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INTEGRATING BUILDING AND CONTEXT INFORMATION FOR AUTOMATED ZONING CODE CHECKING: A REVIEW

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SUMMARY: *Interoperability approaches have attracted much attention in the AEC/FM industry with the increased interest in Building Information Modeling (BIM) studies since 2000's. Especially, the integration of BIM with GIS is crucial for areas, which need detailed information on buildings and their surroundings. Automated code compliance checking against zoning codes is an area that requires both zoning data and building design data. In an ideal automated zoning code checking process, building codes should be retrieved from the responsible authority, data regarding the neighborhood the project is located in should be retrieved directly from the local municipality's GIS, and the building project should be supplied by the designer as a BIM file. The checking process should be able to work with a combination of GIS and BIM data and generate a compliance report. Although recent BIM-GIS integration efforts have been successful in some areas, BIM-GIS integration studies in the context of automated zoning code compliance checking are limited, and the data interoperability problem in this field still needs to be addressed. This paper intends to (1) provide a critical review and analysis of the current BIM and GIS integration studies for building permit processes, (2) present the opportunities that the implementation of integrating BIM and GIS might bring to the automated zoning compliance checking domain and (3) identify promising integration approaches for future efforts.*

KEYWORDS: *automated zoning code compliance checking, BIM, GIS, interoperability*

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1 INTRODUCTION

Over the last twenty years, the AEC/FM industry has gone through a transformation driven by the adoption of Building Information Modeling (BIM) (Elshafey et al., 2020). By providing access to project data, BIM creates opportunities for more effective collaboration among all stakeholders in the industry. However, BIM focuses on the data at the building scale, while many stakeholders also require data at the neighborhood scale in order to evaluate how buildings relate to their surroundings. City scale information typically reside in Geographic Information Systems (GIS). With advances in digital twins and internet of things, more applications require simultaneous access to data at both scales. The increasing need for data sharing and collaboration requires better software interoperability and data integration (Gilbert et al., 2020).

Architects, as they design using BIM software, need context data for a variety of tasks, while the GIS domain requires building data whenever more detailed information on buildings is needed. Integrating BIM and GIS allows improving the managing of design information in various phases of a project's lifecycle, from early planning and design to construction, operation, and maintenance. Integration of the two data models also has a notable effect on solving the multi-disciplinary problems in design, construction, operation and infrastructure domains. While BIM and GIS technologies are closely related, they remain mostly isolated. Distinctive development of BIM and GIS tools, and professional divisions are the main reasons for the differences as well as a lack of cooperation between BIM and GIS. The differences between the two domains need to be overcome.

Automated zoning code compliance checking is one of the areas that require zoning data from GIS and building data from BIM. It has long been an area of research that aims to provide computational support for conformance checking process of building designs against zoning codes developed by government agencies (Macit İlal and Günaydın, 2017). The automation of the processes for obtaining building permits promises to simplify the workflows at authorities, speed up turnaround in feedback, shorten approval processes for buildings, prevent errors due to manual checking and help prevent inconsistencies in interpreting zoning codes.

Zoning codes contain rules, standards, and statements that define conditions and constraints related to data on the surroundings such as parcels, blocks, existing buildings, roads, sidewalks and setback distances. They are legal documents for the verification of building designs. They define technical and functional requirements that buildings and their settlements must satisfy throughout buildings' intended lives (Dimyadi et al., 2014). Many countries have national building codes set by government agencies that are valid for all building design and construction projects. Some local jurisdictions such as regions where there is a historic fabric are allowed to develop their own building codes. Compliance with all relevant codes is required to obtain a building permit from local municipalities.

Code checking needs both zoning data and building design data. For example, Izmir Municipality Housing and Zoning Code (Izmir Municipality, 2013) is a legal document that specifies minimum requirements that must be met by buildings and their surroundings. It comprises six sections, where section III includes the rules that are checked in the process of approving building designs. Nearly half (20 of 43) of the rules in section III require zoning data to carry out the checking. For example, consider the following rule on setback distances:

> *"In blocks that have planned-unit order, if there is an existing building in any of the parcels within the same block, setback distances should be the same as setback distances used in that parcel"* (Izmir Municipality, 2013).

For this rule, data on the whole block is needed for code checking. The rule requires the base geometry of the building footprint and the parcel geometry in order to be able to calculate the setback distance. Also required is the setback distance data of all parcels adjacent to the same road in the same block. For the purpose of finding the parcels that are adjacent to the same road in the same block, the spatial relationship of parcels and the surrounding roads should be queried using their geometry locations. The construction order information of the block is also required as the requirements of the rule on setback distances differ in terms of different construction orders. The rule is illustrated in FIG. 1. Building footprint and parcel geometry will reside with BIM data. However, footprints of the rest of the buildings, parcels in the block and the surrounding roads along with the construction order of the block should reside with the GIS system of the municipality.

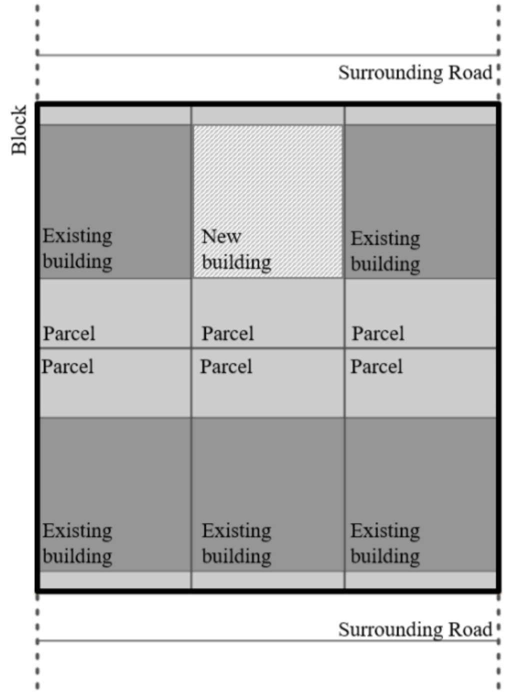

FIG. 1: Illustration of setback distance rule

As a second example, consider the following rule on ground floor base levels:

> *"The ground floor base level of a building should be planned between + 0.50 meters to +1.00 meters from the upper level of the sidewalk"* (Izmir Municipality, 2013).

For this rule, information on the sidewalk that faces the parcel is required for performing code checking against zoning codes. If the parcel is adjacent to more than one road, the widest road should be identified first. If the parcel is adjacent to two or more roads as shown in FIG. 2, the widest road that the parcel is adjacent to should be used as a reference. If the roads have equal widths, then the levelling should be referenced from the shortest frontage. As a second step, the sidewalk that is adjacent to that road should also be identified. Hence, in addition to the data on the surroundings, zoning code checking requires spatial querying of spatial features based on containment, adjacency and intersection relations. The parcel geometry will reside with BIM data, while the number of roads facing the parcel, the width and level of these surrounding roads and the related sidewalks should reside with the GIS system of the municipality where the spatial queries can be performed.

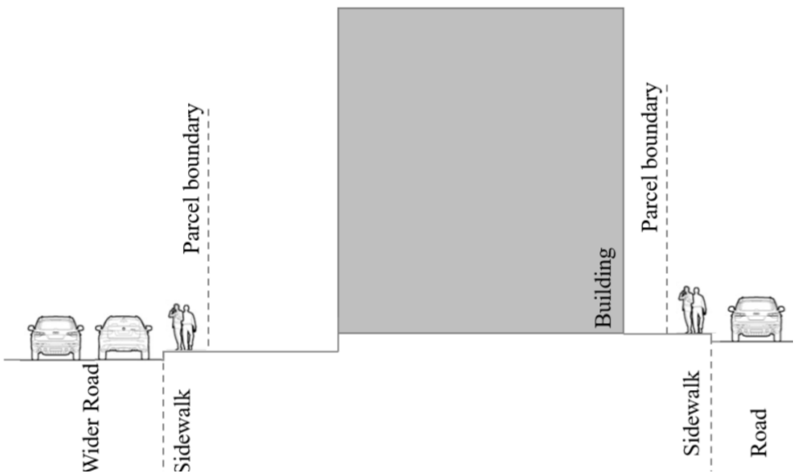

FIG. 2: Illustration of ground floor base level rule

In an ideal automated zoning code checking process, building codes should be retrieved directly from the responsible authority authoring the code. The digital representation of the codes should be independent from both the building model and the city model. The designed building project to be checked will naturally be supplied by the architect as a BIM file. The required data on the building's settlement should be retrieved from the local municipality's GIS. Hence, automated compliance checking against zoning codes implies BIM-GIS interoperability and integration of geo-information with detailed building data (Van Berlo et al., 2013, Onstein and Tognoni, 2017, Olsson et al., 2018, Noardo et al., 2020). It requires zoning codes, data on the neighborhood the building is located in and building design in a digital interoperable environment. However, in existing design environments, it is currently not possible to access zoning information that building regulations require. BIM tools integrate and manage data from numerous disciplines about design, construction, operation and maintenance processes, but they have limitations in modeling context (Malsane, 2015; Sun et al., 2019), and storing and managing geographical information on the surrounding landscape of buildings (Mignard and Nicolle, 2014, Rafiee et al., 2014). Furthermore, BIM models are not capable of querying topological relationships (such as containment, intersection or adjacency) between building and its surroundings and store topological data which is in fact required by automated zoning code compliance checking processes (Isikdag et al., 2008, Karan and Irizarry, 2015). On the other hand, Geographic Information Systems are able to store, analyze and manage geographical information. They can query attributes of geographical objects based on defined constraints, analyze information referring to the questions that have been asked using geographically referenced location and shape of spatial features, and generate new knowledge based on the spatial queries and analyses. As building codes contain rules with conditions depending on spatial relations between building, parcel, block, road and sidewalks, GIS are crucial in complementing building data with their detailed spatial querying capabilities.

Technically, all required data for an automated zoning code checking process may be modeled exclusively in BIM or GIS. However, with current technology this is impractical. Designers would not want to manage information on the whole neighborhood in their building models, and planners would not want to deal with building details while working on city-wide analyses. In recent years, digital city models have been developed for zoning data storage, management and communication. However, currently, in municipalities the checking process still includes mostly manual work using text-based building code documents. There is a dependence on traditional procedures of using information from printouts and archive documents in zoning code checking procedures. A reliable automated code compliance checking against zoning codes promises significant improvement over current practices.

Additionally, current BIM software used in the code checking processes are required to hold regulation specific data; however, they are not able to contain all the needed building code information for a fully automated zoning code checking, and integrating building into the city fabric, and are not suitable for visualizing and analyzing data at the city level (Malsane, 2015; Knoth et al., 2018; Sun et al., 2019). The process for building permit is a multidisciplinary process, and BIM data should be considered together with its context for the efficiency and the consistency of the permit process (Noardo et al., 2020). Yet, how BIM and GIS data should be brought together for automated zoning code checking has not been sufficiently explored by previous research and is bound to attract more attention which is the main motivation behind this review.

2 METHODOLOGY

This paper presents a review of BIM-GIS integration approaches with a special focus on automated code compliance checking against zoning codes. Digital representation of rules, and system architectures for rule checking are the two main topics that have attracted many researchers in the area of automated zoning code checking. Integration of building data with its context has not received as much attention by researchers. When a literature search was conducted on Web of Science and Scopus databases with the following keyword combinations: "BIM" and "GIS" and ("Zoning code checking" or "building permit" or "construction permit" or "building licensing" or "building regulation checking"), a total of 8 papers including journal papers and conference papers were retrieved. A further 2 articles and 1 PhD Thesis was identified when references cited in these papers were examined. In these studies, although IFC was used as the common format for representing the required building data, GIS data in various level of detail and in diverse formats such as CityGML, InfraGML or XPlanGML were used, the required GIS data was drawn from different sources and the required building data was modeled using different BIM software such as Archicad or Revit. Thus, there is no common or preferred data format for representing context data, the used software environments differ and there are various approaches for

BIM-GIS integration with a special focus on automated code compliance checking against zoning codes in literature. In order to determine the appropriate approach for data integration in this field, a wider review covering BIM-GIS integration in related fields was necessary. Thus, initially a review on research studies that focus on BIM-GIS integration is presented and the challenges, issues, and shortcomings of these integration approaches are reviewed. Then, related research gaps are identified and challenges such as interoperability issues, lack of standards, and lack of solutions for data interoperability are discussed.

The reviewed BIM-GIS integration studies are classified based on the approach they adopt. Three main approaches to BIM-GIS integration are identified within the context of code checking, namely, "Data import/export by conversion", "data extension", and "development of a unified domain model". *Data import/export* includes extraction and then, transfer of data from BIM environment into the geospatial environment and vice versa with the help of data converters. Entities in one data model are mapped to entities or attributes in the other and no new entities need to be defined in either data model. *Data extension* studies enrich either data model with additional information for extending its usage into new domains by defining new entities. *Development of a unified domain model* studies collect data from BIM and GIS environments separately and integrate them within a unified model. The new application uses this integrated domain model. With an independent domain model, neither BIM, nor GIS data models are altered. The number of reviewed papers per each BIM-GIS integration category is given in FIG. 3 below.

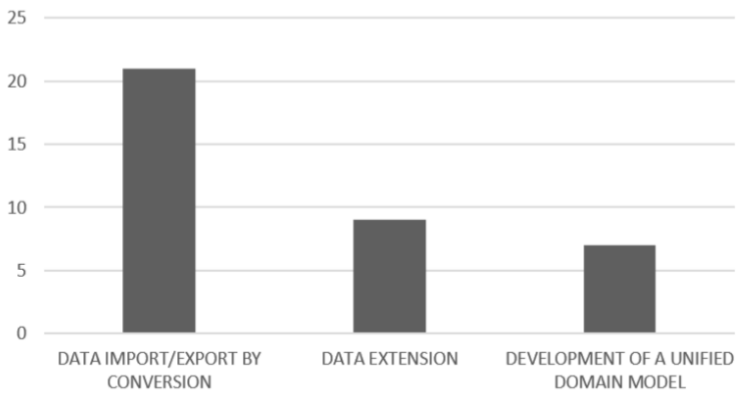

FIG. 3: BIM-GIS interoperability approaches and the number of studies

The next sections will first summarize the automated zoning code checking field. Then, BIM and GIS will be introduced, followed by the review of BIM-GIS integration efforts. The efforts by the data standards organizations will be summarized before the research efforts are reviewed, grouped according to the interoperability approach they have adopted.

3 BACKGROUND

Automated zoning code checking is a process where rules and conditions are applied to a building project, with results such as "pass", "fail" or "unknown" for cases where data is incomplete. (Eastman et al., 2009). If the results indicate that the model or the building components do not meet the requirements, they can be edited considering the results and checked again. The submitted building design must comply with the regulations in the zoning code (Van Berlo et al., 2013). There have been considerable efforts in the past towards automating code compliance checking processes with various approaches, and automating the checking process has drawn the attention of many researchers. Two main issues exist: digital representation of rules, and system architectures for rule checking.

3.1 Rule Representations

Efforts focusing on how to create representational models of standards written in natural languages started in 1960s and continued to be developed and improved over many years since then (Fenves and Garrett, 1986). For example, Goel and Fenves (1969) developed a system for compliance checking of the structural design standards with the help of computers using the standards modeled in the form of decision tables. Fenves and Garrett (1986) developed a knowledge-based system approach for representing standards. Later, Garrett and Hakim (1992) and de Waard (1992) proposed an object-oriented information model for building regulations. Yabuki and Law (1993) combined first order predicate logic with object-oriented modeling approach for building standards representation, processing and documentation. Kiliccote and Garrett Jr (1998) developed a context-oriented approach for modeling design standards. However, these early studies adopted a hard-coding approach, which required in-depth programming skills and knowledge for modeling the building regulations. To overcome the challenges of hard-coding approach, researchers started to concentrate on semantic modeling approach for knowledge representation. The SMARTcodes project adopted a semantic modeling approach to automate the digitization of building codes into a computer implementable format and defined the RASE (Requirement, apply, selection, exception) methodology (Conover, 2007). Macit İlal and Günaydın (2017) and Macit et al. (2015) developed a four level representation for modeling regulations modifying the RASE methodology. Hjelseth and Nisbet (2011) also studied knowledge representation using RASE methodology and found out that RASE can operate on different types of documents with reliable results. Another effort for the representation of building regulations has been developed by Brasebin et al. (2011). Using Local Urban Planning Schema of France, they modeled the geospatial features in the building codes including urban zones, parcels, roads, buildings and then formalized the regulations based on the Object Constraint Language. Lee et al. (2016) proposed a system for converting the natural language text of the Korean Building Act into a computer-interpretable format for evaluating building permit requirements. In their rule based semantic approach, Beach et al. (2015) introduced a methodology that allows domain specialists to formulate the rules and create and maintain their own automated regulation checking systems. The system is validated by using building codes from construction domain. Ontology-based approaches have also been adopted by researchers for modeling building regulations (Pauwels et al., 2011). Yurchyshyna et al. (2008) proposed an ontology based approach and Dimyadi et al. (2015) developed a regulatory knowledge model for the formalization of design codes.

3.2 System Architectures

The second main issue is the development of checking systems. Several efforts have attempted to develop automated building code checking systems. Employed by the Singapore Building and Construction Authority, the Singapore CORENET project is the first automated code compliance checking system that was used in AEC industry. The project aimed to provide a web based electronic system for rule checking over submitted building documents considering building control, fire code, environmental health, public housing and vehicle parking (Liebich et al., 2002). Norwegian efforts for rule checking aimed to check BIM projects for evaluating spatial program requirements, and building accessibility using the relationships between building components such as spaces, doors, ramps, stairs and windows (Lindberg, 2006). Later, the Cooperative Research Center for Construction Innovation in Australia developed the Design Check project that aimed to automate checking of buildings against Australia's requirements related to disabled accessibility (Eastman et al., 2009). SMARTcodes project by the International Code Council (ICC) focused largely on representing the paper based building codes as computer executable code sets and, automate web-based rule checking of building designs (Conover, 2007). General Services Administration (GSA) in United States funded development of a code-compliance checking system for building projects in the areas of circulation and security validation (Eastman et al., 2009). SEUMTER is a Korean electronic system that helps the automation of building rule checking for fire prevention (Choi et al., 2014). Malsane et al. (2015) developed a building regulation-specific object model to support automated compliance checking of dwelling houses against England and Wales Building Regulations focusing on fire safety. Choi et al. (2014) proposed an automated system for checking BIM data of high-rise and complex buildings against the evacuation regulation compliance. In the study of Dimyadi et al. (2014), a two-part regulatory knowledge representation was developed for performance-based design of buildings focusing on fire safety. There have been also multiple approaches that use semantic modeling and ontologies in combination with artificial intelligence and natural language processing techniques (Pauwels et al., 2011; Salama and El-Gohary, 2011, 2016; Zhang and El-Gohary, 2012; Baumgärtel et al., 2015; Zhang et al., 2015).

The studies mentioned above in the context of code compliance checking represent a significant development in this research area and there is an increasing demand for using BIM tools in code checking processes and building permit approval processes (Eastman et al., 2009, Hjelseth, 2015). BIM's capability to hold semantic and geometric information, which describe all the building data, made BIM a basis for automated code compliance checking processes (Nguyen and Kim, 2011, Preidel and Borrmann, 2018). Yet, BIM is not designed to store data at the city level. It is clear that BIM data needs to be complemented by data from sources that can store city level information.

4 INTEGRATING BUILDING DATA WITH GEOSPATIAL CONTEXT

4.1 Building Information Modeling (BIM)

The National Building Information Modeling Standard (NBIMS) Committee of the National Institute of Building Sciences (NIBS) Facility Information Council (FIC) defines BIM as "an improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle" (NIBS, 2007). BIM technology supports the collaboration of all stakeholders and applications with the development of an international standard known as Industry Foundation Classes (IFC). IFC is the widely accepted open, vendor-neutral and non-proprietary data format developed by buildingSMART organization. It contributes to the interoperability requirements of various software and focuses on product and process modeling (Inyim et al., 2014). IFC is a sharable data schema providing the same semantic interpretation between domains and focuses on defining a common language to enhance the collaboration, efficiency, productivity, delivery time, cost, and quality both for AEC/FM domain, and cross domain and cross-disciplines (Isikdag et al., 2008, Kiziltas et al., 2010). IFC is an object-oriented data standard based on class definitions representing building related objects. Both 2D and 3D geometry of objects and semantic data containing attributes of objects and their relationships are the content of IFC (Isikdag et al., 2008, Hijazi et al., 2009, BuildingSMART, 2016). IFC is currently the emerging data schema in the industry. By its semantic data storage capability and ability for interoperability, IFC acts as a benchmark and testbed for new models (Akin, 2010).

IFC 4 Addendum 2 is the latest official version of IFC data schema and it defines objects used in the following domains: Architecture, building controls, construction management, electrical, heating, ventilating and air conditioning (HVAC), plumbing, fire protection, structural analysis, and structural elements (BuildingSMART, 2019). Considering automated zoning compliance checking, there is no site related domain. Only a small amount of required zoning data can be modelled by using the entities such as ifcSite and IfcCivilElement. In the current situation, IfcCivilElement entity is used to define elements within a civil engineering works such as road segments, bridge segments, pavements, etc. Thus, this entity indicates that future versions of IFC data schema may include specialized classes and properties of road, bridge or pavement in detail.

4.2 Geographic Information Systems (GIS)

ESRI as the global market leader in GIS (Esri, 2018) defines GIS as "a framework for gathering, managing, and analyzing data." With Geographic Information Systems we are able to store, model, query, analyze and present geographical data. These systems manage spatial data referenced by geographic coordinates, query attributes of features based on a defined relationships and generate map displays and data reports based on spatial analysis. By using GIS, users are able to relate geospatial information with geographical entities. A GIS is a spatial database that collects and manages various types of information on digital maps. It relates spatial features with spatially referenced data. The stored data can be translated into multiple formats, which makes data interoperability possible between different applications. GIS is generally used for urban scale studies, topological, network and land use analyses, interactive spatial planning, determining the project location using real world coordinates, analyzing, monitoring and managing large amounts of outdoor data, working with site topography, land boundaries, land parcels and soil type etc.

CityGML, developed by the Open Geospatial Consortium (OGC), is the widely used open data schema for representation, storage and exchange of semantically-rich 3D city models for the GIS domain. The CityGML consist of 5 Levels of Detail (LOD) where the amount of detail that city model objects have increases with increasing LOD. While landscape can be represented with LOD0, detailed architectural models can be represented with LOD4 (Groger et al., 2012).

4.3 BIM-GIS Interoperability

Since BIM supports collaboration between multiple professions from early design phase through construction and operation, the interoperability of BIM with other systems, such as GIS, is becoming increasingly important. Even though they have different data models, different geometric representations, different access methods, and were developed for different purposes, BIM and GIS domains require information from each other and complete each other. They play important roles within the lifecycle of facilities. Architects using BIM require GIS data for multiple tasks, e.g., site selection, creating solutions at the city scale, and relating a building to its surroundings (Akin, 2010). On the other hand, designers using GIS require BIM data whenever building scale data is needed. The required contextual data for BIM environment can be provided by GIS. Integrating BIM and GIS environments enables effective management of design information in various phases of a project's lifecycle, from planning and design to construction, operation, and maintenance.

For modeling the real world, data from both BIM and GIS is needed. Integrating the two data schemas has an important effect on solving the multi-disciplinary problems in design, construction, infrastructure and maintenance domains. For example, Rafiee et al. (2014) conducted a research for evaluating view quality of windows by analyzing the amount of surrounding physical objects visible from the view from each window. For the research, both locations of windows from a BIM environment and the type and position of physical features in the view such as 3D trees and 3D buildings from a GIS environment are required (Rafiee et al., 2014). Similarly, in case of a fire emergency, both fire escapes in the building and closest safe open spaces around the building should be considered, to create an effective evacuation plan. For determining the noise level for specific locations, traffic noise from the outdoor environment and sound absorption coefficients for multiple material types of building elements within the buildings should be taken into account. An urban infrastructure project needs both models from BIM and information from the urban planning domain. For designing energy-efficient buildings in neighborhood scale, the building envelope, interior plan organization, and the current energy systems used in surrounding buildings should be considered together.

Hence, there are a significant number of areas that require interoperability between BIM and GIS, one of which is automated code checking. Following a summary of what data standards organization on both fronts have been working on, research efforts focusing on interoperability will be reviewed. Besides efforts specifically on BIM-GIS integration for automated zoning code checking, efforts on related fields are also included to expose when and how each of the three interoperability approaches are utilized by various researchers.

4.3.1 Efforts by data standards organizations

For improving interoperability between BIM and GIS, many software developers have to agree on common semantics, interfaces, information models, guidelines and schemas. Such agreements that are supported by community are typically documented as standards. The Open Geospatial Consortium (OGC) is an international non-profit organization that focuses on developing standards to support the industry consensus development in the area of geoprocessing and related information technologies. The standards that OGC develops are freely available (OGC, 2008). OGC cooperates with standard developers such as the National Institute of Building Sciences (NIBS) and the buildingSMART. For instance, The Integrated Digital Built Environment joint working group (IDBE) aims to bring experts from the OGC and the buildingSMART to support the development of open standards and interoperability between geospatial and built environment domains. At 2020, the group published a report where the existing standards (IFC, CityGML, LandInfra) are evaluated and the challenges for their integration are described. The difference of data schemas in how they represent real-world objects, the difference of objects in case of mapping and coupling wrong concepts to each other or coupling objects that are not similar/identical and the difference in case of geometric representations are some of the challenges that are described which cause problems on data integration. Additionally, several actions are proposed as a means of progressing. Creating a shared resource from terms that the standards already contain and making that resource publicly available and developing a collaborative mechanism are some of the actions points of the project for supporting data integration and interoperability (Gilbert et al., 2020).

The close coordination, communication and collaboration of numerous organizations, professionals and developers supports standards-based interoperability between the geographic information and building communities. For instance, following the approval of the OGC membership, 3D Information Management (3DIM) study group, previously known as the CAD-GIS Working Group was formed in mid 2000s. The group focused on improving interoperability of geospatial data and services across AEC/FM, 3D, and GIS domains (Reed, 2010). The OGC Land and Infrastructure Domain Working Group (LandInfraDWG) was founded in 2013 and is collaborating with buildingSMART for integrating the data model that the group developed with BIM. The InfraGML data model contains infrastructure facilities, road, railway, survey, drainage, water distribution systems, land features and land division related data (Liu et al., 2017, OGC, 2019). IndoorGML Standard Working Group is another working group that focuses on developing standards for the geospatial domain. They developed the

IndoorGML data model, which will be an OGC GML application schema and planned to become a complementary standard to CityGML and IFC to support location based services for indoor navigation (Liu et al., 2017, OGC, 2019a).

The OGC developed numerous standards to enable collaboration between BIM-GIS including: OGC and ISO Web Map Service (WMS) Interface Standard; OGC Web Map Context Standard (WMC); OGC Web Feature Service (WFS) Interface Standard; OGC and ISO Geography Markup Language (GML) Encoding Standard; OGC CityGML Encoding Application Schema for GML version 3.1.1; and OGC KML 2.2 Encoding Standard. GML and CityGML are the more widely used data models for interoperability in comparison to other standards. They define classes, spatial properties and relations of urban features such as buildings, water bodies, vegetation, transportation facilities and city furniture with their geometry, topology, semantics, and visualization properties (Reed, 2010). Urban management, town planning, architectural design, environmental analysis, disaster management, facility management, and site surveying are examples to areas where GML and CityGML are used (Kiziltas et al., 2010).

buildingSMART, like the OGC, is an international organization that develops software solutions and standards to improve industry consensus. buildingSMART aims to support standardizing processes, workflows and procedures for BIM and has a worldwide network. IFC, BIM Collaboration Format XML, BIM Collaboration Format API, Framework for object oriented information, IFC4 Design Transfer View, IFC4 Reference View are international standards that buildingSMART manages for transporting building related information throughout the AEC/FM and 3D GIS domains (BuildingSMART, 2016). Even though, there are many different approaches to solve the problem of interoperability between BIM and GIS for the AEC industry, a clear path forward has not yet been identified.

4.3.2. Interoperability approaches

The integration approaches of BIM-GIS are categorized into three levels by Amirebrahimi et al. (2015) which are process level, application level and data level. This study focuses on the data level integration approaches as the recent studies mainly focus on integrating two domains at the data level. The integration approaches are discussed below under the headings of “data import/export by conversion”, “data extension”, and “development of a unified domain model” as diagrammatically shown in FIG 4.

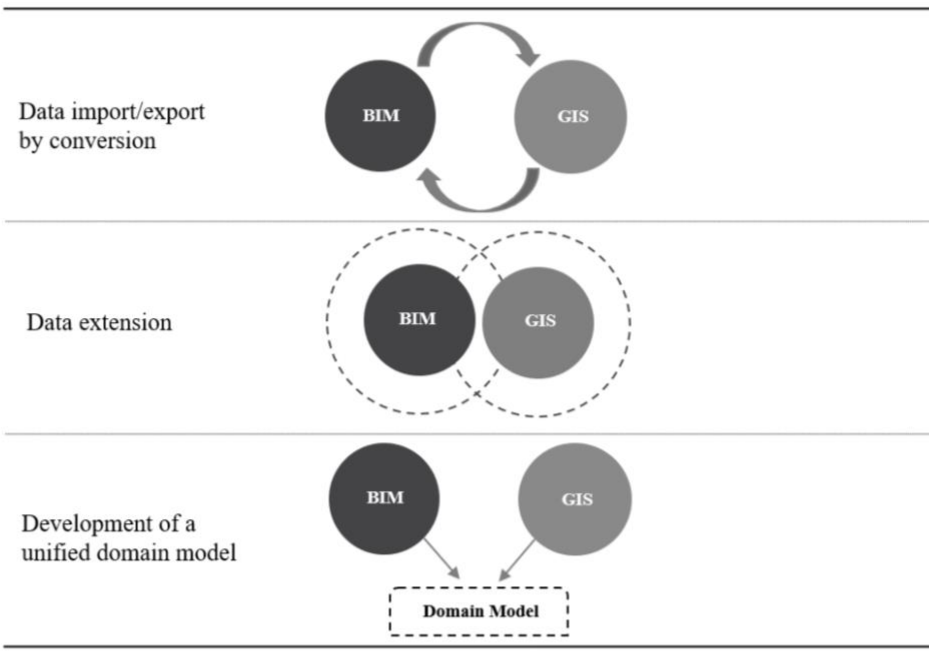

FIG 4: BIM-GIS interoperability approaches

4.3.2.1 Data import/export by conversion

Due to significant differences in the origins and methodologies of BIM and GIS, some researchers believe that achieving a common data model is naturally difficult and inappropriate. These researchers mostly adopt data converters/translators in their approaches, which convert one data schema into another data schema compatible with the software it is going to be transferred to. IFC and CityGML are the most comprehensive and representative data formats in BIM and GIS domains, respectively. Thus, many studies focused on converting and translating them to be compatible with each other within BIM or GIS. These conversion processes are mapping-based processes and require the identification of a set of rules and methods for mapping the objects and extracting geometries. Using a mapping standard such as the B2GM developed by Kang (2018) helps the user to define and control the integration process, decreases the time spent for a mapping process and prevents errors and interpretations that can be done during a manual transformation process.

Most commercial BIM and GIS tools have data conversion capabilities and extensions to allow direct access to other formats (Casey and Vankadara, 2010). For instance, ESRI ArcGIS's Data Interoperability extension enables translation between formats using import and export functions within the software. The interoperability extension allows ArcGIS users to use and exchange data in numerous formats such as Autodesk 3ds, Autodesk AutoCAD DWG/DXF, BIM Collaboration Format (BCF), Bentley MicroStation Design V7/V8, Autodesk Revit, CityGML and IFC (Esri, 2015). However, the translated data is mostly read only and limited in import and export. In addition, not all GIS features have definitions in IFC and vice versa. For example, a feature defined as sidewalk in GIS, may not find a response in BIM environment after a data translation process, and that will end in information loss or mapping to a wrong object.

While some studies used BIM and GIS tools that have data conversion abilities to enable direct access to other formats, other studies developed new data converters, plug-ins to BIM/GIS tools by using the application-programming interfaces or used the existing translators for converting IFC into CityGML and vice versa. For example, Wu and Hsieh (2007) formulated a methodology to convert IFC model objects to the GML features with the aim of using building information data in GIS environment. They developed a transformation tool, which is named IFC2GML to demonstrate the applicability of their proposed methodology. IFC2GML firstly parses the IFC file and applies a filter for selecting the required objects and their properties. Secondly, IFC2GML parses the geometrical data of the selected objects and transforms the coordinate system from the local Cartesian coordinates into real world coordinates. At the final step, IFC2GML constructs the corresponding GML file. Isikdag et al. (2008) studied the integration of building data into a geospatial context and developed software components for extracting the required data from the IFC model and transforming this data into GIS by focusing specifically on two areas; location selection and emergency response operations for a fire situation. Hijazi et al. (2009) also studied integration of the 3D building data into GIS with the development of a software component that converts IFC data into CityGML data. Donkers et al. (2016) presented an automatic translation algorithm that translates BIM projects modelled in IFC format into CityGML format. The algorithm firstly conducts a semantic mapping process between BIM and GIS objects, then extracts and transforms the IFC data into CityGML and finally checks the validity of the results. During mapping some entities such as IfcRoof can be semantically assigned to a CityGML object directly, while the mapping of some entities such as IfcPlate is not certain and the IfcPlate entity can mean anything. Thus, manual interventions are also required during mapping before conducting the semantic and geometric conversion process for creating a CityGML model from an IFC model. Zhu et al. (2019) proposed an open-source solution to overcome the challenges of the usual tools used for geometry conversion such as the Data Interoperability extension for ArcGIS. They developed an automated multipatch generation algorithm (AMG) to convert the IFC (BIM) into shapefile (GIS), which needs to be improved for its efficiency with further studies. Rafiee et al. (2014) studied data conversion from BIM to GIS to integrate a building model stored in IFC format into a GIS environment for performing an efficient spatial analysis. They converted the geometry and semantics of objects defined in IFC into a vector geographic format using the ETL process. For transforming the local coordinate system into a geographic coordinate system, the researchers applied a method that they developed which included scaling, rotating and translation processes. The final model included both the building data and the surrounding together.

Usage of existing data conversion plugins to BIM/GIS tools and Application Domain Extensions (ADE) also exists in literature. In the approach of Irizarry et al. (2013), detailed building data modelled in BIM was inputted into GIS using a plugin interface embedded in the BIM software for improving the visual monitoring of material delivery during construction processes. The approach included the transformation of the coordinate system, restructuring the geometry and property of BIM objects by using the plugin, and finally, using combined data in GIS to map the entire supply chain process and to minimize the logistics costs. In the study of Sebastian et al. (2013), the BIM IFC model of a pedestrian bridge was transformed into CityGML format using an Application Domain Extension (ADE) for planning the construction process and analyzing its effects on the urban environment. IFC has higher level of semantics compared to CityGML and direct mapping from IFC to CityGML would cause data loss. Hence, the CityGML data standard was extended initially using an Application Domain Extension (ADE) both to be compatible with the IFC objects and to decrease the amount of data loss during data transformation from IFC to CityGML. Elbeltagi and Dawood (2011) integrated a BIM model into GIS and aimed to create a link between their building model and a geographic information system for time control of construction projects. With the help of the Globe Link automated module, they published the building data into Google Earth where the construction process within the distribute sites can be visualized. The building data that was created using Autodesk Revit 2010 was exported into Google Earth using XML-based file format Keyhole Markup Language (KML). The exported KML file included all the required data of the building components. Amirebrahimi et al. (2015) developed a method that firstly translated the exported IFC elements from BIM to ESRI geodatabase objects and then to CityGML using the ArcGIS Interoperability Extension and integrated with geographical data in GIS to conduct detailed analysis and support 3D visualization of the potential damages of flood to buildings. Tan et al. (2018) proposed a web system that integrates BIM and GIS data for optimizing lift operations and arranging vessel transport schedules for disassembly of multiple offshore platforms. Their approach included extraction of building data from BIM as an IFC file, and its integration into ArcMap platform by data transformation using the Data Interoperability extension for ArcGIS as in the study of Amirebrahimi et al. (2015). Akob et al. (2019) studied conversion of BIM elements into GIS features for design, planning, monitoring of construction and operation and maintenance of a highway project in Malaysia. They converted and imported BIM data into ArcGIS to be able to visualize and analyze BIM data within its context. Shi and Liu (2014) introduced a platform that transfers extracted IFC data from BIM environment into geospatial context to support evacuation planning in case of a fire. By using the simulation platform that was established based on a 3D GIS, the geometric and semantic information of objects extracted from Autodesk Revit software were transferred into GIS environment.

Isikdag and Zlatanova (2009) proposed a semantic information mapping approach between BIM and GIS environments for enabling automatic exchange of data between IFC and CityGML models. They focused on unidirectional data transfer from BIM to geospatial environment. The transformation process included defining the required data that will be transformed and building up the rules for both semantic transformation and geometric transformation of the defined data. The corresponding IFC properties and entities were semantically matched to CityGML objects such as; *IfcRoof* entity is represented with *RoofType* object in CityGML, and *IfcDoor* and *IfcWindow* classes are represented with the *Door* and *Window* objects in CityGML. In addition to unidirectional information transfer studies, bidirectional transformation of information back and forth between BIM and GIS was also studied by researchers such as in the study of Ohori et al. (2017). They carried out a research project called GeoBIM in the Netherlands that proposes guidelines for bidirectional information transfer of BIM and GIS data and reuses building data in the geospatial context and vice versa. Irizarry and Karan (2012) studied the implementation of BIM data in the GIS domain and integration of the output of the GIS to the BIM domain for finding optimal solutions for selecting, and locating tower cranes on construction sites. In another study, Karan and Irizarry (2015) focused on two scenarios for data integration: (1) importing the site topography modeled in GIS into BIM and (2) importing temporary facilities modeled in BIM into a GIS environment by using semantic web services during the preconstruction stage. Yamamura et al. (2017) also included the usage of both BIM and GIS for using the possibilities of both environments. They firstly integrated GIS data into BIM platform for energy performance analysis, and then extracted and integrated the building data into GIS environment for checking the analysis results at the city scale.

Data conversion is based on published format specifications such as Geodatabase XML format schema and the shapefile format, and these specifications are used as guidance during the conversion processes. In this regard, Kang's (2018) study differs from the data conversion studies above who focus on the development of data converters, plugins and extensions. Kang (2018) developed a conceptual data mapping standard ISO N19166 and a data mapping mechanism for BIM-GIS integration. The mechanism firstly identifies the required data based on the specific use case and defines mapping rules for transforming the semantics and geometry of BIM objects such as building, wall, floor into GIS objects. It extracts objects from BIM and converts them into GIS objects using the Extract Transform Load (ETL) concept. The aim is not to define general mapping rules for BIM and GIS models, but to conceptually define mapping requirements for specific use cases such as facility management because of the semantic mismatches between BIM and GIS objects and the different level of granularity the data models have.

Different from the studies mentioned above that studied the integration of building data into geospatial context, Park et al. (2014) developed a system that extracts the geospatial data from GIS and integrates it into the CAD environment for estimating the probable costs of a national road structure. The system was developed on the commercial program RD which runs on Autocad platform. After the GIS data is inputted into CAD environment, the combined data can be used for calculating the construction cost of road and bridges structures.

In the area of automated zoning code compliance checking, Benner et al. (2010) studied integration of building data and geospatial data to support building licensing processes by transforming BIM data in IFC format into a CityGML city model where the rule checking will be performed. They integrated geo information with building data, and enabled automated check of a building for its consistency against legal regulations. In some studies, programs such as the open source Building Information Model Server (BIMserver), or Safe Software's Feature Manipulation Engine (FME) were also used for translating IFC data model into CityGML data model and vice versa, such as in the approach of Chognard et al. (2018). They studied bidirectional data conversion between IFC and CityGML using the FME tool. They aimed to include all the required data in IFC for a building permit procedure. Hence, they firstly converted GIS data that includes information about the ground, surrounding buildings, parcels and trees into IFC using a specialized data conversion tool FME. However, FME did not convert the real-world coordinates into the local Cartesian coordinates successfully. Therefore, the researchers developed a new method using geometric reasoning for mapping the coordinates of the two environments. Another problem was converting 2D geometry in GIS into 3D modeling environment of BIM. As a result, the objects in GIS were extruded and converted into 3D volumes before using FME. On the other hand, Ohori et al. (2017) developed an interface to be able to convert BIM data into GIS data and studied the integration of the building model with a city model for checking of the BIM data against a zoning plan in a building permit application process. Van Berlo et al. (2013) used data import approach together with data transformation to create an integrated model for checking building permits. Additionally, this model enabled architects to use geospatial data in early stages of design. In their approach, firstly, they converted geographic features into IFC objects and then they imported these objects into BIM environment where the rule checking process will be conducted. Three of the regulations that were studied and checked in the study were maximum allowed building volume, maximum percentage of built-up area on the site, and maximum allowed noise level on each facade (Van Berlo et al., 2013). Olsson et al. (2018) studied BIM-GIS integration for automating building permission process and then, checking of building model against Swedish building permit standards. Their approach included importing a BIM model into a geospatial environment, as municipalities who conduct the checking process are more familiar to geospatial environments rather than BIM environments. The main criteria that were studied within automated checking processes were the building height and the building footprint area.

Data import studies aim to use the strengths of BIM and GIS domains all together and to manage BIM data and GIS data in the context of the other (Irizarry and Karan, 2012). Even though the strengths of both programs can be utilized, there can be data loss during data conversion due to semantic mismatches and different level of detail between BIM data and GIS data. Karan and Irizarry (2015) state that an object in GIS can have a different meaning or may not have a correspondence when transferred into a BIM environment. They give the following example: Land cover can be represented with different classes including bare ground, vegetation, man-made structure, and body of water in GIS, while all of these different classes can only be represented with a single topography surface class in the BIM model. Isikdag and Zlatanova (2009) give another example: A slab opening such as a gallery space can be represented with the IfcOpening entity in the IFC, while there is no class in CityGML that represents this kind of opening without using a door or window. El-Mekawy et al. (2012) also evaluated the approaches in literature for unidirectional information transfer between IFC and CityGML data models and concluded that because of the semantic differences between IFC and CityGML data, unidirectional solutions are not successful for conversion of all the required data. This information loss is more problematic for bidirectional transformation where data transfer occurs twice.

4.3.2.2 Data extension

Data model extension approaches add information that do not already exist in the IFC data schema and thus, expand the scope of the data schema by integrating concepts from other domains. New entities can be added or new property sets can be defined for enriching the IFC data model with additional information and for increasing its area of usage. The buildingSMART Data Dictionary (bSDD) provides guidance to users for extending the IFC schema (Gilbert et al., 2020). Model View Definition (MVD) is a standardized framework defined by buildingSMART for extending IFC to specific domains. MVDs contain a group of selected entities from the full IFC schema definition. In addition to being a subset of the full IFC schema, MVDs can contain additional constraints and requirements and there is also a possibility to extend the MVDs with additional classifications and properties (Van Berlo, 2019). IFC can be also extended manually by using property-set extensions. The objects such as parcel, block or sidewalk needed for an automated zoning code compliance checking process can be modelled in a BIM environment through these property-set extensions of the IFC schema. However, these property-set extensions are specific to the document and this independent development of zoning objects will create inconsistences in case of data sharing among project team members.

In addition to IFC extension approaches, there are also data model extension approaches for CityGML for adding information that CityGML does not already have and thus, expand the scope of the geographical model. It is possible to extend the CityGML data model through the Application Domain Extension (ADE) mechanism for more special domains (Gilbert et al., 2020).

The possibility of extending IFC has already been demonstrated by various researchers. For example; Ma et al. (2011) proposed an IFC data model extension for integrating construction related data. They firstly analyzed Chinese standards and defined the data needed for construction cost estimating for tendering. Then the data is represented using the entities in the IFC standard. Some of the objects are defined with the corresponding entities in the IFC standard; however, the researchers proposed using IfcProxy for the entities that have no specific corresponding entity as IfcProxy entity enables to model constructs that are not defined by IFC (BuildingSMART, 2019). At the end of the study, the IFC model was able to meet the information requirements for construction cost estimation during tendering in China. As a further research, the researchers emphasize that the property sets that do not have any specific correspondence in IFC should be submitted to the IAI and those data should be added into IFC standard as a data extension. Lee and Kim (2011) proposed an extension to IFC data model for road structures. As definitions for IFC specification are not enough to represent bridge and tunnel properties in detail, they defined new entities and properties for extending the IFC standard. For example, they defined a new 'IfcGroundReinforcingElement' entity for representing various reinforcing elements for ground, because the 'IfcReinforcingElement' entity of the IFC is limited to only representing steel elements reinforcing concrete members (Lee and Kim, 2011). Borrmann et al. (2015) developed an IFC data schema extension for modeling multi-scale representations of shield tunnels. In IFC, there is a hierarchical structure including Site, Building, and Building Storey objects where a site can include buildings and a building is composed of building storeys. Researchers used this hierarchical aggregation structure of IFC and defined new entities to represent shield-tunnel specific elements and object relationships for extending the IFC data model to be able to create multi-scale representations of shield tunnels. De Laat and van Berlo (2011) studied the extension of the CityGML for integrating building data into GIS data. They used BIMserver to export building data to CityGML and added those new objects and properties transformed from the IFC schema into CityGML and developed a CityGML extension called GeoBIM.

In the area of automated code compliance checking, Malsane (2015) and Malsane et al. (2015) proposed an IFC-compliant England and Wales building standard specific object model focusing on fire safety and extended the building model as existing IFC schemas are not rich enough for use in the automated compliance checking process. Through the domain extension approach, they included the concepts specific to England and Wales into a building schema that they developed. The current classes and properties of IFC are used for creating the detailed domain specific data such as defining "Habitable Space" concept from "IfcSpace" entity of IFC (Malsane et al., 2015). Salama and El-Gohary (2011) also asserted that a BIM model is not enough to represent the data required for compliance checking against laws and regulations. Hence, they proposed an approach that included the extension of BIM model to add the missing information specifically for the purpose of construction operations and then checking the model's compliance with regulations. Onstein and Tognoni (2017) also studied the extension of the IFC data schema for building permit applications. They aimed to model both building data and neighborhood data using IFC. Hence, they firstly defined the required data for the use case, and then used some entities and properties for defining the neighborhood that contain parcels, roads, water systems etc. For example, the researchers selected and used IfcGeographicElements entity to represent water drainage system and parcel, while they used IfcCivilElement for representing neighboring buildings and existing roads. However, this process includes a manual mapping process which can create inconsistencies and mismatches in case of sharing data with other software. Thus, there should be a common understanding of how neighborhood data can be represented with IFC entities or the upcoming standards should define new extensions for containing neighborhood data.

4.3.2.3 Development of a Unified Domain Model

Unified model-oriented approach requires the extraction of building data and the data on the surroundings from BIM and GIS domains separately and their integration within an independent unified model. Hence, the integrated environment can manage information coming from BIM and GIS domains in the same structure and with the same tools. For example, Hor et al. (2016) developed a novel interoperability approach using semantic web technologies and Resource Description Framework (RDF) graphs for processing BIM and GIS data. The novelty of the developed approach comes from the integration of BIM and GIS data into one unified model that is called Integrated Geospatial Information Model (IGIM). IGIM contains three modules; BIM and GIS RDF graph construction, a semantically integrated model construction that includes all classes, and attributes from both BIM and GIS schemas and query of data using SPARQL language. Gilbert et al. (2018) introduced a scale-free and multi-format approach to support integrated infrastructure management for modeling of buildings, the urban environment and infrastructure networks. The approach uses a graph database to drive, integrate and query the utility network data represented in separate data formats: the CityGML UtilityNetwork Application Domain Extension (ADE) and IFC. The data in varying data formats are integrated, forming a single network graph model without relying on the existing schemas. Kim et al. (2015) developed a semantic data integration system for BIM and GIS data to perform spatial analysis required for earthwork calculations. The system allows infrastructure data extraction from BIM environment and geographic data extraction from GIS environment separately and their integration in a common platform. Knoth et al. (2018) introduced a model for interoperability where the common elements from various data formats are extracted and then integrated into one common core model. The common elements are the most fundamental elements that exist in all buildings to store digital building information such as storey, wall, space etc. As the building is at the overlap of two domains: architecture and spatial planning, the model can be exchanged easily between BIM and GIS disciplines.

Considering automated zoning code compliance checking area, Hbeich et al. (2019b) studied BIM-GIS integration for representing detailed building with its surroundings and aimed to transform urban regulations rules into SPARQL queries which are required to query and check the data within an automated checker environment (Hbeich et al., 2019a).They proposed a semantic integration approach where the data models remain independent from each other but required concepts and properties are mapped for creating a coupled common model that contains the required building data and its surroundings. Firstly, they created ontologies for IFC and CityGML data separately and then aligned the ontologies by mapping only required concepts and properties to create a base model to be checked in a code checking application. For instance, IfcSpace from IFC ontology is mapped to Room object in CityGML ontology; IfcSlab from IFC ontology is mapped to FloorSurface object in CityGML ontology; and IfcWall from IFC ontology is mapped to WallSurface object in CityGML ontology. Demir Altıntaş and İlal (2021) also formulated a methodology for the creation of a third-party platform that retrieves building data in IFC format and the neighborhood data in GML format from both BIM and GIS environments separately and then integrates them in a unified domain model appropriate to code compliance checking processes. For validation of the methodology and testing the platform, a proof of concept prototype was developed. The prototype draws zoning regulations, reads the BIM file sent by the designer, and draws the data on the neighborhood the building is located in from GIS and conducts the checking process.

5 DISCUSSION

Recent BIM-GIS integration studies cover a wide range of topics such as site selection, fire safety, accessibility, evacuation planning, circulation and security planning, energy conservation, coverage and shadow analysis, height analysis, construction processes and cost estimation, infrastructure management and preconstruction operations. However, BIM-GIS integration studies in the context of automated zoning code compliance checking (Benner et al., 2010; Van Berlo et al., 2013; Ohori et al., 2017; Onstein and Tognoni, 2017; Chognard et al., 2018; Olsson et al., 2018; Demir Altıntaş and İlal, 2021) are limited in literature. The number of reviewed papers per each BIM-GIS integration approach and the number of automated zoning code compliance checking papers for each of these categories is depicted in the chart shown in FIG 5 below.

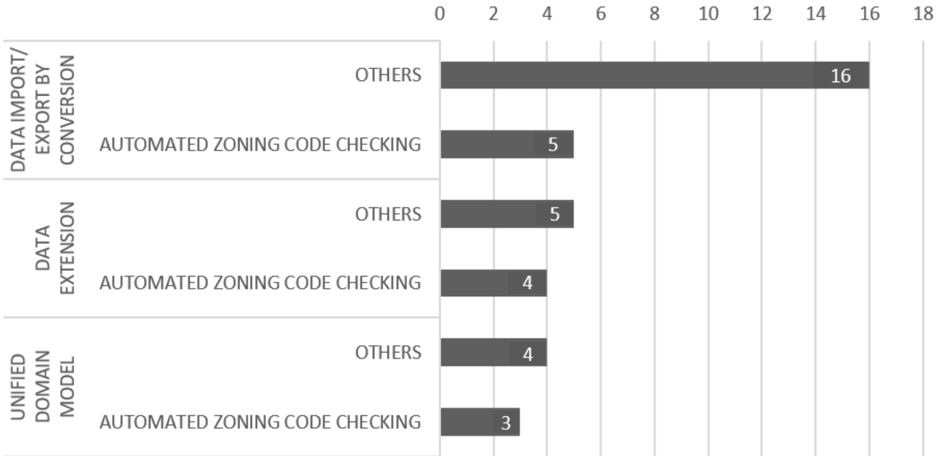

FIG 5: The number of automated zoning code checking papers per each BIM-GIS integration category

The studies for the integration of BIM and GIS data often use the two most prominent open data standards: IFC for the BIM domain, and CityGML for the GIS domain. These two data models embodying semantic information are representative of BIM and GIS data in general. IFC is widely used in BIM environment and CityGML is widely used in GIS environment (Ohori et al., 2017). However, IFC and GML data schemas are incompatible as they are different in terms of representation, scale and aim. They are developed for different domains and processes. For instance, IFC data schema holds much more detailed data from numerous disciplines than GML. Some concepts in GML such as water bodies, tunnels, railways, sidewalks/paths, vegetation, plant covers have no corresponding entities in IFC data schema and vice versa. Information loss from IFC to GML is inevitable (Van Berlo et al., 2013). Among the reviewed papers, it is seen that researchers try to map the already existing data standards IFC and CityGML for interoperability mostly using data conversion/transformation approaches. However, there is no method that has been adopted as a standard. Recently, the buildingSMART community started running an international project and invites industry experts with experience and knowledge from various domains to collaborate with them on adressing how the IFC schema can be extended for site, landscape and urban planning domains (BuildingSMART, 2018). There is a high potential for these developed schema and MVD solutions to ease data modeling, workflows, and required information exchanges for urban design and planning. If this project is successful, from a zoning code checking perspective, all the required data will be available in the BIM environment, eliminating the need for context data from GIS.

There is also a recent collaboration of Esri with Autodesk for studying the integration of BIM and GIS environments. Currently, they aim to create an interoperable workflow with participants from various disciplines without any data loss. Hence, it will be possible to visualize a detailed building with its context helping to coordinate the management of the project. Currently, designers can work with the BIM based engineering software Autodesk Civil 3D and InfraWorks directly from Autodesk Connector for ArcGIS and are able to integrate the required context data into the project at the early design phases (Esri, 2019, 2021).

Even though many researchers have studied the interoperability between BIM and GIS domains and how to address all the differences between them, there are still many challenges to be overcome and it is still hard to integrate data throughout the design, construction and maintenance processes. Information access and conversion/translation problems between BIM and GIS result in data loss, incomplete and unreliable transformations of data, incorrect mapping, and manual re-entry of information. Data extension approaches are also problematic since, the aim of BIM is to support lifecycle of a building project from design to construction and the aim of GIS is to store, analyze and manage spatially referenced geographical data for urban scale studies. Thus, it is impractical to expect BIM to explicitly manage geospatial data; and GIS to define detailed building data, and extend data storage capability of the two domains except their scope.

Semantic web is a promising integration approach whose development is led by the World Wide Web Consortium (W3C) and supported by researchers from various disciplines and industries. The semantic web consists of a web of linked data that can be processed by the computers and enables the integration of information from different disciplines with the usage of interrelated datasets. These datasets can then be shared effectively by wider communities (Pauwels et al., 2011). However, the semantic web technologies are still evolving and maturing and there is still a need for a globally agreed ontology definition. Currently, there is independent development of competing ontologies for various domains with inconsistencies between them (Karan et al., 2016, Liu et al., 2017, Zhang, 2018). To represent building models, ifcOWL ontology as the buildingSMART standard is available and building data can be represented using semantic web and linked data technologies (BuildingSMART, 2021).

One BIM-GIS integration approach that is proving to be effective for numerous fields, is to develop independent applications that retrieve data from both BIM and GIS domains. The data format and structure of either side is not changed. Data is accessed and extracted from BIM and GIS applications separately and then placed in a unified domain model for building and geographical data (FIG. 6). The parsed data sets are coupled by matching entities that are semantically equivalent (e.g. the “site” entity in BIM matches the “parcel” in GIS), forming a unified domain model appropriate to the field (Hor et al., 2016, Demir Altıntaş and İlal, 2018, Gilbert et al., 2018, Knoth et al., 2018). The integrated model manages both the data on the surroundings defined in GML and the building data defined in IFC and then can be the base for exchanging data. This approach does not require BIM or GIS environments to extend their data schemas but depends on the definition of domain-specific models. However, since a third, parallel model is generated, maintaining consistency between models is a challenging issue that needs to be considered. This limitation makes this approach more appropriate for applications in fields where model elements are not generated or extensively modified but are examined for evaluation and analysis purposes.

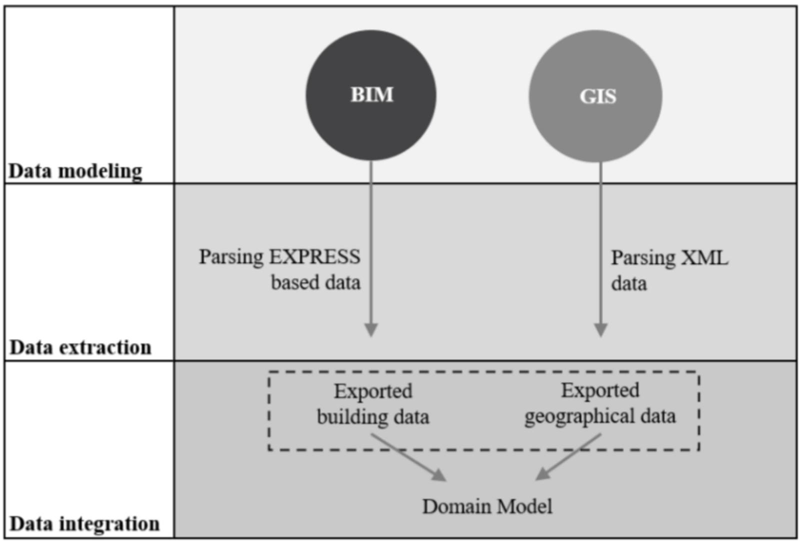

FIG. 6: Domain integration approach for BIM-GIS interoperability

For defining a unified domain model, first, the data required by the domain in question should be identified and how much of the data can be modelled with BIM model or GIS model should be determined. Then, based on the data identified in the previous step, BIM and GIS domain models should be constructed. Finally, an application should be developed integrating the two domain models. Identifying the required data in the field of research is crucial, as BIM and GIS have detailed data sets and trying to use all the details will increase the workload and slow down the visualization process (Ohori et al., 2017).

6 CONCLUSION

Automated zoning code compliance checking processes require information from both the building information domain and geographic information domain. They involve two very different levels of information, data structures, standards, aims and scopes. The number of studies that focus on BIM-GIS interoperability for automated zoning compliance checking are limited but represent a significant progress. Yet, they deal with standards of specific disciplines checking individual building projects detached from their neighborhoods. They do not claim a generic method applicable to all types of rules. Since the legal systems and the building standards between countries differ, the provided solutions are not comprehensive enough to contain the concepts mentioned in other building regulation documents. In addition, the current BIM software used in these rule checking studies are expected to contain code specific data. However, BIM tools are not able to contain all the needed building code data for a fully automated zoning code checking (Malsane, 2015).

For automated zoning code checking as well as other domains involving analysis and evaluation, a promising approach is the development of independent, third-party applications that retrieve data from both BIM and GIS sources. This approach avoids data translations where models are incompatible since the independent model can preserve the original semantics. It also prevents incorrect mapping and thus, data loss. The independent nature of the coupling environment also does not require extending data sets and does not depend on specific implementations for either BIM or GIS environments. However, without mechanisms to ensure consistency of multiple models, this approach will be limited in applications requiring modification of model entities.

Shortcomings aside, there is a need for defining how data related to the surroundings can be integrated with BIM data for an automated zoning code compliance checking process. At a minimum, zoning data stored in the GIS environment should be interoperable with building data stored in BIM. If designers can easily reach zoning data during the architectural design process, they will be capable of ensuring during the design process that each aspect of their project complies with the zoning standards before submitting to municipalities. Designers will be able to combine the zoning information obtained from the municipality with their own project data within an automated code-checking application and identify problematic points in their designs on their own. At the other end, the municipalities will also be able to use the same integrated digital model, and carry out faster approval workflows with more accurate results and decreased manual labor.

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