjacency or overlap: this information can be derived from geometric information, or it might be derived by stating in a clear way the topological relations between features. Topological rules have been set within the GEOBIMM project to validate the spatial relationships of elements of the underground networks on site.

4.2.4 Development of the user interface for the FM system: The goal of the user interface, called Workspaces, is to make the user's interaction as simple and efficient as possible, in terms of data arrangement (data importing and processing) and data visualisation, providing functionalities of data displaying and collaboration. To ensure the effectiveness of the operational aspects of maintenance on the underground networks, there is the need to organically collect the data: three dimensional and geometrical specifications, related to design and construction of the networks systems, and nongeometric data and requirements to support successful implementations of BIM in FM. These are operating conditions, specification and alphanumeric information related to a wide range of activities from installation to operation and maintenance. The development of the user interface is currently underway, and its description is not on the scope of this paper.

5. RESULTS

The BIM methodology enables to digitally visualise several information that describes a real construction element. The organisation of this information must follow specific logics, related to the goals and uses that the BIM model must absolve, such as the creation of a model of the current state of underground networks, the construction of new parts of networks or the management and maintenance of the services. What and how to model depends on the purpose for which the BIM model is developed. Distribution systems components must contain specific geometric, semantic, geographic and alphanumeric information related to the family type they belong to, and they must refer to the precise IFC organization.
Guidelines that support in developing BIM models and BIM objects for their immediate integration in GIS-based systems have been created, reporting and describing in detail the following key features for BIM – GIS interoperability for the FM of underground networks

5.1 The IFC structure for underground networks

The goal drives the logic of articulating the spatial structure of the underground network systems and their components. IFC can be used to describe the network structure, their components with their geometric and attributive properties as well as the relations between them since the objective is both to map and digitalise the technical components of the underground networks and to use these digitalised components to streamline operations and maintenance activities. The spatial structure of IFC allows to articulate the BIM models through a tree organisation, according to the model management criteria. To define a clear modelling procedure, it is important to break down the underground network into a hierarchical structure, and assign each physical components to this structure, considering that each one of these can belong to only one level of the hierarchy. An IFC file has a default decomposition structure, which starts with a project and descends into a site, a facility, individual storeys, down to specific elements.
Since the standardization process of the IFC encoding for infrastructure constructions is ongoing, a hierarchal standard has not yet been defined for underground networks, characterized by a horizontal spatial development. Consequently, the spatial structure of the subsurface networks, translated into the IFC standard, is affected by this "Building" organization on "Levels" (Figure 3).

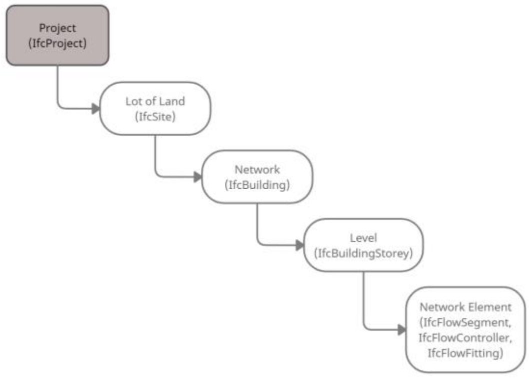

Figure 3. Underground utility networks data structure.

The first level of the spatial structure is the IfcSite, that is the part of territory where the distribution system is located. Streets and sidewalks are the specific areas of the municipal territory in which the underground utilities are located. The second level is where the type of work is defined, which may be a building structure (IfcBuilding) or other types of infrastructure, such as the underground networks. The next step of decomposition concerns the layer (IfcBuildingStorey), which is the physical space that hosts network components. In contrast with a building decomposition, the level for underground utilities is a specific physical location placed at a defined height where all the components of the systems can be modelled. The last level of the spatial structure identifies the physical objects (IfcElement) of the water supply network and of the black and white sewer system.
In order to guarantee an appropriate modelling procedure for these elements, especially during updating and data transferring to the GIS-based FM system, they definitely have to refer to this spatial decomposition.

5.2 The BIM library and its IFC Schema

The underground network systems are composed by linear and punctual elements with different technical characteristics and operational and maintenance aspects.
The IFC4 version defines IfcDistributionFlowElement providing the elements of a distribution system, such as a utility infrastructure system for the distribution of water. Under this entity the subtype defines the pipes, related components, properties, and relationships including the IfcFlowController, a device used to regulate water flow in a pipe network, the IfcFlowFitting that is a junction or transition in a flow distribution system, the IfcFlowSegment that defines the pipe segments, and the IfcDistributionPort that defines pipe connections (nodes, ports). These entities have been chosen since they are well defined for MEP (Mechanical, Electrical and Plumbing) design for sewer and plumbing/drainage systems and their characteristics suit well for the definition of the components needed by the underground network systems.
Five IFC entities of BIM objects have been identified to represent the components of the underground networks and corresponding GIS features, that are vector data with attributes and shapes represented using geometry. They are listed in the following table (Table 1):

IFC Entities	GIS Features
IfcFlowSegment: it is typically straight, sloped, contiguous with two relationship ports, those enabling the connection with	Polyline: it is a sequence of joined vertices which geometry consists of two or more vertices and the first and last vertex are not equal

other elements (IfcRelConnectsPorts). Geometric Parameters, such as Length, slope or Nominal Diameter attributes are provided in the Property Set as default attributes.	
IfcFlowFitting: it defines the existence of a junction or transition in a flow distribution system (e.g. elbow, tee, etc.).	Topological primitives (virtual node) in order to ensure the flow continuity remaining invisible to user.
IfcFlowController: it defines the existence of elements used to regulate the flow of a distribution system.	Point feature, where the geometry consists in only one single vertex.
IfcFlowTerminal: it defines a fixed element as the terminal or start of a distribution system at which the system interfaces with an external environment.	Point feature, where the geometry consists in only one single vertex.
IfcDistributionPort: it defines the connection between the pipes and the nodes using IfcRelConnectsPortToElement.	Topological primitives (node): it supports the definition of the model in managing spatial relationships by representing spatial objects as graph of topological primitives.

Table 1. List of IFC entities, GIS features and topological elements

Instructions have been developed for the correct geometric and alphanumeric information definition of all the elements of the identified IFC entities: how the element must appear from the geometric point of view, how elements are related to each other, and the list of Informative Property Sets that are needed for maintenance and monitoring operations. System families and parametric loadable families in a common exchange format have been created, to facilitate and standardize modelling process.

5.3 Objects geometric description

The BIM objects must have a three-dimensional graphical representation described by a constructed solid geometry corresponding as closely as possible to the real objects' geometric and material characteristics. Geometric information must be expressed using shape, size and position in the spatial context in both absolute and relative terms. The required Level of Detail based on current Italian Regulation UNI 11337-4:2017 is LOD D - Detailed object. The definition of solids, IFC geometry types defined in ISO 10303, should be based on parameterised geometric primitives so that full reconfiguration of the object is possible using equations and formulae.

5.4 Georeferencing

BIM models must be oriented according to the geographical north and georeferenced according to a Geographic Coordinate Systems with the corresponding EPSG code. Each IfcDistributionElement has a specific position in space and an assigned geometric representation, which may be expressed in relation to other entities. The IFC file must include a project geographical definition (global position using X,Y,Z coordinates). The BIM model represents the orientation with respect to the geographical north, the X-Y planimetric development of the underground network and the corresponding Z elevations for each component, representing the real elevations at which the elements are installed, so it is possible to visualise for all of them the easting and northing planar coordinate in units [m]. This geographic information can be assigned, i.e. in Autodesk Revit, using the Survey Point: adding specific planar coordinates to one point of the system the entire model acquires georeferenced position in the world (Figure 4a). Thus, the export of the IFC file preserves geo-referencing and the global position coordinates can be visualised for each element. Only in this way, by assigning x, y coordinates to a file, the precise georeferencing of the model can be assured and it is possible to overcome the barriers with GIS platforms. The resulting georeferenced file can be placed in its correct and precise location on a map in a GIS software. Otherwise, adding only the location (IfcSite), the result is the information concerning the toponymy, widely used by public bodies but not sufficient to provide precise indications on the location of each element of the underground networks (Figure 4b).

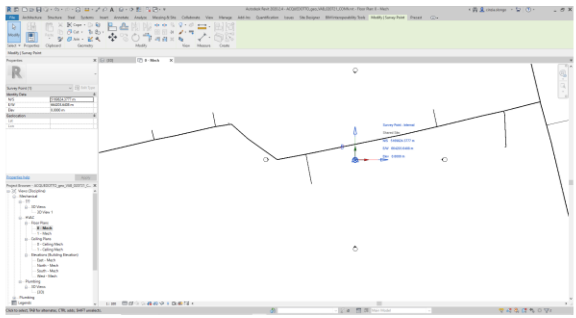

Figure 4a. Specific geographic information on X, Y, Z coordinates from Survey Point in Autodesk Revit, expressed in geometrical coordinates [m].

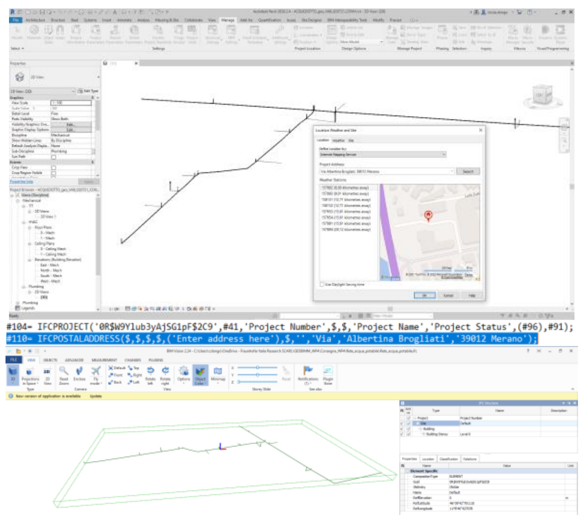

Figure 4b. Toponomy information in IfcSite, from Location in Autodesk Revit, expressed by Longitude, Latitude and Elevation.

5.5 Semantic and topological editing and enrichment for interoperability of IFC elements

The definition of BIM objects depends both on the IFC entities assigned to them but also on the relations they establish with other objects or with external entities to which the objects can

be associated, by inheriting certain characteristics such 'part of' and 'type of' (IfcRelationship).
Geospatial semantics and topology can facilitate the integration of IFC file in GIS by enhancing the interoperability of the geospatial data. Objects must hold relations of contiguity with close entities, so that the topological analysis of the model is consistent and everywhere satisfied. The IFC model is indeed organised according to a specific spatial-topological hierarchy. BIM elements that geometrically appear closed, connected or strictly dependent should report these links through explicit relations, that are identifiable and possibly modifiable. A major approach for enabling interoperability and knowledge sharing between different applications is developing ontologies. Geospatial ontologies can be codified by description logics through the definition of classes and relations, and consist both of geospatial features and geospatial relations: geospatial features include point, line, and area concepts, and relations include equal, touch, disjoint, intersect, cross, within, contain, near, overlay, connected, in front of, and around, etc. (Zhang, 2019). Each of the entities in the system has its defined attributes and are connected via nodes using IfcRelConnectsPortToElement so that entities that are adjacent or linked by other types of constraints must appear as connected via these ports (Sharafat et al., 2021).
After IFC file export, some inconsistencies of topological relations can appear: indeed, due to the lack of effectiveness of BIM-based tools for modelling those facilities, i.e. the underground networks, which do not fall within the design of buildings domain, it is necessary to manually modify and enrich the relationships necessary for the topology to be correct.
Whether these relations are missing for the distribution systems components, the process for semantic enrichment enables adding topological relations to support software in interpreting the content and relations and other semantic information.
As a result of this research, spatial and topological mapping should be implemented when relations are missing: IFC can be edited using source code editor and adding three rows compiled with correct references to elements (IfcDistributionPort, IfcRelConnectsPortToElement and IfcRelConnecsPorts as shown in Figure 5a) that build up the relation between two elements whether they are IfcFlowSegment, IfcFlowFitting or IfcFlowAccessory, so that these relations then appear also in any BIM viewer (Figure 5b).

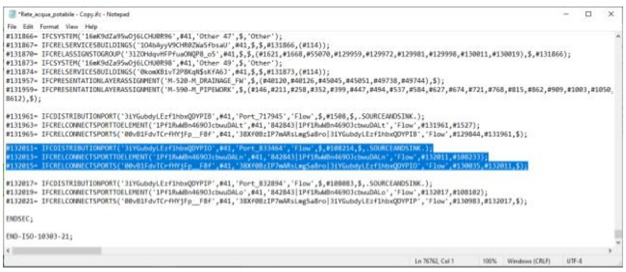

Figure 5a. IFC code editing for topological relations enrichment

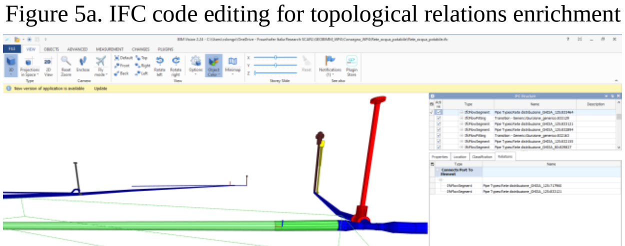

Figure 5b. Result of topological enrichment and visualization of relations among elements in a BIM viewer.

By doing this, IFC entities can be translated into GIS features, using the implementation of a formal logic-based semantics for geospatial queries and SPARQL endpoint in order to provide schema and rules to interpret and represent the data and to automatically assign metadata of each element for achieving the automatic population of the FM platform database (Figure 6).

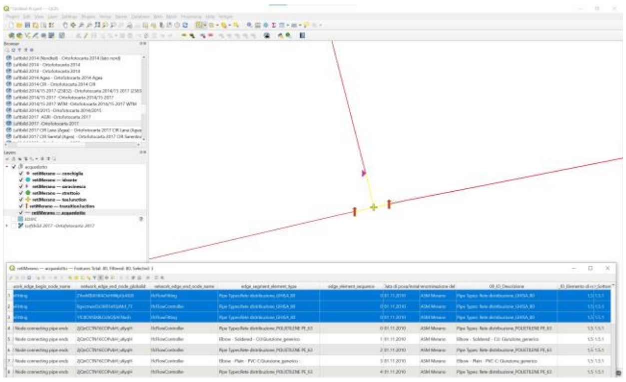

Figure 6. Result in QGIS of SPARQL endpoint for geometric and alphanumeric description (source: R3GIS Ltd)

6. DISCUSSION AND CONCLUSION

6.1 Discussion

This paper reports the guidelines for the BIM-GIS interoperability. Above all, two aspects emerge as essential to assure this integration as a first step in the evolution process of the use of IFC for the FM of underground networks:

a) the use of the IFC schema as a link between BIM and GIS domains with the correct topological settings using IfcRelConnectsToElements and IfcRelConnectsPorts. If missing, these IFC entities have to be manually added, as above described, to ensure the connectivity among all the elements of an underground network and to correctly describe: the topological relationship of the elements within the BIM model, the correct geometric visualisation in 2D/3D of each part of the network and their related semantic information.
b) the georeferencing method, that cannot be limited to the use of the IfcSite entity. In fact, the IfcSite can only provide information on the part of territory where the facility is located but it is not enough to ensure the correct and precise georeferencing of each element within a BIM Model. A geometric coordinate system must be integrated from a survey in the real environment by means of the Survey Point in the case of Autodesk Revit.

These guidelines are further used as inputs to write a guideline for the development of BIM models compliant with IFC format and with GIS integration.
Once the underground networks are imported in the GIS-based FM system according to these guidelines, each component of the network is described by the geometric and alphanumerical information required by the public organization to perform its FM activities.

6.2 Conclusions and future works

The purpose of this paper is to describe the method proposed by the GEOBIMM project to overcome the existing barriers towards the integration and interoperability between BIM and

GIS domains and to present the first results obtained: the guidelines for the BIM-GIS integration within the domain of the GEOBIMM project. The method proposed by the GEOBIMM project can successfully integrate BIM files in GIS platforms for the underground networks by mapping and enriching IFC using the entities and indications above discussed.
The project is still ongoing focusing on the development of the user interface for the exploitation of the BIM data, for FM activities, into the GIS-based FM system, currently in use by the public organization.

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REFERENCES

Andrianesi D. E., Dimopoulou E., 2020. An integrated BIM-GIS platform for representing and visualizing 3D cadastral data, *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.*, VI-4/W1-2020, 3–11, doi.org/10.5194/isprs-annals-VI-4-W1-2020-3-2020

Amirebrahimi, S., Rajabifard, A., Mendis, P., & Ngo, T.D., 2015. A Data Model for Integrating GIS and BIM for Assessment and 3D Visualisation of Flood Damage to Building.

Arroyo Ohori, K., Diakité, A., Krijnen, T., Ledoux, H., Stoter, J., 2018. Processing BIM and GIS Models in Practice: Experiences and Recommendations from a GeoBIM Project in The Netherlands. *ISPRS International Journal of Geo-Information*,7, 2018.

Associazione delle organizzazioni di ingegneria, di architettura e di consulenza tecnico-economica (OICE) 2018. Report OICE sulle gare BIM 2018 per opere pubbliche. Analisi del mercato e delle gare. *Proceeding of the OICE Congress,* Rome 14.02.2019.

Biljecki, F., Stoter, J., Ledoux, H., Zlatanova, S., Çöltekin, A., 2015. Applications of 3D city models: State of the art review. *ISPRS International Journal of Geo-Information*, 4(4), 2842-2889.

Chaabane S., Jaziri W., 2017. Automated mapping for geospatial ontologies integration*. Annals of GIS*, 23:4, 269-279. doi:10.1080/19475683.2017.1368706.

Chen M., 2017. Comprehensive application of BIM and GIS technology in underground integrated pipings network. *Construction in Shanxi*, 4–5. https://doi.org/10.13719/j.cnki.cn14- 1279/tu.2017.19.141

Cheng J.C.P., Deng Y., 2015. An Integrated BIM-GIS Framework for Utility Information Management and Analyses. *Computing in Civil Engineering 2015*, 667-674, doi: 10.1061/9780784479247.083

Diakite, A.A., 2018. About the Geo-referencing of BIM models. https://pdfs.semanticscholar.org/5806/b7cbcd95c1135db66769f942ffa4e695a5f6.pdf (17 January 2022).

Ellul C., Stoter J., Harrie L., Shariat M., Behan A., Pla A., 2018. Investigating the State of Play of GeoBIM across Europe. *In Ken Arroyo Ohori, Anna Labetski, Giorgio Agugiaro, Mila Koeva and Jantien Stoter (eds.), 13th 3D GeoInfo Conference, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* IV-4(W6).

Floros, G. S., Ruff, P., and Ellul, C., 2020. Impact of Information Management during Design & Construction on downstream BIM-GIS Interoperability for Rail Infrastructure, *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., VI-4/W1-2020, 61–68*, https://doi.org/10.5194/isprs-annals-VI-4-W1-2020-61-2020.

Fosu, R., Suprabhas, K., Rathore, Z., Cory, C., 2015. Integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) – a literature review and future needs, *Proceedings of the 32nd CIB W78 Conference*, Eindhoven, The Netherlands, 27–29.

Garramone, M., Moretti, N., Scaioni, M., Ellul, C., Re Cecconi, F., & Dejaco, M.C., 2020. BIM and GIS integration for infrastructure asset management: a bibliometric analysis. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 77-84.

Kokla M., Guilbert E., 2020: A Review of Geospatial Semantic Information Modeling and Elicitation Approaches. *ISPRS Int. J. Geo-Inf.* 2020, *9*, 146. doi.org/10.3390/ijgi9030146.

ISO. ISO 10303-105:2014 Industrial automation systems and integration – Product data representation and exchange. *Int Organ Stand*. 2014.

Italian Government 2016. D.lgs 50/2016: Codice dei contratti pubblici.
https://www.bosettiegatti.eu/info/norme/statali/2016_0050.htm (17 January 2022).

Kumar, K., Labetski, A., Ohori, K.et al. 2019.The LandInfra standard and its role in solving the BIM-GIS quagmire. *Open geospatial data, softw. stand*.4,5 (2019). https://doi.org/10.1186/s40965-019-0065-z

Liu, X., Wang, X., Wright, G., Chen, J.C., Li, X., Liu, R., 2017. A state-of-the-art review on the integration of Building Information Modeling (BIM) and Geographic Information System (GIS). *ISPRS International Journal of Geo-Information*, 6, 53.

Maguire, D. J., 1991. An overview and definition of GIS. *Geographical information systems: Principles and applications*, 1(1), 9-20.

Matt, D.T. et al. 2018. BIM Report Alto Adige 2018: Sondaggio sulla conoscenza e sull’ uso del BIM tra gli operatori del settore delle costruzioni.
https://www.fraunhofer.it/content/dam/italia/it/documents/per_il_sito_BIM%20report%20Alto%20Adige_GT_Versione%20per%20PDF.pdf (17 January 2022).

NBS 2019. What is building information modelling. https://www.thenbs.com/knowledge/what-is-building-information-modelling-bim (17 January 2022).

Noardo, F., Ellul, C., Arroyo Ohori, K., Biljecki, F., Harrie, L., Krijnen, T., Stoter, J., 2020a. The ISPRS-EuroSDR GeoBIM benchmark 2019. *ISPRS- Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.- Proceedings of XXIV ISPRS Congress*. ISPRS.

Noardo F., Ellul C., Harrie L., Overland I., Shariat M., Arroyo Ohori K., StoterJ., 2020b: Opportunities and challenges for GeoBIM in Europe: developing a building permits use-case to raise awareness and examine technical interoperability challenges, *Journal of Spatial Science*, 65:2, 209-233, doi:10.1080/14498596.2019.1627253

Preciados Royano, A., Díaz Severiano, J.A., Gómez-Jáuregui, V., Manchado del Val, C., López Iglesias, J., Fernández García, O., & Otero González, C., 2019. 3D Semantic-Rich Modelling of Underground Utility Networks, doi: 10.1007/978-3-030-41200-5_52

Sharafat A., Khan M.S., Latif K., Tanoli W.A., Park W., Seo J., 2021: BIM-GIS-Based Integrated Framework for Underground Utility Management System for Earthwork Operations. *Appl. Sci.*, *11*, 5721. doi.org/10.3390/app11125721

Sun, J., Mi, S., Olsson, P., Paulsson, J., Harrie, L., 2019. Utilizing BIM and GIS for Representation and Visualization of 3D Cadastre. ISPRS International Journal of Geo-Information, 8, 503.

Ullah, K. et al. 2020. BIM adoption in the AEC/FM industry – the case for issuing building permits. *International Journal of Strategic Property Management*, 24(6), 400-413. https://doi.org/10.3846/ijspm.2020.13676

Vishnu, E. and Saran, S.,2018. Semantic Modeling of Utility Networks Implementation of Use Cases for Dehradun City, *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 425, pp. 139–145, 2018. doi:10.5194/isprs-archives-XLII-5-139-2018.

Zhang C., 2019. Ontology for Geospatial Semantic Interoperability. *The Geographic Information Science & Technology Body of Knowledge* (4th Quarter 2019 Edition), John P. Wilson (ed.). doi:10.22224/gistbok/2019.4.9

Zhao L., Liu Z., Mbachu J., 2019: An Integrated BIM–GIS Method for Planning of Water Distribution System. *ISPRS Int. J. Geo-Inf.*, *8*, 331. doi.org/10.3390/ijgi8080331.