

# Integrating BIM & GIS to Support Regulatory Applications

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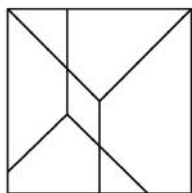
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**buildingSMART Canada is committed to supporting the digitalization of Canada's built asset industry by developing and helping promote the adoption of open, international standards and solutions.**

buildingSMART Canada is the community for visionaries working to transform the design, construction, operation, and maintenance of Canada's built environment.

As a Canadian federally incorporated Not-for-Profit Corporation, the Canadian chapter of buildingSMART International provides the appropriate body and home for Canadian BIM and digital project and asset lifecycle delivery Standards and best practices development.

It exists to support the implementation of BIM in a way and at a pace that enables industry to successfully achieve its objectives and deliver value to Canadians.

Canada and Canadian professionals have a long history and reputation of collaboration and communication between countries and regions. The chapter continues to fulfill this role, supporting the development and application of standards from high-level to practical use.



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## ABSTRACT

The integration of Building Information modelling (BIM) and Geographic Information Systems (GIS) has significant potential to improve applications within regulatory frameworks. In November 2024, the National Research Council in collaboration with buildingSMART Canada published *Toward a Digital Construction Platform - The Digitalization of National Construction Codes & The Development of a National Common Data Framework*, highlighting the importance of enhancing interoperability among digital tools, platforms, and data used by industry professionals, government agencies, and regulatory bodies (NRC 2024, 102). The report identifies the crucial role of BIM and GIS integration specifically for municipalities in automating zoning compliance checks, thereby enabling more thorough regulatory reviews throughout the development approvals process.

The integration of BIM and GIS data would allow regulatory agencies to situate building asset models within their environmental context, enabling improved decision-making and streamlined workflows for various regulatory processes, including data management, compliance validation, and permit approvals. However, leveraging BIM-GIS integrated solutions requires addressing key challenges, including consistent data requirements, revised object conceptualizations, alignment of geometric representations, and reliable georeferencing. This paper identifies existing standards for each data domain, highlighting both the benefits and challenges of their interoperability.



1.0

# INTRODUCTION



# 1.0 INTRODUCTION

Building Information Modelling (BIM) and Geographic Information Systems (GIS) are distinct information domains: BIM has been developed and primarily used by the architecture, engineering, construction, and owner industries since the early 2000s; GIS dates to the early 1960s and is actively used throughout the geospatial sector to visualize spatial data for planning, infrastructure and resource management, and emergency response among other things. There are a range of industries that fall within the geospatial sector including utilities, logistics, transportation, natural resources, real estate, and environmental management. Although both BIM and GIS data offer valuable insights for regulatory applications, their integration presents challenges due to differing conceptualizations and domain-specific developments (Noardo et al. 2020, 1). In order to meet the requirements for permitting approvals, regulatory agencies require building and geospatial information from a variety of sources, including building codes, planning acts, GIS constraint layers, permit forms, 3D design mock-ups, and existing infrastructure data.

As municipalities work towards creating smarter, more resilient communities, there is increasing demand for enhanced accuracy and efficiency in planning, operations, performance evaluation, maintenance, and emergency response. Integrating BIM and GIS data will allow municipalities to streamline information-sharing and reuse, while reducing the risks of data loss or misinterpretation. This will enable the automation of regulatory tasks, such as identifying requirements and highlighting potential issues. (Autodesk and Esri 2022, 18-24). This paper explores how regulatory agencies can benefit from BIM-GIS integration, identifies existing standards for each domain, outlines the benefits of integration, highlights key challenges to be addressed, and proposes the development of a common data platform as a unified solution to meet the needs of regulatory agencies.



**2.0**

# **DEFINING BIM AND GIS**

# BIM

## Building Information Modelling

BIM is defined as the “use of a shared digital representation of an asset to facilitate design, construction, and operation processes to form a reliable basis for decisions” (ISO 19650-1:2018, 5). It is a process that results in a central 3D model linked to databases containing detailed information about the asset. BIM data can include drawings, photographs, documents, video, audio, and geometry. For regulatory agencies specifically, incoming BIM data typically contains information about a design such as material specifications, 2D and 3D geometry, dimensions, volume, and area. Common open BIM data formats include Industry Foundation Classes (IFC), Construction Operations Building Information Exchange (COBie) and BIM Collaboration Format (BCF).

## Geographic Information Systems

# GIS

GIS is defined as a system for storing, manipulating, and visualizing information that has an associated real-world location (ISO 23611-6:2012, 4). GIS data can describe naturally occurring geological features (oceans and mountains), built features (city furniture, roads, and buildings), as well as transient features (weather patterns, population distributions, and man-made boundaries) (Natural Resources Canada 2019). Regulatory agencies rely on a diverse range of 2D and 3D geospatial data, such as point clouds, photographs, zoning and property boundaries, environmental constraints, and social patterns, to document and analyze the urban environment. Common open data formats include GeoJSON, Geographic Markup Language (GML), GeoTIFF, DEM, and JPEG (“Data Interoperability | GIS Data Types & Open Data Capabilities”, n.d.). The Shapefile format is another widely used vector data format, although it is proprietary to Environmental Systems Research Institute, Inc. (ESRI), with an open specification (ESRI Shapefile Technical Description 1998).



Figure 1: A BIM model is a collection of data pertaining to an asset. CIMS' Canada's Digital Twin (CDT) platform demonstrates the information a BIM can contain: 3D geometry, alphanumeric data, 2D drawings, and relational data.

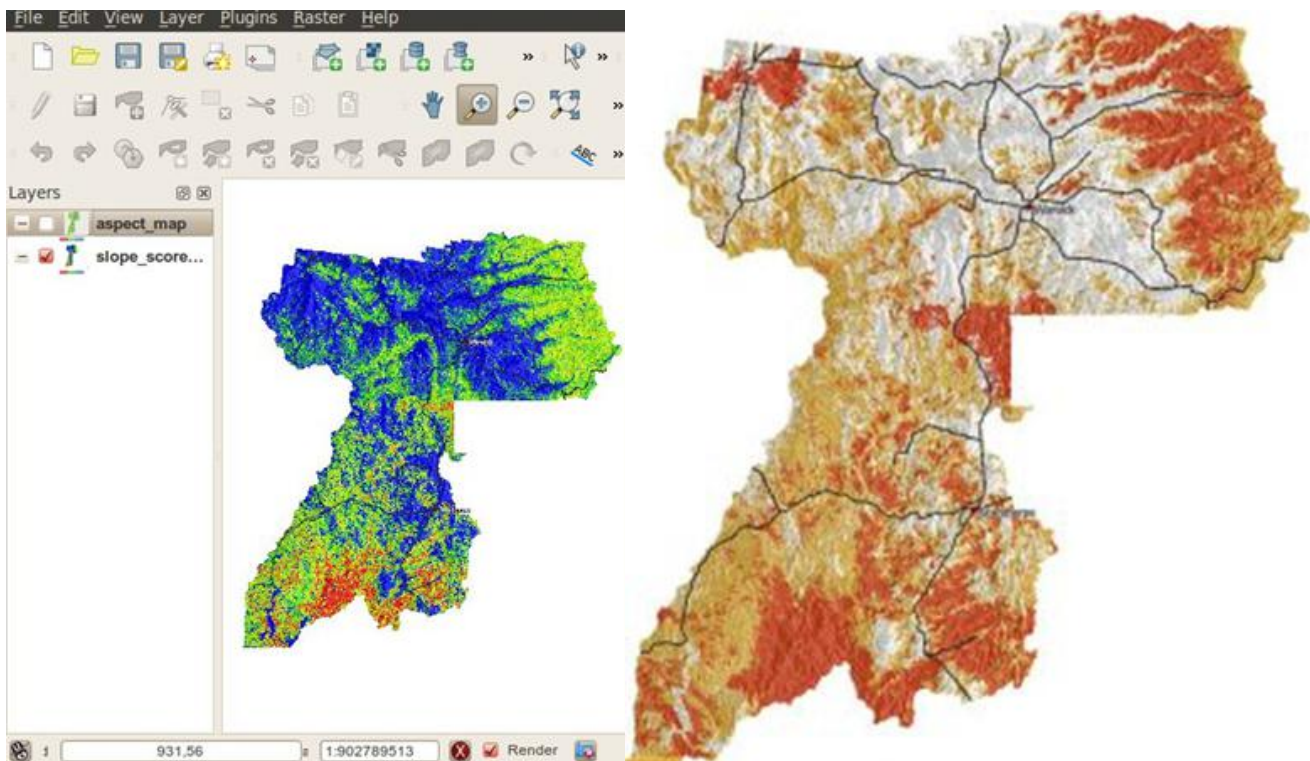


Figure 2: Bushfire hazard mapping and severity assessments conducted using QGIS, an open source GIS software (Woodrow 2011).



# 3.0 STANDARDS

Standards are vital to facilitate the collection, exchange, and use of information (Natural Resources Canada 2019). While technological advancements often outpace the development of standards, these standards remain crucial to ensuring predictability and consistency in the creation and dissemination of deliverables. Organizations such as the International Organisation for Standardization (ISO), the Comité Européen de Normalisation (CEN), buildingSMART International (bSI), and the Open Geospatial Consortium (OGC), along with government bodies and technical committees, play a key role in creating and updating standards. These standards guide processes and results, establishing a baseline level of repeatable quality.

### 3.1 BIM Standards

As BIM becomes more widely adopted, users are recognizing that establishing structure and consistency through standards is key to broadening its benefits beyond individual projects (Poirier, n.d.). ISO, CEN, bSI, and OGC are among the key organizations developing foundational guidelines for standardized BIM implementation. In Canada the lack of an organized government mandate for adoption or standardization has resulted in inconsistent adoption of BIM across projects and organizations (Cozzitorto et al. 2024, 71). A significant step forward came in late 2024 when the CSA Group (formerly the Canadian Standards Association) adopted ISO 19650, officially recognizing it as a National Standard of Canada for BIM implementation.

Currently, the most widely recognized standards for BIM are outlined in Table 1. Among these, the Industry Foundation Classes (IFC) stands out as the most internationally recognized and adopted data model schema for openBIM (Noardo et al. 2020, 4). IFC, developed by bSI, is the openBIM standard that is used to import and export building objects and their properties (Oxlade 2018).



**Table 1: BIM Standards**

| Name                                                                                             | Date                                 | Organization          | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|--------------------------------------------------------------------------------------------------|--------------------------------------|-----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ISO 19650-1:2018<br>ISO 19650-2:2018<br>ISO 19650-3:2020<br>ISO 19650-4:2022<br>ISO 19650-5:2020 | 2018<br>2018<br>2020<br>2022<br>2020 | ISO                   | Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling <ul style="list-style-type: none"> <li>Describes how to develop BIM-specific conventions and frameworks for information management</li> </ul>                                                                                                                                                                       |
| EN ISO 16739-1                                                                                   | 2024                                 | ISO<br>CEN            | Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries <ul style="list-style-type: none"> <li>An open international standard regarding the IFC developed by bSI</li> </ul>                                                                                                                                                                                                                                                                                              |
| IFC Specifications Database                                                                      | 2022                                 | bSI                   | <ul style="list-style-type: none"> <li>Contains IFC specifications and documentation</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                            |
| BIM Collaboration Format (BCF)                                                                   |                                      | bSI                   | <ul style="list-style-type: none"> <li>bSI openBIM standard</li> <li>Communicates coordination issues between different BIM platforms (Oxlade 2018)</li> </ul>                                                                                                                                                                                                                                                                                                                                                             |
| ISO 29481-1:2016<br>ISO 29481-2:2012<br>ISO 29481-3:2022                                         | 2016<br>2012<br>2022                 | ISO                   | BIM information models - Information delivery manual<br>Part 1: Methodology and format <ul style="list-style-type: none"> <li>Specifies a method for information delivery</li> </ul> Part 2: Interaction framework <ul style="list-style-type: none"> <li>Specifies a framework to map responsibilities and interactions for accurate and repeatable information exchange</li> </ul> Part 3: Data schema <ul style="list-style-type: none"> <li>Specifies a data schema for the methodology in ISO 29481-1:2016</li> </ul> |
| ISO 12006-2:2015                                                                                 | 2015                                 | ISO                   | Building construction - Organization of information about construction works - Part 2: Framework for classification <ul style="list-style-type: none"> <li>Specifies a framework to develop built environment classification systems</li> </ul>                                                                                                                                                                                                                                                                            |
| ISO 12006-3:2022                                                                                 | 2022                                 | bSI<br>ISO            | Building construction — Organization of information about construction works — Part 3: Framework for object-oriented information <ul style="list-style-type: none"> <li>Defines an interoperability format for language dictionaries</li> </ul>                                                                                                                                                                                                                                                                            |
| User Guide for Geo-referencing in IFC                                                            | 2021                                 | bSI<br>bS Australasia | <ul style="list-style-type: none"> <li>Establishes map location and site configuration to create georeferenced projects using IFC</li> <li>Guide to incorporating cadastral data</li> <li>Address IFC2x3 and IF4 (embedded georeferencing)</li> </ul>                                                                                                                                                                                                                                                                      |

## 3.2 GIS Standards

At the international level, geographic information standards are shaped by organizations such as ISO/TC 211 Geographic Information/Geomatics, CEN/TC 287 Geographic Information, and OGC, which produce guidelines and frameworks for structuring geographic data. Among these, the OGC City Geography Markup Language (CityGML) is recognized as the “most internationally widespread standard for storing and exchanging 3D city models with semantics in the geospatial domain” (Noardo et al. 2020, 4). CityGML serves as an open standard for 3D city model exchange, comparable to IFC in BIM. Other GIS standards include OGC IndoorGML, ISO 19152:2012 Land Administration Domain Model (LADM), and the Infrastructure for Spatial Information in the European Community (INSPIRE). OGC IndoorGML 1.1 focuses on defining the geometric and semantic properties of indoor spaces, specifically for navigation (OGC 2020, viii). LADM is essential for managing both 2D and 3D cadastre, detailing the Rights, Restrictions, and Responsibilities (RRR) assigned to spatial units (Alattas et al. 2017, 3). When combined with physical asset standards such as IndoorGML, CityGML, and IFC, LADM provides jurisdictional context. For instance, IndoorGML and LADM together can model movement through space based on access rights (Alattas et al. 2017, 1). When used in conjunction with CityGML, the combined model can express the ownership structure of physical assets (Li et al. 2016, 50). The most widely recognized standards for GIS are outlined in Table 2.

At the federal level, the GeoConnections Program<sup>[1]</sup> operated by Natural Resources Canada (NRCan) provides funding for projects that address geospatial issues by developing or implementing standards-based solutions. These standards and operational policies will specify the creation, reproduction, renewal, and maintenance of mapping data in Canada and contribute to the modernization of the Canadian Geospatial Data Infrastructure (CGDI)<sup>[2]</sup> (Natural Resources Canada 2019). The geospatial standards and operational policies currently implemented to use and share geospatial data in the CGDI are described on the Government of Canada website<sup>[3]</sup>.

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<sup>[1]</sup> <https://www.google.com/url?q=https://natural-resources.canada.ca/science-data/science-research/geomatics/canada-spatial-data-infrastructure/geoconnections-announcement-opportunities-fiscal-years-2025-2026-2026-2027&sa=D&source=docs&ust=1744219610334265&usg=AOvVaw3KiPuoJbPRmwR-FkKwLB2x>

<sup>[2]</sup> <https://www.google.com/url?q=https://natural-resources.canada.ca/science-data/science-research/geomatics/canadian-geospatial-data-resource-centre&sa=D&source=docs&ust=1744219610335967&usg=AOvVaw3ondri68390zsPNdNvMeh1>

<sup>[3]</sup> <https://natural-resources.canada.ca/maps-tools-publications/tools-applications/geospatial-standards-operational-policies>

| Table 2: GIS Standards                  |              |              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-----------------------------------------|--------------|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Name                                    | Date         | Organization | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| CityGML-1 3.0                           | 2021         | OGC          | OGC City Geography Markup Language (CityGML) Part 1: Conceptual Model Standard <ul style="list-style-type: none"> <li>Defines the open CityGML Conceptual model for the representation and exchange of 3D city models (OGC 2021, 25)</li> </ul>                                                                                                                                                                                                                                                                                    |
| LandInfra 1.0                           | 2016         | OGC          | OGC Land and Infrastructure Conceptual Model Standard (LandInfra) <ul style="list-style-type: none"> <li>Defines an open conceptual model regarding land and civil infrastructure (OGC 2016, 17)</li> </ul>                                                                                                                                                                                                                                                                                                                        |
| ISO 19157-1:2013<br>ISO/TS 19157-2:2016 | 2013<br>2016 | ISO          | Geographic information — Data quality<br>Part 1: General requirements <ul style="list-style-type: none"> <li>Defines guidelines on how to describe and measure data quality</li> </ul> Part 2: XML schema implementation<br>Defines data quality in XML                                                                                                                                                                                                                                                                            |
| ISO 19109:2015                          | 2015         | ISO          | Geographic information - Rules for application schema <ul style="list-style-type: none"> <li>Specifies procedures for creating and managing application schemas</li> </ul>                                                                                                                                                                                                                                                                                                                                                         |
| ISO 19103                               | 2015         | ISO          | Geographic information - Conceptual schema language <ul style="list-style-type: none"> <li>Specifies how to implement the conceptual schema language, Unified Modelling Language (UML)</li> </ul>                                                                                                                                                                                                                                                                                                                                  |
| ISO 19104:2016                          | 2016         | ISO          | Geographic information — Terminology <ul style="list-style-type: none"> <li>Specifies the requirements for the development of terminological entries</li> <li>Development of concepts</li> <li>Establishes and manages terminology registers</li> </ul>                                                                                                                                                                                                                                                                            |
| ISO 19105:2022                          | 2022         | ISO          | Geographic information — Conformance and testing <ul style="list-style-type: none"> <li>Specifies the framework, concepts, and methodology for conformance testing</li> <li>Defines the criteria to claim conformance to the family of applicable standardization documents regarding geographic information</li> <li>Provides a framework for specifying abstract test suites composed of abstract test cases grouped in conformance classes</li> <li>Defines the procedures to be followed during conformance testing</li> </ul> |

| Table 2: GIS Standards |      |              |                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|------------------------|------|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Name                   | Date | Organization | Description                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| ISO 19112: 2019        | 2019 | ISO          | <p>Spatial referencing by geographic identifiers</p> <ul style="list-style-type: none"> <li>Defines the components of a spatial reference system</li> <li>Defines a schema for spatial reference systems based on geographic identifiers</li> </ul>                                                                                                                                                                                           |
| ISO 19106: 2004        | 2004 | ISO          | <p>Geographic information — Profiles</p> <ul style="list-style-type: none"> <li>Addresses specifications for the ISO standards which are abstract and may not be implemented directly</li> <li>Specifies two types of profiles that can be developed which are a subset of the standard, and an extension of the standard for a specific application field</li> </ul>                                                                         |
| ISO 19107: 2019        | 2019 | ISO          | <p>Geographic information — Spatial schema</p> <ul style="list-style-type: none"> <li>Specifies conceptual schemas for describing the spatial characteristics of geographic entities,</li> <li>Specifies a set of spatial operations consistent with these schemas,</li> <li>Defines standard spatial operations for use in access, query, management, processing, and data exchange of geographic information for spatial objects</li> </ul> |
| ISO 19108: 2002        | 2002 | ISO          | <p>Geographic information — Temporal schema</p> <ul style="list-style-type: none"> <li>Defines the concepts for describing temporal characteristics of geographic information</li> <li>Defines the basis of temporal feature attributes, feature operations, and feature associations</li> <li>Defines the temporal characteristics of the geographic metadata</li> </ul>                                                                     |
| ISO 19109: 2015        | 2015 | ISO          | <p>Geographic information — Rules for application schema</p> <ul style="list-style-type: none"> <li>Defines rules for creating and documenting application schemas</li> <li>Defines the principles for the definition of features</li> <li>Integrates standardized schemas from other ISO geographic information standards</li> </ul>                                                                                                         |
| ISO 19110: 2016        | 2016 | ISO          | <p>Geographic information — Methodology for feature cataloguing</p> <ul style="list-style-type: none"> <li>Defines rules for creating and documenting application schemas</li> <li>Defines the principles for the definition of features.</li> <li>Uses the conceptual schema language for application schemas</li> <li>Integrates standardized schemas from other ISO geographic information standards</li> </ul>                            |

| Table 2: GIS Standards |      |              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|------------------------|------|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Name                   | Date | Organization | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| ISO 19111: 2019        | 2019 | ISO          | <p>Geographic information — Referencing by coordinates</p> <ul style="list-style-type: none"> <li>• Defines the conceptual schema for the description of referencing by coordinates</li> <li>• Describes the minimum data required to define coordinate reference systems</li> <li>• Defines spatial coordinate reference systems where coordinate values do not change with time</li> <li>• Defines parametric coordinate reference systems which use a non-spatial parameter that varies monotonically with height or depth</li> <li>• Defines temporal coordinate reference systems which use temporal quantities that change with time</li> </ul>    |
| ISO 19112: 2019        | 2019 | ISO          | <p>Spatial referencing by geographic identifiers</p> <ul style="list-style-type: none"> <li>• Defines the components of a spatial reference system</li> <li>• Defines a schema for spatial reference systems based on geographic identifiers</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                  |
| ISO 19145:2013         | 2013 | ISO          | <p>Geographic information — Registry of representations of geographic point location</p> <ul style="list-style-type: none"> <li>• Identifies and describes the structure of a register, the representations of geographic point location which includes the elements for the conversion of one representation to another</li> <li>• Specifies the XML implementation to implement a registration of geographic point location representations</li> </ul>                                                                                                                                                                                                 |
| ISO 19152:2012         | 2012 | ISO          | <p>Geographic information — Land Administration Domain Model (LADM)</p> <ul style="list-style-type: none"> <li>• Defines the basic information related to the components of land administration which include the elements above and below the surface of the earth</li> <li>• Provides a conceptual model for different actors, administrative units, restrictions, rights, legal spatial units, spatial sources, and representations,</li> <li>• Provides terminology for land administration, based on various national and international systems, which includes the description of different formal or informal practices and procedures</li> </ul> |

### 3.3 BIM and GIS Integration Standards

Currently, no comprehensive standard exists for integrating BIM and GIS, but efforts are underway to bridge the gap. A key example is the strategic roadmap “Enabling Information Continuity Across BIM-GIS Domains,” developed by buildingSMART and the Open Geospatial Consortium (OGC).

The two most prominent open standards for BIM and GIS—IFC and CityGML<sup>[1]</sup>—are undergoing revisions with integration in mind. IFC2x3, uses the Cartesian coordinate system to locate elements in an IFC dataset. In the next version, IFC4, the coordinate system for local elements can be projected onto a geographic coordinate system, improving alignment with geospatial data (“F.1 IFC2x3 to IFC4,” n.d.). The most current version as of 2024 is IFC4.3 and is published by ISO as ISO16739-1:2024. It extends upon IFC4 by including the horizontal infrastructure domains that are supported by the Transportation module in CityGML, such as roads, railways, ports and waterways, and bridges (Kelly, n.d.).”

Revisions to CityGML that facilitate better integration with IFC include:

- new feature types and better-defined space boundaries that explicitly connect volumetric elements with their boundary surfaces (Kutzner, Chaturvedi, and Kolbe 2020, 50); and
- a new concept of spaces that aligns the `IfcSpace` class (which defines rooms as physically unoccupied spaces) with the `BuildingRoom (Unoccupied Space)` feature type in CityGML (Kutzner, Chaturvedi, and Kolbe 2020, 58).

ISO TR 23262:2021 is a document focused on the integration of BIM and GIS, rather than being a domain-specific standard. The main objective of ISO TR 23262:2021 is to align standards developed by ISO/TC 211 for GIS and ISO/TC 59/SC 13 for BIM (such as those listed in Table 1 and Table 2). Unlike other BIM and GIS standards, ISO TR 23262:2021 is not a guideline. Instead, it lays the groundwork for future standardization by comparing existing GIS and BIM schemas to identify barriers and opportunities for interoperability. ISO TR 23262:2021 refers to relevant standards to establish links between concepts in BIM and GIS and suggests where these impacted standards could be extended to improve interoperability. Examples include: mapping conceptual schema languages, defining terms and definitions, creating a user guide for georeferencing, and applying GIS metadata workflows to BIM.

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<sup>[1]</sup> CityGML 2.0 was released in March 2012; its subsequent version, CityGML 3.0, began development in 2013 and was released in 2021.



# **4.0 COMPARING LOD IN BIM & GIS**

While both BIM and GIS use the acronym LOD, it represents different concepts in each domain. To avoid confusion in this paper, LODev will refer to Level of Development in BIM, and LoD will refer to Level of Detail in GIS. Both LODev and LoD are categories that describe model scalability, but the order of the levels is not indicative of value (Biljecki, Ledoux, and Stoter 2016, 27). They serve to isolate relevant information based on modelling uses and stakeholder requirements, and communicate reliability. For example, a LoD0 model may be sufficient for broad, city-scale analysis, whereas higher LoD levels are needed for detailed analysis of individual buildings or assets. LODev is defined by the Level of Development LOD Specification by BIMForum[1]. OGC's CityGML schema ("OGC City Geography Markup Language (CityGML) Part 1: Conceptual Model Standard" section 7.2.5) is an example of how LoD is defined for GIS data types[2].

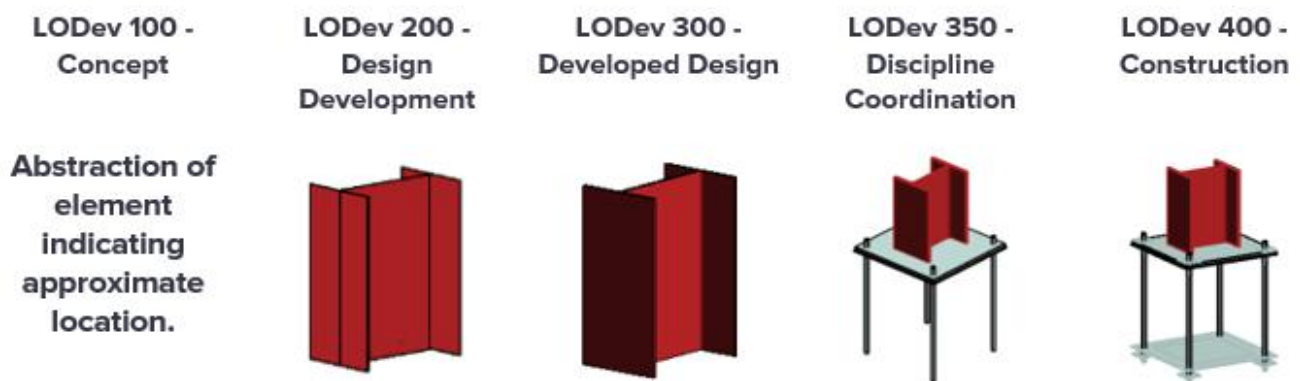


Figure 3: A steel framing column through LODev100 to LODev400. The geometric information provided at LODev 500 will depend upon the specific needs during operations. Images from "Level of Development LOD Specification Part 1" ("Level of Development LOD Specification Part 1" 2024, 26, 31).

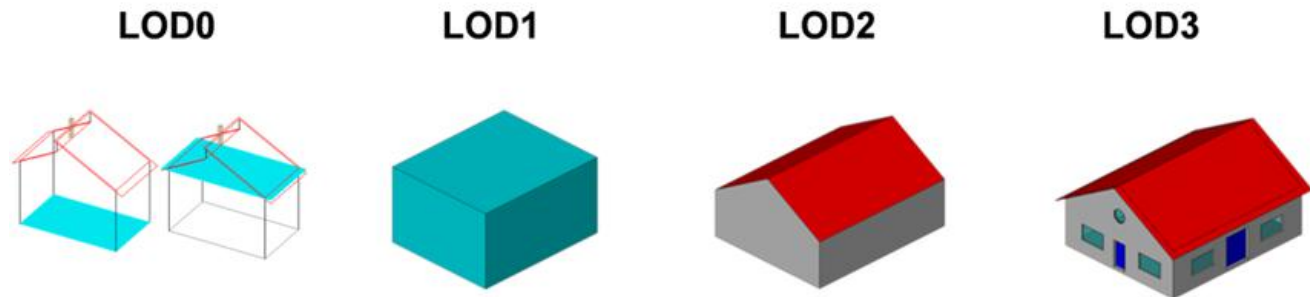


Figure 4: The geometric breakdown of the same building in LoD0 to LoD3. Image from "OGC City Geography Markup Language (CityGML) Part 1: Conceptual Model Standard" (OGC 2021, 36)

[1] <https://bimforum.org/wp-content/uploads/2024/11/LOD-Spec-2024-Part-I-official-English.pdf>

[2] <https://docs.ogc.org/is/20-010/20-010.html#geometry-lod-section>

## 4.1 Level of Development (LODev) in BIM

In BIM, LODEv defines the detail, dimensionality, location, appearance, author, and date of geometric information (“Level of Development LOD Specification Part 1” 2024, 11). It is a measure of how complete or developed an element is as the model progresses through various stages of design, construction and operation and communicates the reliability of the information. The stages range from LODEv 100 (concept stage) to LODEv 400 (construction), with LODEv 500 reserved for representing existing conditions. Figure 3 illustrates how a steel framing column is represented from the concept stage of a project (LODev 100) through to construction (LODev 400).

## 4.2 Level of Detail (LoD) in GIS

LoD, originating from CityGML, describes the geometric abstraction of 3D city models, with different levels indicating the degree of detail included. The levels of LoD range from LoD0 (generalized) to LoD4 (highly detailed). In CityGML 3.0, LoD focuses solely on geometric detail abstraction, with earlier versions combining geometric and semantic details (OGC 2021, 37).

## 4.3 Key Differences and Similarities Between LODEv and LoD

LODev defines the degree of maturity for element geometry; LoD is more specific and defines how much geometric detail is included in the element (“Level of Development LOD Specification Part 1” 2024, 11). Both are cumulative, meaning all lower level requirements are included<sup>[1]</sup>.

While LODEv and LoD both serve to define model detail and abstraction, they differ in their scope and application:

- LODEv refers to the reliability of the detail, dimensionality, location, appearance, author, and date of geometric information for an object.
- LoD refers to the complexity of the object geometry compared to the physical object.

<sup>[1]</sup> Except LODEv 500.



**Table 3: summarizes the definitions of LODev and LoD according to BIMForum and CityGML 3.0. A summary of the different stages within the Level of Development and Level of Detail.**

| Level of Development                                                                                                                                                                                                                                                               | *Level of Detail                                                                                                                                                                                                             |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>LODev 100 - Concept</p> <p>Symbolic or other generic representation. There are no geometric representations. The attached information defines the existence of an object only. Any information derived from LoDev 100 elements must be considered approximate.</p>              | <p>LoD0</p> <p>Non-volumetric and highly generalized model. Includes representations such as floor/ceiling plans and points.</p>                                                                                             |
| <p>LODev 200 - Design</p> <p>Development: Elements are generic placeholders graphically represented with approximate quantity, size, shape, location, and orientation.</p>                                                                                                         | <p>LoD1</p> <p>A 3D solid block model created by vertical extrusions from the footprint of the model in LoD0. Horizontal or vertical surfaces can represent area boundaries.</p>                                             |
| <p>LODev 300 - Developed</p> <p>Design: The object is graphically represented such that its quantity, size, shape, location, and orientation can be measured. Element properties can be directly measured from the project and located accurately to a defined project origin.</p> | <p>LoD2</p> <p>The block model is less abstracted and becomes split geometrically into broad geometry categories such as walls, roofs, rooms, doors, and ground surfaces. The model is realistic, but still generalized.</p> |
| <p>LODev 350 - Discipline Coordination</p> <p>Measurements and quantities can be obtained directly from the model.</p> <p>This LoDev usually requires trades and fabrication knowledge to ensure that objects are developed to support construction level coordination.</p>        | <p>LoD3</p> <p>The lowest level of spatial abstraction. A highly detailed geometric model that includes small shape details. A 3D mesh would fall under LoD3.</p>                                                            |
| <p>LODev 400 - Construction</p> <p>Elements contain sufficient detail and accuracy for fabrication, assembly, and installation. Measurements and quantities can be obtained directly from the model.</p>                                                                           |                                                                                                                                                                                                                              |
| <p>LODev 500 - Existing Conditions</p> <p>Elements are field-verified representations that support the day-to-day operations of the asset.</p>                                                                                                                                     |                                                                                                                                                                                                                              |

## 4.4 Reconciling LODev and LoD in BIM-GIS Integration

When integrating BIM and GIS data, it's crucial to identify the appropriate LODev (Level of Development) and LoD (Level of Detail). If the required level of detail or development is not considered during data conversion or retrieval, the result may be overlapping or missing geometry, which can affect the accuracy and completeness of the model (Noardo et al. 2020, 30).

Figure 5 demonstrates which LODevs may appear at each LoD according to definitions from BIMForum and CityGML 3.0.

As BIM and GIS data grows in size and complexity, especially at the city scale, identifying the Level of Information Need (LoIN : ISO 7817-1:2024), a concept used in BIM, can ensure that only the appropriate information is included, enhancing the model's performance and usability. LoIN clarifies data representation and requirements by distinguishing between geometry and associated data. By separating these elements, it becomes easier to identify what data is necessary for specific model uses, thus improving efficiency in both BIM and GIS applications. This separation can also ensure that only the required level of data is included at each stage of analysis, reducing ambiguity and preventing unnecessary complexity in model construction.

|      | LODev 100                                                                           | LODev 200                                                                           | LODev 300                                                                           | LODev 350                                                                            | LODev 400                                                                             | LODev 500                                                                             |
|------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| LoD0 |  |  |                                                                                     |                                                                                      |                                                                                       |  |
| LoD1 |                                                                                     |  |  |                                                                                      |                                                                                       |  |
| LoD2 |                                                                                     |  |  |   |                                                                                       |  |
| LoD3 |                                                                                     |                                                                                     |                                                                                     |  |  |  |

Figure 5: The LoD of a model should be tailored to a specific purpose. Each successive LODev has different requirements that can be fulfilled by an LoD. In practice, the boundaries between levels will likely not be as defined as is suggested here. Image from "An improved LOD Specification for 3D building models" (Biljecki, Ledoux, and Stoter 2016, 26).



**5.0**

# **BIM & GIS INTEGRATION**

## 5.1 Benefits of Integration

In 2022, Autodesk and Esri released a report titled “GIS and BIM Integration: A High-Level Global Report,” which outlines the benefits of integrating BIM and GIS workflows. The report, informed by stakeholders across the architecture, engineering, owner, operator and municipality (AECOOM) sectors, highlights several key advantages, particularly in regulatory processes. These benefits are listed in Table 4.

Table 4: Benefits identified when implementing BIM and GIS integrated workflows (Autodesk and Esri 2022, 18-24).

These benefits are particularly relevant to regulatory agencies, which aim to streamline the analysis and approval of regulatory requirements across the lifecycle of assets (“Guidance for Regulators on Use of openBIM” 2024, 15). Currently, this process often involves the manual review of a substantial amount of potentially conflicting information stored in various locations. BIM-GIS integration facilitates the direct comparison of proposals against regulations (e.g., zoning and environmental context), code requirements (e.g., load conditions and dimensions), and recommendations (e.g., technical reports, studies, and community feedback).

| Benefits of Integrated BIM and GIS Solutions |                                                                                                                                                                                                                        |
|----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sustainable project delivery                 | <ul style="list-style-type: none"><li>• Enhanced ability to consider environmental and social impacts</li><li>• Reduced material usage</li><li>• Increased project resilience</li></ul>                                |
| Improved processes and outcomes              | <ul style="list-style-type: none"><li>• Reduced overall project duration</li><li>• Reduced total construction cost</li><li>• Faster plan approval and permits</li></ul>                                                |
| Project risk reduction                       | <ul style="list-style-type: none"><li>• Improved project budgeting forecasting</li><li>• Enhanced ability to manage project complexity</li><li>• Reduced conflicts, changes, and field coordination problems</li></ul> |
| Organizational benefits                      | <ul style="list-style-type: none"><li>• Increased win rates for the pursuit of new work</li><li>• Improved client satisfaction</li><li>• Additional services (customer support and training)</li></ul>                 |

The benefits of BIM and GIS integration can be seen across projects of all scales, contributing to improved outcomes and efficiency as shown in Figure 6. By enabling users to visualize a digital asset within its real-world context, integrated BIM and GIS workflows can significantly improve the timeliness, predictability, transparency, and outcomes of approval processes—ultimately increasing return on investment in both small and large-scale projects.

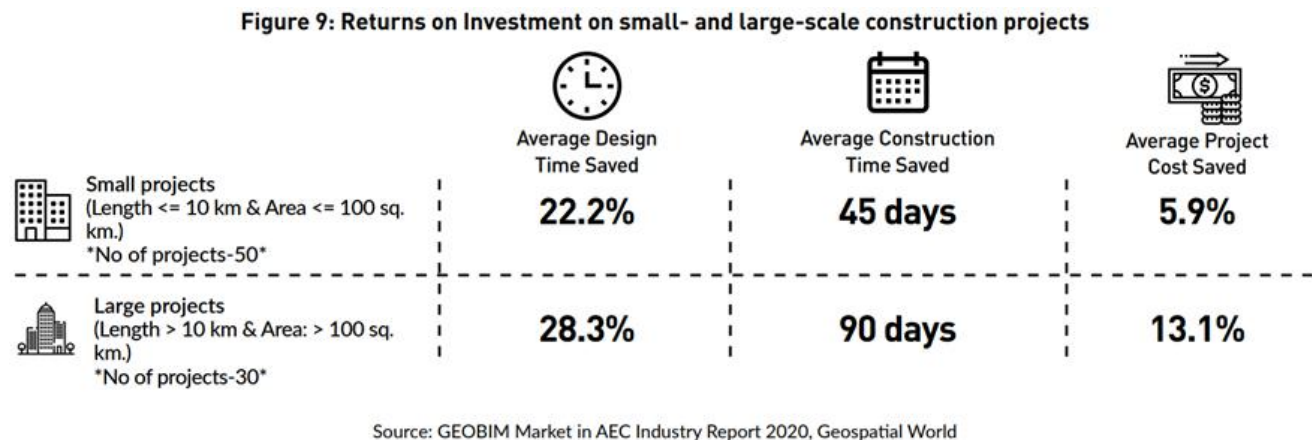


Figure 6: Returns on Investment on Small and Large-Scale Construction projects from “GIS and BIM Integration: A High Level Global Report” (Autodesk and Esri 2022, 25).

## 5.2 A Roadmap for Integration

A significant step towards integration was undertaken by a joint working group formed by buildingSMART International (bSI) and the Open Geospatial Consortium (OGC). In 2024, the strategic roadmap: Enabling Information Continuity Across BIM-GIS Domains, was released, outlining specific actions to achieve the use of open standards in BIM and GIS data modelling and integration.

The primary objectives of the roadmap are:

- Solve impactful use cases that benefit from improved connection of BIM and GIS data.
- Provide standardized toolkits to advance use cases in real-world applications.
- Demonstrate the advantages of adopting open standards for data modelling and integration.
- Educate a new generation of data suppliers and users who are simultaneously adept at enterprise-scale BIM-GIS data and acutely aware of the use cases that demand continuity in information modelling.
- Engage the traditionally siloed BIM and GIS communities with a common purpose to foster a collaborative, harmonized, and consistent approach to information management across their ecosystems (bSI and OGC 2024, 3)

The roadmap outlines a series of activities required to achieve these objectives, unfolding over 4 years.

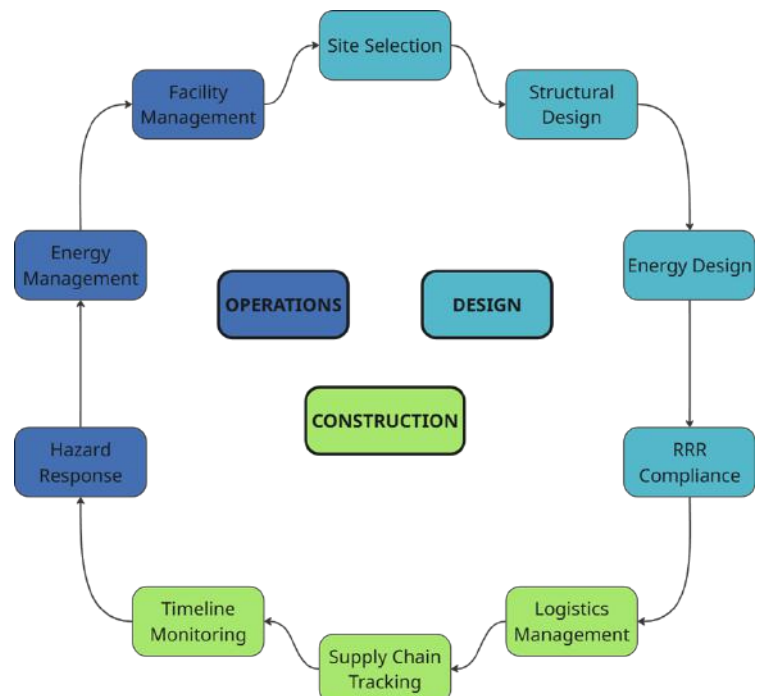


Figure 7: Geospatial data adds context to detailed IFC models of Carleton University CIMS' CDT open-source platform.

### 5.3 Opportunities for Integration

Opportunities for integrated BIM-GIS solutions exist throughout all stages of design, construction, and operation for regulatory agencies (Elsheikh et al. 2021, 3). Integration ensures that information is reused and updated consistently, improving efficiency and reducing redundancy. While this paper focuses on regulatory agencies, it is important to note that other stakeholders also benefit from these integrated solutions.

Figure 8: Project activities that can be improved by providing access to detailed building data alongside coarse city and landscape data. Sourced from "GIS and BIM Integration: A High Level Global Report" (Autodesk and Esri 2022, 32).

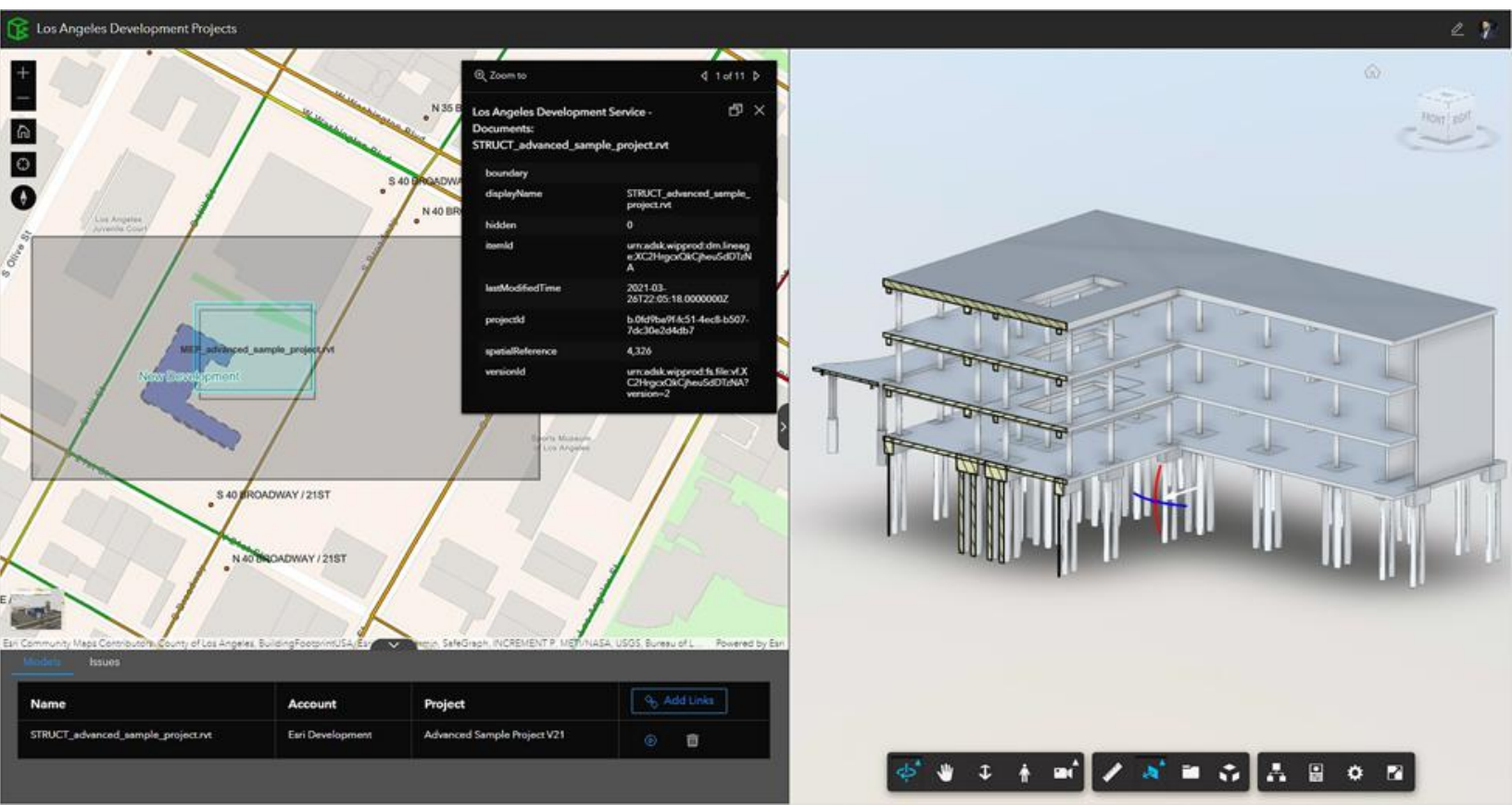


### 5.3.1 Design: Automating Permits and Approvals

The development approval process typically involves a thorough review of applications based on regulations, requirements, and recommendations. However, it is often lengthy and fraught with uncertainties, leading to increased costs and potentially unsatisfactory outcomes for regulatory agencies, developers, and communities (Altus Group Economic Consulting 2022, 41).

When BIM and GIS data are not integrated, the information is often fragmented, leading to multiple versions of data and additional time spent gathering resources. However, integration enhances the approval process in several key ways. By situating a digital asset within its real-world context, it provides a more comprehensive understanding of the proposed development and its potential impact. It also ensures that a centralized, reliable source of information is available, significantly reducing the time that regulatory agencies spend processing applications. Additionally, integrated BIM-GIS information enables agencies to provide applicants with clear and detailed feedback, offering the reasoning behind application decisions. With this feedback, applicants can make more informed revisions to their submissions. Furthermore, BIM-GIS integration supports the creation of accurate 3D city models, offering a visual, digital alternative to traditional 2D verification processes.

Figure. 9: Connecting Autodesk Construction Cloud (ACC) with Esri ArcGIS combines project information with geospatial context for improved design review, visualization, and exploration (“BIM and GIS Cloud Collaboration,” n.d.).



Ultimately, integrated BIM-GIS data helps decision-makers in planning and regulatory compliance to:

- Assess what and where improvements are needed
- Provide clear, actionable feedback to applicants
- Identify potential coordination issues
- Ensure compliance with codes, bylaws, and legislation

The integration of BIM and GIS data also creates opportunities for automation in the application verification process, provided the data is consistently characterized (Noardo et al. 2020, 227). For instance, clash detection can identify whether a BIM model intersects with a bounding box representing GIS-based zoning regulations (Trebbi et al. 2019, 119-120). To avoid data misrepresentation, regulations must be clearly defined; however, not all regulations are suitable for automated verification. While regulations can be quantitative, visual, or qualitative, quantitative regulations are best suited for automatic rule-checking when formatted in a machine-readable format (Olsson et al. 2018, 2). By standardizing integrated data to ensure consistency, automatic compliance verification can be implemented, which reduces processing times and enhances objectivity (Noardo et al. 2020, 210). Figure 10 illustrates an automated verification process.

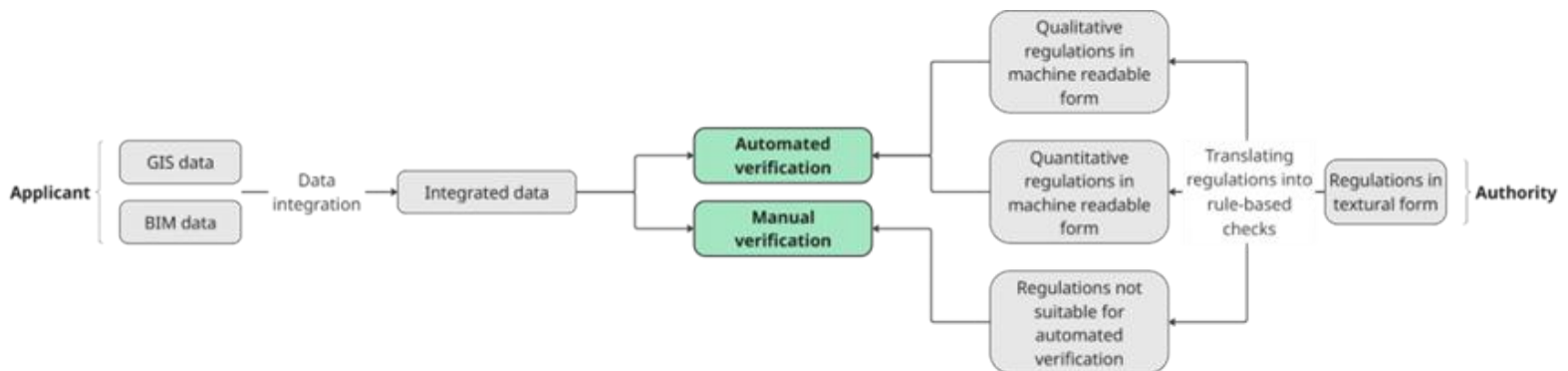


Figure 10: The authority and applicant must both provide consistently formatted inputs for automatic rule checking to be available (Olsson et al. 2018, 3).

### 5.3.2 Construction: Tracking Project Deliverables

The integration of building-scale information from BIM and city-scale spatial data from GIS provides both macro and micro perspectives that benefit design and on-site teams during the construction phase. Integrated data allows contractors and subcontractors to make more informed decisions, saving time and money (Autodesk and Esri 2022, 27). Ultimately, integrated BIM-GIS data supports construction teams by streamlining key applications throughout the building process.

These applications include:

- Progress tracking: Monitoring project milestones and ensuring timelines are met.
- Error identification: Detecting and resolving issues early to minimize delays and costs.
- Monitoring equipment and materials: Managing resources effectively to prevent shortages or misallocation.
- Detour and navigation routing: Optimizing on-site movement and addressing disruptions to improve efficiency (Noardo et al. 2020, 211).



Figure 11: ACCA's usBIM.geotwin supports the use of openBIM, geolocalised and integrated with GIS, to assess the spatial and territorial implications of design decisions, improve collaboration and coordination between multidisciplinary design teams, track progress, and manage issues ("ACCA Software," n.d.).

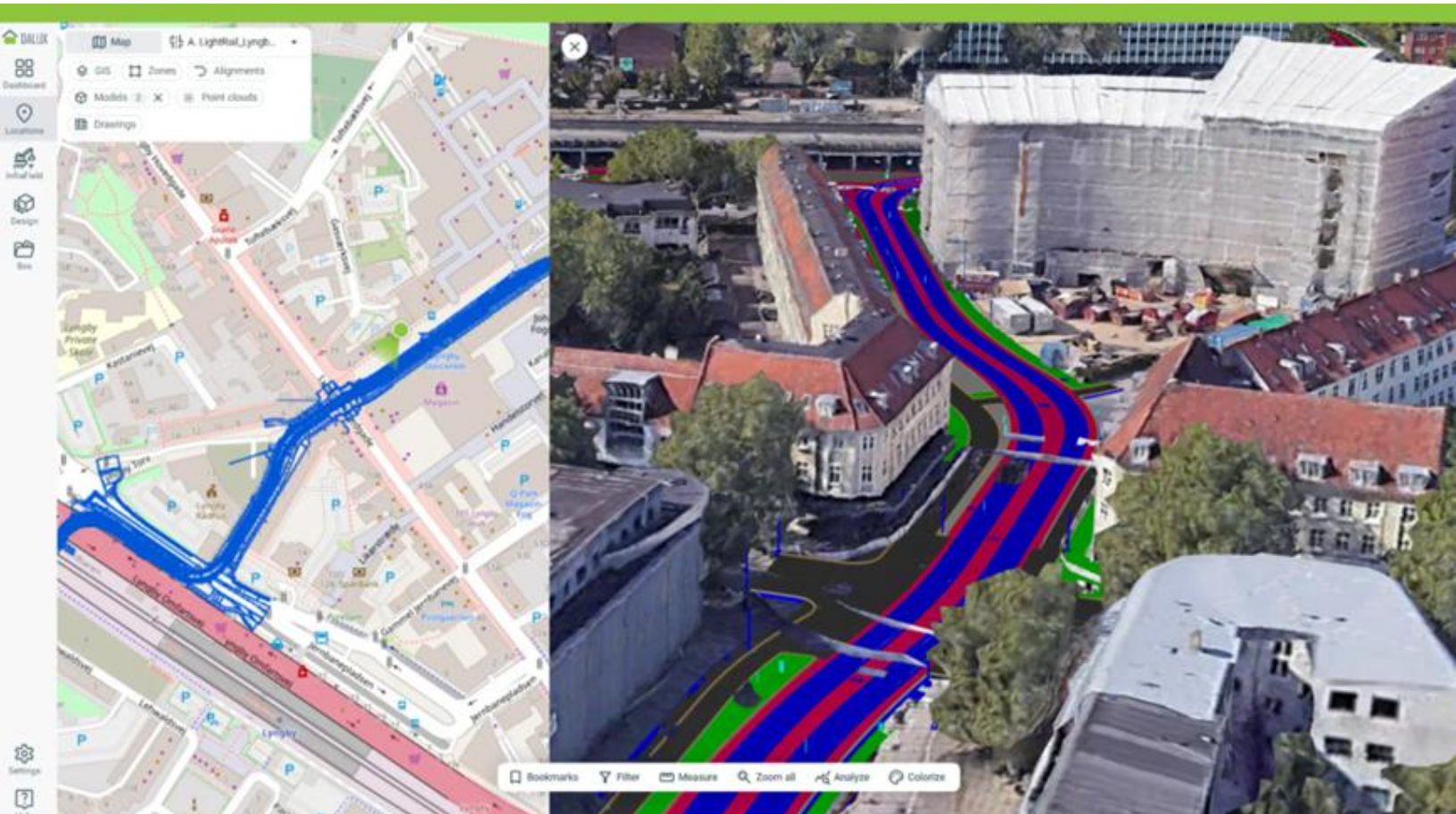
### 5.3.3 Urban Planning

Access to past, present, and future information is crucial for holistic urban planning and decision-making. While GIS is a long-established tool for urban planning and data management (Zhu, Wu, and Anumba 2021, 1), BIM-based approaches remain less widespread. In Canada, there are individual initiatives involving BIM, but they risk becoming fragmented and case-specific without a cohesive framework at the national, provincial, or municipal level (Tahrani et al. 2015, 9). By contrast, countries such as the United Kingdom (UK), the United States of America (USA), the United Arab Emirates (UAE), Finland, and Denmark have mandated the use of BIM for public works to improve project delivery and asset management (Tahrani et al. 2015, 5; Zhu, Wu, and Anumba 2021, 1).

Urban planners face the challenge of managing an ever-expanding portfolio of natural and built assets, increasing in size, complexity, and interdependence. Effective decision-making requires the ability to analyze places and their relationships, but insufficient or isolated information often limits this process (Elsheikh et al. 2021, 2). GIS provides essential topological analysis for large-scale data such as utility networks, transportation pathways, and waterways, helping to identify patterns, trends, and location-based solutions (Elsheikh et al. 2021, 2). Meanwhile, BIM offers detailed and realistic 3D models of both new and existing assets, complementing the large-scale representations provided by GIS (Zhu, Wu, and Anumba 2021, 1).

The integration of BIM and GIS allows urban planners to better understand the impact of various initiatives on cities as a whole. By georeferencing 3D assets and incorporating them into an integrated city model, planners can retain valuable BIM information beyond the design and construction phases, ensuring its utility throughout the lifecycle of the asset.

*Figure 12: Dalux's InfraField allows a project to be placed within its geospatial context, helping to communicate the project design and how it affects the surrounding environment ("Dalux," n.d.).*



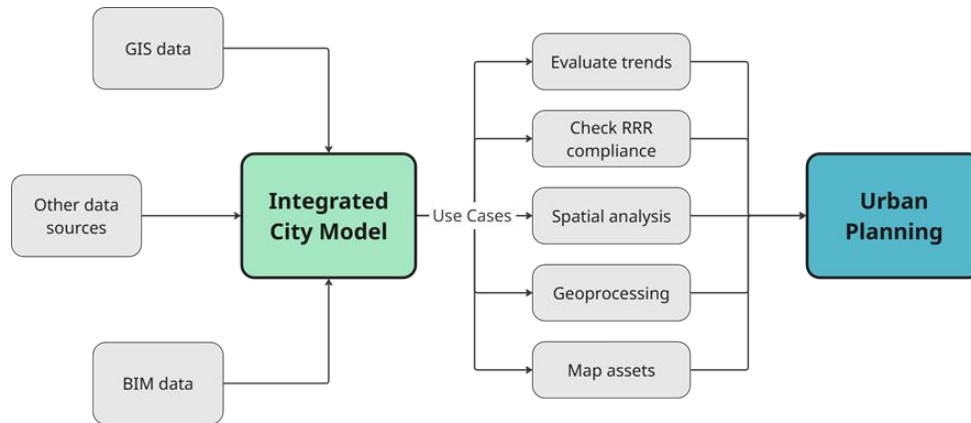


Figure 13: The integration of BIM and GIS data alongside additional data sources provides a comprehensive perspective of the past, existing, and future environment to support urban planning applications.

## 5.4 Critical Challenges

While leveraging integrated BIM and GIS information offers significant advantages for both small and large-scale projects, the process of integrating these technologies presents notable challenges. These technologies were developed independently for different industries and are at varying stages of implementation and maturity (Autodesk and Esri 2022, 35). As a result, both technical and conceptual barriers complicate efforts to harmonize the two domains. Addressing these challenges is essential for creating cohesive and integrated workflows. Table 5 summarizes the differences in characteristics of BIM and GIS that add complexity to developing integrated solutions. IFC and CityGML will be the focus for the following discussion of critical challenges, as they are widely used open standards that represent their respective domains (Yelin and Ilal 2021, 2).

|                                         | 3D City Models                                            | BIM                                                                |
|-----------------------------------------|-----------------------------------------------------------|--------------------------------------------------------------------|
| <i>Geometry</i>                         | mainly boundary representation (explicit)                 | mainly parametrically modelled solids (implicit)                   |
| <i>Main data source</i>                 | survey of real world objects                              | design                                                             |
| <i>Approximate range of detail (d)</i>  | $1000 > d > 0.1$ m                                        | $50 > d > 0.001$ m                                                 |
| <i>Semantics</i>                        | aimed at the description of city/landscape representation | aimed at the description of small building elements representation |
| <i>Georeferencing</i>                   | compulsory                                                | optional                                                           |
| <i>Supported analysis and decisions</i> | city-level                                                | building-level                                                     |
| <i>Evolution of</i>                     | Geographical Information Systems (GIS)                    | Computer-Aided Design (CAD)                                        |
| <i>Dominated by</i>                     | government                                                | industry                                                           |

Table 5: Key differences between GIS-based 3D city models and BIM data as identified in “Tools for BIM-GIS Integration (IFC Georeferencing and Conversions): Results from the GeoBIM Benchmark 2019” (Noardo et al. 2020, 3).



6.0

# TECHNICAL CHALLENGES

## 6.1 Standardization of Information Requirements

Effective large-scale analysis at municipal and regional levels using BIM and GIS relies on having accurate, consistent, and standardized information across datasets. To achieve this, regulatory agencies must standardize and minimize ambiguity in the rights, restrictions and responsibilities (RRR) applied during the verification and analysis of incoming data. However, the inconsistent application of existing standards creates significant challenges for regulatory clarity (Noardo et al. 2020, 211).

Adopting a unified set of BIM and GIS standards tailored to the Canadian AECOOM industries, will foster consistency across projects and enable regulatory agencies to establish clear information requirements. Without a standardized structure, regulatory submissions often vary, requiring manual interpretation and hindering automation. Just as permit forms mandate a minimum set of information for each project, specifications are essential for the seamless integration of building and geospatial information.

To further enable automation, the RRRs for checking submissions must be structured to eliminate ambiguity. These criteria can be divided into three categories: quantitative, visual, and qualitative (Olsson et al. 2018, 2). Quantitative criteria, such as maximum building height, lot coverage, and setback distances, are well-suited for automated rule-checking due to their pass-fail nature. Visual criteria, such as the spatial configuration of units within a lot, and qualitative criteria, such as maintaining the character of an area based on tangible and intangible values, are less easily automated. However, situating models in their real-world contexts can assist with compliance checks that are difficult to automate.

Uniformly defining quantitative RRRs is essential to ensure calculations can be applied consistently across assets with minimal manual intervention. However, existing IFC and CityGML standards cannot supply information because they do not currently support such fields. For example, common RRR concepts such as “block, parcel, setback distance, garden, slope, land use, roads, streets and topological relationships between geometric entities” do not exist as IFC attributes (Yelin and Ilal 2021, 1). Similarly, CityGML lacks attributes that define the orientation of a lot and cannot differentiate between the front yard, exterior side yard, interior side yard, and rear yard (Yelin and Ilal 2021, 1). Identifying and reporting these gaps is crucial to enabling the evolution of these standards and ensuring that they better meet the needs of regulatory users.

## 6.2 IFC and CityGML Object Conceptualization and Semantics

The fundamental differences between the conceptual languages and structures underlying IFC and CityGML specifications also pose challenges for integration. These differences significantly affect their interoperability and integration.

IFC is based on the EXPRESS language as defined by ISO 10303-11 standards. EXPRESS is designed to define complex data models in the engineering and construction industries through textual and graphical methods. It allows for the specification of classes within a domain, along with their attributes and constraints. EXPRESS also describes relations between classes and numerical constraints (The EXPRESS Definition Language for IFC Development 2019, 1). Figure 14 is an example of the IFC structure in EXPRESS-G. EXPRESS-G is the graphical notation within the EXPRESS language (“Introducing the EXPRESS language family”, n.d.).

The CityGML Conceptual Model has eleven thematic modules including Building, Bridge, Tunnel, Construction, CityFurniture, CityObjectGroup, LandUse, Relief, Transportation, Vegetation, and WaterBody, as shown in Figure 15. The CityGML schema outlines five modules related to city object representation: Appearance, PointCloud, Generics, Versioning, and Dynamizer. These modules provide concepts for representing appearances, geometry, generic objects, relationships, concurrent versions, histories, time series data, and sensor integration for city objects (OGC, 2021, 26).

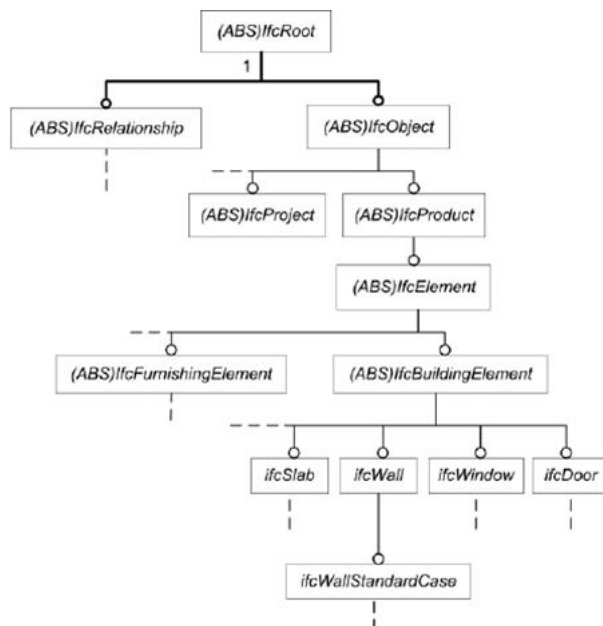


Figure 14: EXPRESS-G diagram (Dimyadi and Spearpoint 2008, 1330).

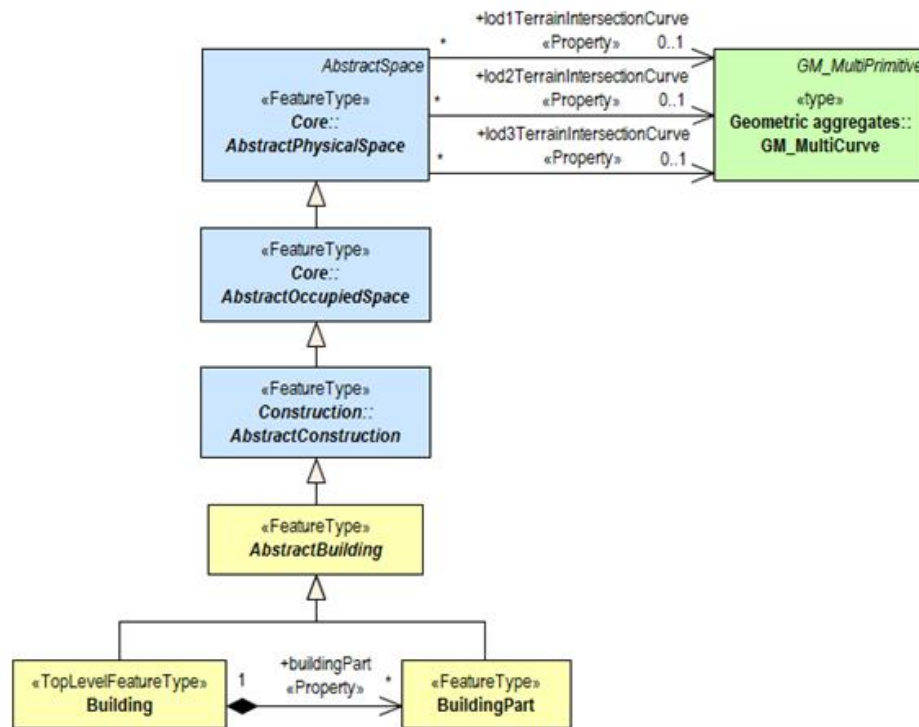


Figure 15: Example UML diagram used for the CityGM Standard (OGC, 2021).

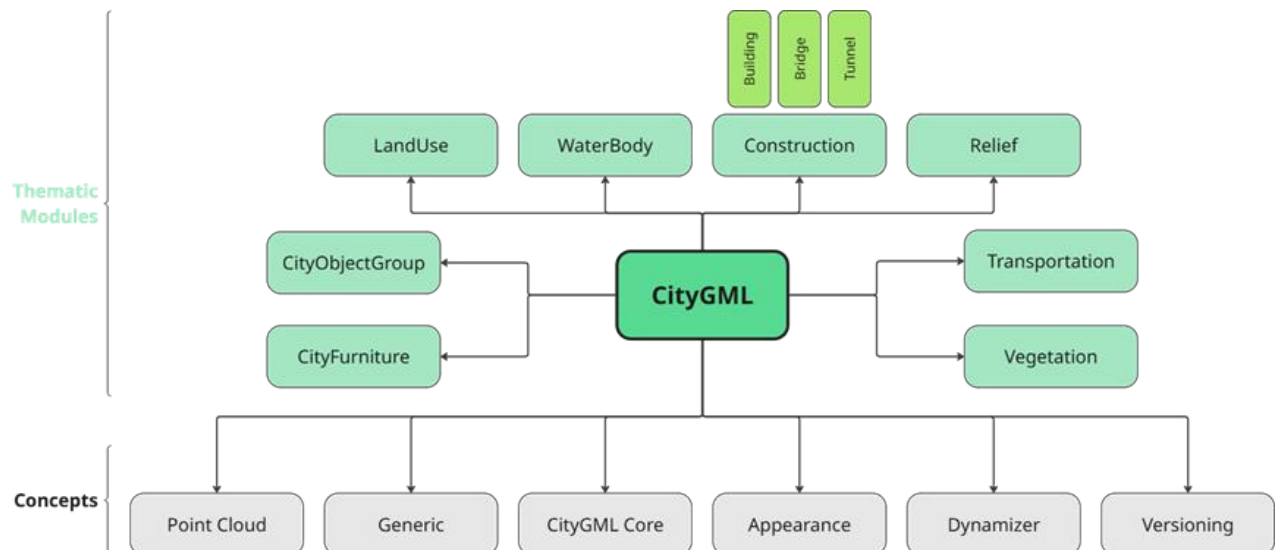


Figure 16: An overview of CityGML's thematic modules (OGC, 2021, 26).



The working principles and semantic modelling of objects are different in CityGML and IFC. Each schema has different thematic coverage with some overlap as shown in Figure 17. Figure 18 demonstrates how the conceptualization of the same physical object can differ across BIM and GIS standards. CityGML uses unique identifiers for each geographic feature, and feature types have spatial and non-spatial properties and relationships with other feature types. Features have multiple geometry objects representing different LoD or spatial abstractions (OGC, 2021, 27). CityGML uses different geometric representations such as spatial aggregates and composites. Volumetric shapes are represented according to ISO 19107 standards by following the boundary-representation (B-Rep) presentation (OGC, 2021, 29-30). CityGML identifies a clear semantic concept of the 'spaces' and 'space boundaries'. The boundaries are the ones that connect and limit the spaces. Therefore the semantic distinction of the space itself and how it is categorized differs from a traditional IFC model (OGC, 2021, 33).

CityGML conceptual models have LoD levels related to their geometry detail. The classification of real-world objects depends on the semantics of the object, since CityGML allows different levels of geometric representation for an object (OGC, 2021, 36). Differences in the conceptualization of identical real-world objects also demand subjective intervention to interpret any equivalence or similarity. For example, OccupiedSpace and UnoccupiedSpace change according to the LoD, which represents manual interpretations that may not be consistent throughout a project and take time to identify.

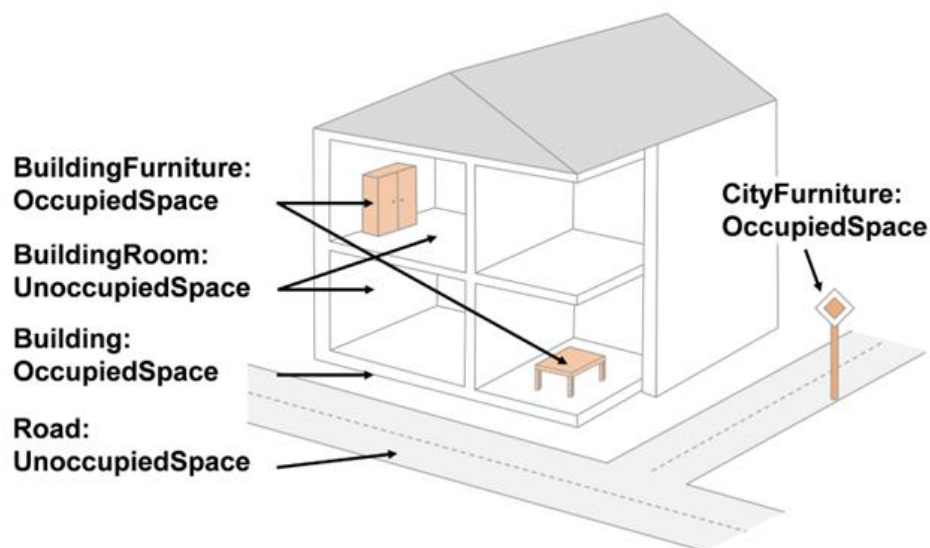


Figure 19: Occupied and unoccupied spaces: representation of a house (OGC, 2021, 34)

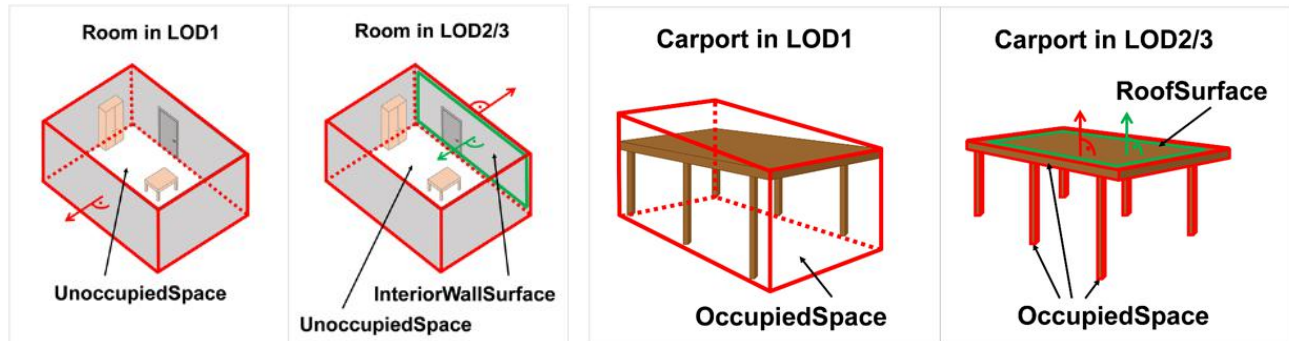


Figure 20: Representation of a room as Unoccupied Space and representation of a carport as OccupiedSpace in different LoDs (OGC, 2021, 55-54).

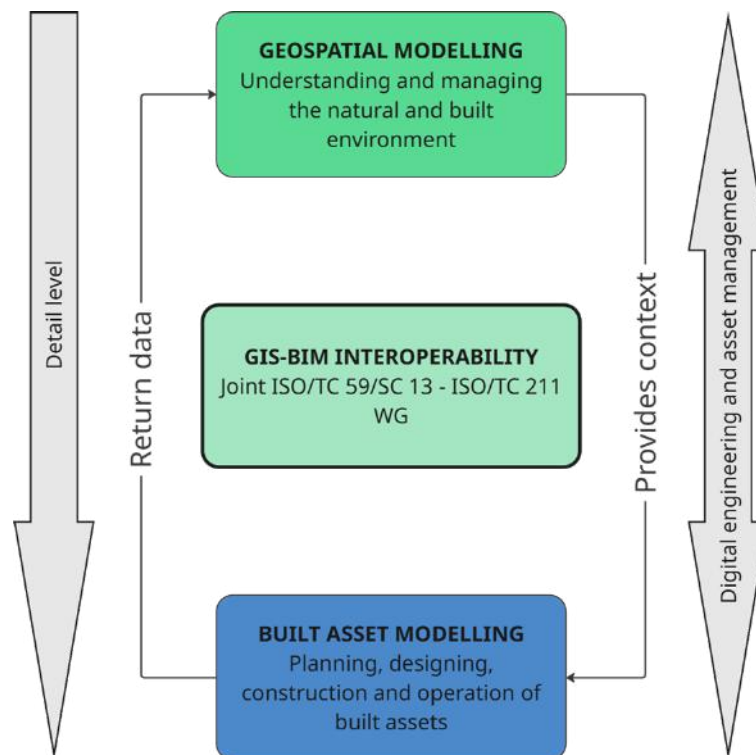


Figure 21: Cycle of information flow between geospatial and BIM domains (ISO/TR 23262, 2021, vi). Diagram adapted from ISO/TR 23262.

## 6.3 Geometric Representation

The geometric representation of entities differs significantly between BIM and GIS, reflecting the focus and scope of each domain. With advancements in computing and data acquisition, geospatial models are increasingly incorporating 3D features, and BIM models often include contextual elements (Ohori et al. 2018, 1). This convergence of BIM and GIS data has highlighted the differences in how each domain approaches geometric representation. CityGML is designed for spatial coverage and city-wide analyses, defining objects at a relatively coarse spatial resolution. In contrast, IFC represents building and infrastructure components at a fine scale, prioritizing detailed architectural and engineering design. These distinctions shape how each standard models geometry.

CityGML primarily employs Boundary Representation (B-Rep) (Gilbert et al. 2021, 9). IFC, however, supports multiple modelling techniques, including B-Rep, Constructive Solid Geometry (CSG), and Swept Solid (Olsson et al. 2018, 309). While B-Rep represents geometry as polygonal surfaces, IFC allows for both surface and solid modelling (Ohori et al. 2018, 3), enabling a higher level of detail in BIM.

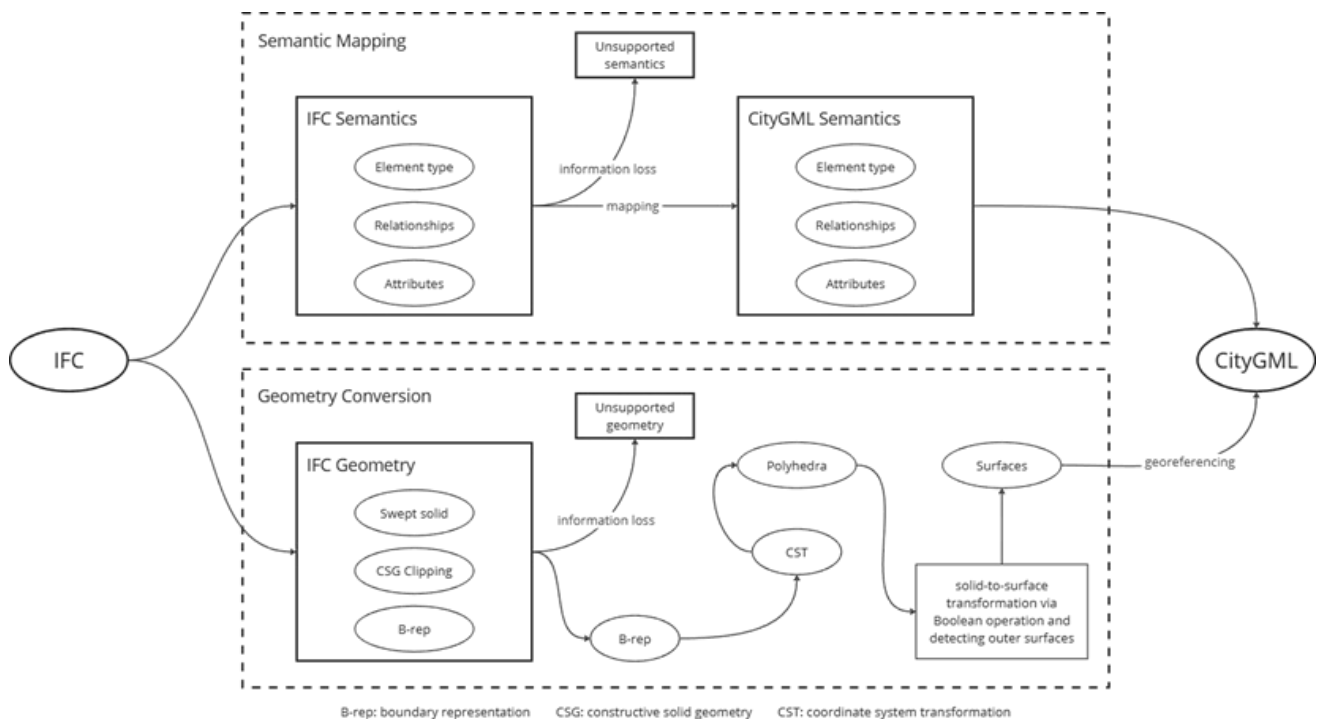


Figure 22: Converting from IFC to CityGML requires geometric and semantic mapping to transfer information. Figure from "A Semantics-Based Approach for Simplifying IFC Building Models to Facilitate the Use of BIM Models in GIS" (Zhu, Wu, and Anumba 2021, 4).

When integrating building and geospatial data, it is sometimes necessary to convert between IFC and CityGML for visualization or analysis. The variability in how an IFC can be modelled introduces challenges when developing a system that can handle the many ways IFC geometry can be expressed. Most conversions address the movement of information from fine IFC data to coarse CityGML data shown in Figure 22. Since IFC data is generally more suitable for a single or small number of buildings, the conversion process has its challenges resulting from the nature of the data formats. In that context, there

is also a higher likelihood of empty fields, as CityGML does not contain certain attributes typical in IFC.

While some data loss is unavoidable, minimizing it remains a priority in BIM-GIS integration. For instance, B-Rep's representation of curves as straight segments can lead to information loss when converting IFC geometry into a series of tangential lines in CityGML (Gilbert et al. 2021, 12). Addressing these limitations requires careful consideration of geometric and semantic mapping to preserve the integrity of spatial data.

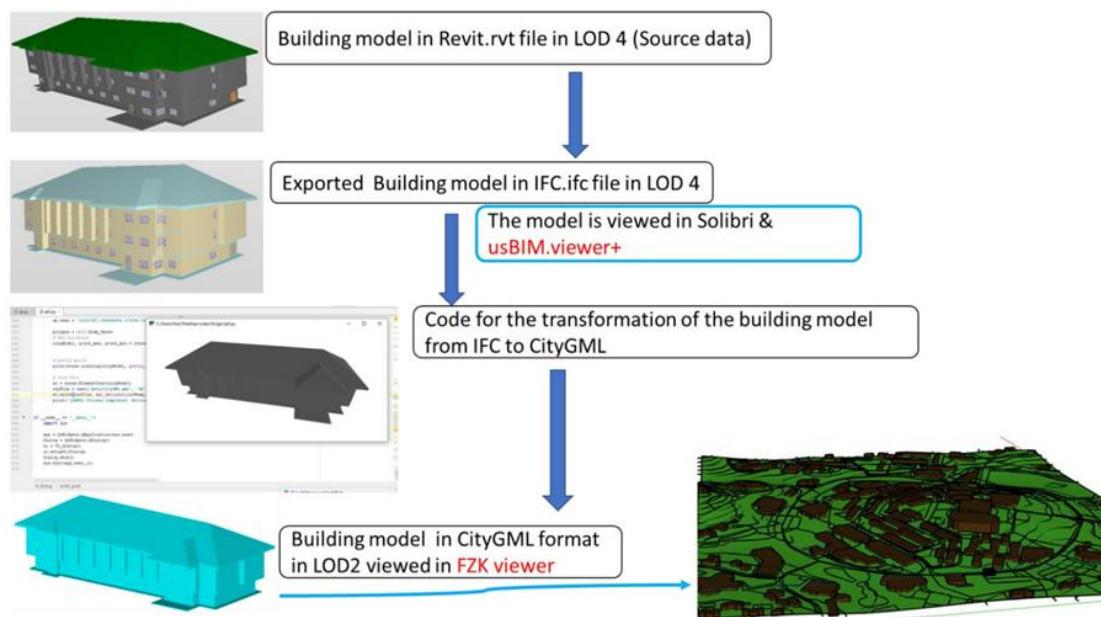


Figure 23: The results of a conversion of a developed BIM model produced in Revit to lower level of detail cityGML model (Jawaluddeen Sani, Amri Musliman, and Abdul Rahman 2022).

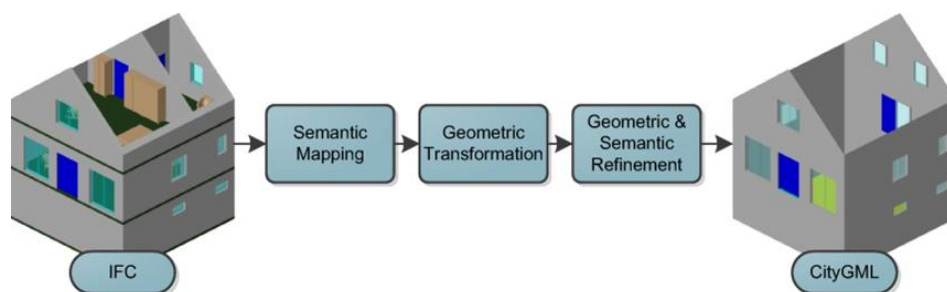


Figure 24: The conversion process developed by Donkers et al. to produce a useable LoD3 CityGML model. Note that this is based on the LoD specifications of CityGML 2.0 which did not include interior elements in LoD3. Figure from "Automatic conversion of IFC datasets to geometrically and semantically correct CityGML LOD3 buildings" (Donkers et al. 2016, 553).

Several studies have demonstrated the conversion of IFC to CityGML, for example: Hijazi, Ehlers, and Zlatanova 2010; Donkers et al. 2016; Ohori et al. 2018, and Stouffs, Tauscher, Biljecki 2018. Donkers et al. developed an automatic conversion algorithm that converted IFC semantics and the necessary geometries to create a CityGML LoD3 that is suitable for geoprocessing.

Earlier conversion approaches often processed all IFC geometries without considering the desired LoD, leading to CityGML models with valid but overlapping and disorganized geometries. This makes it difficult to apply geoprocessing functions for spatial analysis. Figure 24 illustrates the output-based workflow of Donkers et al.'s algorithm, which refines semantics and geometries to meet LoD3 specifications before constructing the final CityGML model. Since only the relevant geometry is created, the resulting model is much better organized and usable.

Building on this work, Stouffs, Tauscher, and Biljecki explored how to minimize unintentional data loss during conversion by implementing Application Domain Extensions (ADEs), a CityGML mechanism that extends the data model to accommodate information not natively supported. Using an ADE allows for the preservation of selected IFC data based on varying use cases (Stouffs, Tauscher, and Biljecki 2018, 11). These algorithms demonstrate that IFC and CityGML can be modified and aligned to better support defined information requirements, improving the interoperability between BIM and GIS.

| IFC                                                                                                                                                                                                                                               | CityGML                                                                                                                                                                                                                                                                                                                    |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Prepare the IFC model so that there are valid volumetric objects, no self-intersecting geometries, and no gaps within enclosed spaces (Ohori et al. 2018, 323). Define additional semantics to the IFC standard (Biljecki et al. 2021, 9).</p> | <p>Provide further specifications to prescribe a common method for the modelling of 3D objects and stricter definitions for the boundary of features (Donkers et al. 2016, 566). Determine if cases are best aided by multiple tailored ADEs or a single comprehensive ADE (Stouffs, Tauscher, and Biljecki 2018, 14).</p> |

Recent revisions to CityGML have incorporated several of these recommendations. In earlier versions, volumetric objects in IFC were typically represented as separate features for interior and exterior boundary surfaces. However, CityGML 3.0 introduced new constructive element classes, enabling the direct mapping of volumetric objects from IFC to CityGML. This enhancement significantly improves the compatibility and representation of volumetric data between the two standards (Kutzner, Chaturvedi, and Kolbe 2020, 50).



## 6.4 Georeferencing and Unique Real-World Identifiers

GIS data inherently connects information to real-world locations using a variety of coordinate reference systems (CRS), tailored to the location and required level of accuracy. In contrast, BIM data predominantly uses local coordinate systems with relative positioning between elements. Only with the introduction of IFC4 has georeferencing been associated with BIM elements. Even then, reference coordinate points or predefined project base points are frequently defined as 0,0,0 in practice, limiting their real-world applicability.

For seamless integration and analysis at both micro- and macro-scales, geometric and geographic representations in BIM and GIS must be accurate and consistent. Real-world positioning is critical for resolving spatial relationships, identifying collisions, and minimizing contradictions. However, inconsistencies in geolocating objects complicate comparisons between BIM and GIS datasets. To address this, regulatory agencies must collaborate with GIS professionals to develop clear guidelines for georeferencing BIM data (Gilbert et al., 2021, 12). For example, reference coordinate points or geolocated base points should be linked to real-time geographic coordination points prior to exporting IFC files.

Currently, there are two key approaches for BIM-GIS integration. The first relies on the proprietary formats and technologies of commercial software, such as Revit and ArcGIS, which provide direct export options. The second emphasizes the versatility of open-source software and open standards like IFC and CityGML (Colucci et al., 2020, 4). While commercial tools streamline integration, open-source workflows often require additional conversion steps. For instance, a Revit file might be exported as an IFC, then converted to a GML format compatible with QGIS.

The first step in integrating BIM and GIS involves preparing the IFC file for export. When IFC files are converted to GML and exported to QGIS, certain non-geometric data—such as year of construction and postal code—are transferred. However, geometric details like dimensions or material properties are often lost during the conversion process. The second step is to match the units used in BIM with those used in GIS. BIM documents are vector-based, but when exported into a GIS system the units may need to be adjusted. Map units in GIS are typically constructed using metric or imperial units, such as meters or inches.

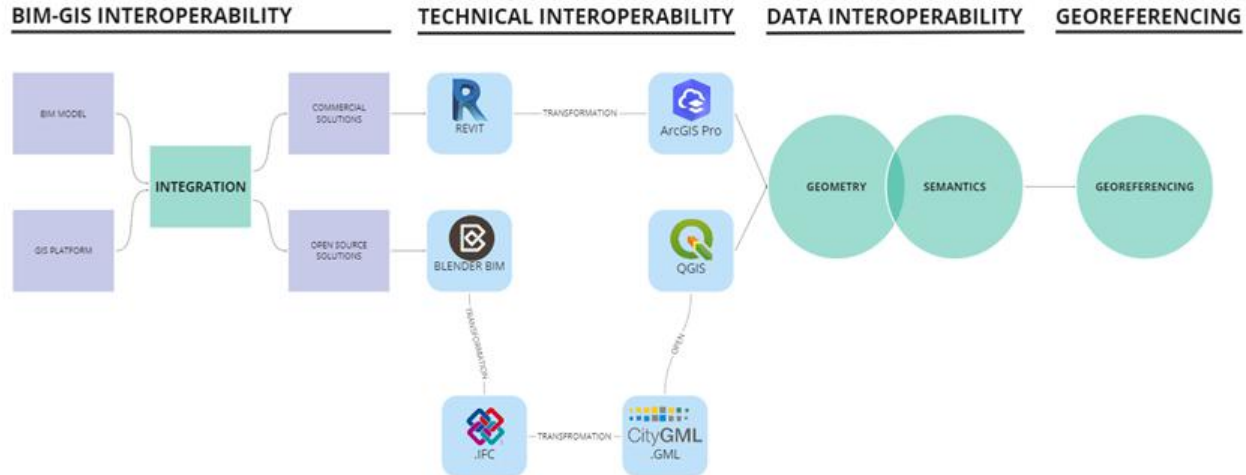


Figure 25: Methodological Framework of BIM-GIS integration adapted from “HBIM-GIS Integration: From IFC to CityGML Standard for Damaged Cultural Heritage in a Multiscale 3D GIS” (Colucci et al. 2020, 11).

Current literature puts forward different methods for georeferencing BIM objects. One approach is to work with predefined project base points or surveyed coordinates with spatial projections. When BIM files contain a project file extension (.PRJ) that requires spatial projections, they must be in the UTM-WGS84 format and include latitude information such as 33N, 35S (Diakite 2018, 2; Colucci et al. 2020, 11). Inconsistencies in the accuracy and method of georeferencing objects must also be reduced. For example, the first method of georeferencing a file using the local coordinate system is to work with the existing connected files. Although the system is intrinsically accurate, issues may arise when the file is connected to others in a city-scale context. Alternatively, a point within the BIM model can be manually matched to GIS map coordinates. However, the lack of standardized conventions for identifying real-world objects increases the risk of errors during manual adjustments, requiring operators to rely on judgment (Diakite 2018, 3; Ellul 2019, 15).

For successful integration, consistent georeferencing must be applied to BIM data to link shared points across datasets. Table 6 highlights different georeferencing approaches, ranging from approximate locations via postal addresses (LoGeoRef10) to highly accurate geolocations using specific CRSs (LoGeoRef50). When georeferencing is taken into account for BIM, a postal address (LoGeoRef10) is the most common way of incorporating a real-world location (Noardo et al. 2020, 6).

```
<Building gml:id="Building0815">
  <gml:name>My nice building</gml:name>
  <externalReference>
    <informationSystem>http://www.adv-online.de</informationSystem>
    <externalObject>
      <uri>urn:adv:oid:DEHE123400007001</uri>
    </externalObject>
  </externalReference>
  <function>1012</function>
  <yearOfConstruction>1985</yearOfConstruction>
  <roofType>3100</roofType>
  <measuredHeight uom="m">8.0</measuredHeight>
  <lod2Solid>
```

Figure 26: A simple Building in CityGML (Kolbe 2007, 36).

**Table 6: Georeferencing approaches ranging from LoGeoRef10 to LoGeoRef20. Table from Tools for BIM-GIS Integration (IFC Georeferencing and Conversions): Results from the GeoBIM Benchmark 2019 (Noardo et al. 2020, 6).**

| LoGeoRef   | Supported CRS                                                                      | Storing Entities                                                                                                                                                                                                                                                                                                                                          |
|------------|------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| LoGeoRef10 | No CRS, approximate location by address.                                           | IfcPostalAddress referenced by either IfcSite or IfcBuilding.                                                                                                                                                                                                                                                                                             |
| LoGeoRef20 | WGS84 EPSG:4326                                                                    | Attributes RefLatitude, RefLongitude, RefElevation within IfcSite.                                                                                                                                                                                                                                                                                        |
| LoGeoRef30 | Any Cartesian CRS, including projected coordinates (CRS not specified in the file) | IfcCartesianPoint referenced within IfcSite (defining the projected coordinates of the model reference point); IfcDirection attribute of IfcSite (stores rotations regarding project or global north. (Ad-hoc solution used by several tools.)                                                                                                            |
| LoGeoRef40 | Any Cartesian CRS, including projected coordinates (CRS not specified in the file) | Attribute WorldCoordinateSystem storing the coordinates of the reference point in any Cartesian CRS (including the projected ones) and direction TrueNorth. Both are stored within IfcGeometricRepresentationContext.                                                                                                                                     |
| LoGeoRef50 | Specific projected CRS, specified by means of the EPSG code                        | In IFC4 coordinates of the reference point are stored in IfcMapConversion using the attributes Eastings, Northings and OrthogonalHeight for global elevation. Rotation for the XY-plane stored using the attributes XAxisAbscissa and XAxisOrdinate. The CRS used is specified by IfcProjectedCRS in the attribute Name by means of the proper EPSG code. |

## 6.5 Common Data Environments (CDEs)

BIM relies on a common data environment (CDE) to facilitate collaborative workflows, enabling multiple users to work simultaneously on a single model. As defined by ISO 19650, a CDE is defined as an “agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process” (ISO 19650-1:2018, 5). Changes made by individual users are periodically synchronized with the central file, ensuring that updates are accessible to all team members. This centralized approach eliminates the need for separate copies of the model for each user. According to ISO/TR 23262 (2021, 18), the advantages of a CDE include reduced time and cost, improved traceability of information deliveries and responsibilities, and the unique identification of intellectual property.

A CDE serves as a foundational tool for BIM-GIS integration, offering significant potential to optimize asset management operations and enhance data management capabilities. Integrating geospatial data with detailed asset information benefits government, public, and private entities by improving workflows and enabling a more comprehensive understanding of the urban environment. Such an integrated platform can facilitate interdepartmental communication and provide a user-friendly interface for visualizing urban data (Huang, Yen, and Shiha 2021, 294).

Web-based CDEs are particularly appealing as they connect dynamic and static data sources, creating customized representations for analysis and visualization (Gilbert et al. 2021, 13). These platforms are often expressed through 3D GIS interfaces, as seen in city initiatives such as New York’s ZoLa, Singapore’s URA Space 2.0, and London’s Datastore (Huang, Yen, and Shiha 2021, 293). The next step in advancing these platforms is the integration of BIM data, which has the potential to transform them into effective tools for city management by leveraging all available data.

## 6.6 Interoperability

Interoperability—the ability of systems to communicate and exchange data without requiring specialized knowledge—can be achieved through information exchange or unified access methods. It operates at three levels: data, syntactic, and semantic (Hbeich and Roxin 2019, 29). Data interoperability addresses hardware and software components, syntactic interoperability focuses on the structure of shared messages, and semantic interoperability ensures consistency in the meaning of exchanged messages (Hbeich and Roxin 2019, 29). ISO 11354-1:2011 ‘Advanced automation technologies and their applications — Requirements for establishing manufacturing enterprise process interoperability’ outlines three semantic interoperability approaches: integrated, unified, and federated. Among these, the federated approach is particularly effective, as it allows multiple schemas to coexist without requiring one party to impose their models, languages, or strategies on others as seen in Figure 27.

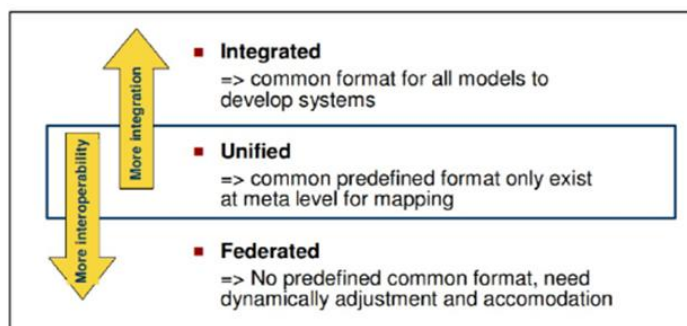


Figure 27: Standard approaches to achieve interoperability (Métral et al. 2010; Hbeich, Roxin, and Bus 2019, 47).

The federated approach is often used in situations where two or more entities rely on different vocabularies or methodologies. In these cases, mappings are established between the input and output data of the entities involved (Hbeich and Roxin 2019, 30). Federation can make use of a CDE to avoid the conversion of one schema to another which would require extensive mapping to transfer data (Gilbert et al. 2021, 13). However, challenges arise due to the complexity of aligning conflicting conceptualizations, especially when integrating BIM data into 3D GIS platforms.

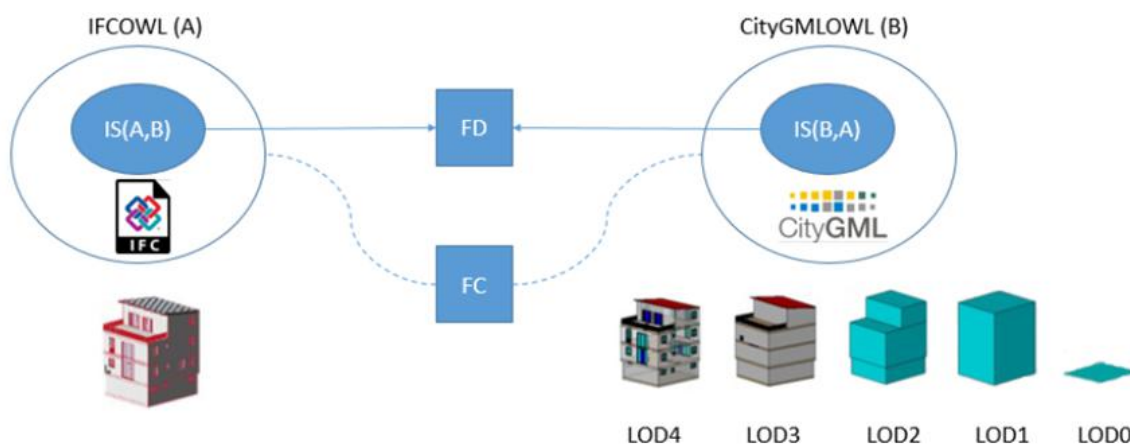


Figure 28: Federated conceptual approach (Hbeich and Roxin, 2019, 34).

Differences in BIM and GIS—such as variations in coordinate systems, spatial referencing, temporal aspects, and semantic vocabularies—create challenges for interoperability. Achieving full interoperability requires establishing semantic links to map the entities and properties of each domain to their equivalents in the other.

Interoperability involves not only data conversion but also the consideration of varying scales and levels of detail, shifting from an architectural to an urban context (Biljecki et al. 2021, 2). The default attributes of IFC and CityGML may not capture all necessary information types. CityGML developers have addressed this by introducing two techniques: generic objects and attributes, and the Application Domain Extension (ADE) mechanism. ADE enriches CityGML's data model by integrating new feature classes and attributes while maintaining its semantic structure (Biljecki, Kumar, and Nagel 2018, 1). Users can build customized, case-specific object types that can be specified with an XML schema definition file or with UML. OGC's best practice guideline "modelling an application domain extension of CityGML in UML" provides detailed instructions for creating an ADE for different purposes to enhance the compatibility and interoperability between different applications (Biljecki, Kumar, and Nagel 2018, 2).

ADEs comprise two groups: the first group supports applications; the second group is generic, without a specific intention to preserve the context of the IFC during the conversion process (Biljecki, Kumar, and Nagel 2018, 5). There are 44 identified ADEs worldwide<sup>[1]</sup>, responding to different aspects of built data management such as energy efficiency, land registry and urban planning. In addition, ADEs have the potential to optimize BIM-GIS

interoperability by providing a specialized framework with a specified framework between two different systems. ADEs also define domain-specific data models and workflows by allowing different geometries, and attribute tables that enhance federated interoperability. They also provide data exchange, data consistency and enhanced analysis capabilities.

A notable example is the CityGML Land Administration Domain Model (LADM) ADE. This extension of CityGML facilitates the representation and management of land administration information (Rönsdorf, Wilson, and Stoter 2014, 320; Lemmen, van Oosterom, and Bennett 2015, 536). The ISO 19152:2012 Land Administration Domain Model (LADM) is an international standard designed to formalize people-land relationships (Lemmen, van Oosterom, and Bennett 2015, 536). While the LADM provides a standardized schema to promote interoperability, it does not function as a data product specification.

Together, the CityGML and LADM ADE standards enable effective communication among diverse stakeholders, including information managers, professionals, and researchers, at national or provincial levels (Lemmen, van Oosterom, and Bennett 2015, 535). In addition to physical and spatial information, land administration data may encompass a wide range of details, such as real and personal property, formal and informal information, various levels of detail, and Indigenous or informal rights (Lemmen, van Oosterom, and Bennett 2015, 538).

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[1] A complete list of ADEs is located in Appendix A.



7.0

# CONCLUSION



The integration of BIM and GIS data can significantly transform how the built and natural environments are represented, analyzed, and managed, offering transformative potential for streamlining regulatory applications. BIM provides detailed, asset-specific information, while GIS offers the geospatial context needed to assess broader environmental, social, and urban impacts. By combining these technologies, regulatory agencies and applicants can address the increasing scale and complexity of projects with greater precision and insight.

This integration empowers regulatory agencies to enhance their review, permitting, and compliance processes with improved accuracy, efficiency, and transparency. At the same time, it equips applicants with the tools to navigate regulatory requirements more effectively. Regulatory agencies benefit the most from integrated solutions in the design and asset management stages. In the design stage, BIM-GIS integration supports the efficient review of regulations, requirements, and recommendations, providing applicants with detailed compliance feedback to inform revisions. In asset management, integrated solutions enable agencies to uncover new insights, identify issues, and develop planning strategies using the most comprehensive and up-to-date information available.

**Key benefits of BIM-GIS integration include an enhanced ability to consider environmental and social impacts, expedite development approvals and permits, improve issue tracking and clash detection, increase client satisfaction, and support informed planning strategies. Achieving these outcomes will require standardizing information requirements, reconciling differences in semantics and conceptualization, enabling diverse geometric representations, and implementing consistent georeferencing practices. Existing literature on BIM and GIS standards also highlights the need for future revisions that prioritize integration. ISO/TR 23262:2021 outlines actionable steps to achieve interoperability, the highest level of coordination between BIM and GIS. Complementary frameworks such as ISO 19152:2012, as well as tools like Application Domain Extensions (ADEs) and Common Data Environments (CDEs), offer solutions for bridging differences in semantics, georeferencing, and data structures. These frameworks foster federated collaboration across disciplines and provide a foundation for advancing BIM-GIS integration.**

Moving beyond basic data integration toward interoperability will involve developing a unified platform that allows simultaneous access to both BIM and GIS data. This shift will enable regulatory agencies to automate permitting validations, enhance data analysis and visualization, and plan for resilient and sustainable communities.



# APPENDIX

The following appendix includes a list of identified ADE from CityGML Application Domain Extension (ADE): overview of developments (Biljecki, Kumar, and Nagel, 2018, 6).

|    | ADE                             | Purpose     | XML Scheme  | UML | Origin      |        |
|----|---------------------------------|-------------|-------------|-----|-------------|--------|
| 1  | Energy ADE                      | Application | X           | X   | Europe      |        |
| 2  | Energy Efficiency ADE           | Application | X           | X   | Italy       |        |
| 3  | Energy Efficiency ADE (ii)      | Application |             | X   | Spain       |        |
| 4  | Noise ADE                       | Application | X           | X   | Germany     |        |
| 5  | Extended Noise ADE              | Application |             | X   | Netherlands |        |
| 6  | Road Traffic Noise ADE          | Application | X           | X   | India       |        |
| 7  | Robotics ADE                    | Application | X           | X   | Japan       |        |
| 8  | UtilityNetworkADE               | Application | X           | X   | Germany     |        |
| 9  | CAFM ADE                        | Application | X           | X   | Germany     |        |
| 10 | Immovable Property Taxation ADE | Application | X           | X   | Turkey      |        |
| 11 | Cadastre ADE                    | Application | X           |     | Netherlands |        |
| 12 | CityGML-LADM ADE                | Application |             | X   | Mixed       |        |
| 13 | Cultural Heritage ADE           | Application |             | X   | Spain       |        |
| 14 | Cultural Heritage ADE (ii)      | Application | X           | X   | Italy       |        |
| 15 | Cultural Heritage ADE (iii)     | Application | X           | X   | Italy       |        |
| 16 | Heritage house ADE              | Application |             |     | Malaysia    |        |
| 17 | Intervention ADE                | Application |             | X   | Spain       |        |
| 18 | BCH Management ADE              | Application |             |     | Belgium     |        |
| 19 | Indoor N&P ADE                  | Application |             | X   | India       |        |
| 20 |                                 | Indoor ADE  | Application | X   | X           | Korea  |
| 21 |                                 | i-SCOPE     | Application |     |             | Europe |

|    |  | ADE                    | Purpose     | XML Scheme | UML | Origin      |
|----|--|------------------------|-------------|------------|-----|-------------|
| 22 |  | HydroADE               | Application |            |     | Germany     |
| 23 |  | AR ADE                 | Application |            | X   | Canada      |
| 24 |  | Collada FX ADE         | Application |            |     | Germany     |
| 25 |  | ENC ADE                | Application |            |     | Germany     |
| 26 |  | Air Quality ADE        | Application |            |     | Italy       |
| 27 |  | IMGeo ADE              | Generic     | X          | X   | Netherlands |
| 28 |  | CityGML-TRKBIS         | Generic     |            | X   | Turkey      |
| 29 |  | INSPIRE ADE            | Generic     | X          | X   | Germany     |
| 30 |  | ACRoofADE              | Generic     | X          | X   | China       |
| 31 |  | CityGML ITINs ADE      | Generic     | X          | X   | Netherlands |
| 32 |  | Vegetation Objects ADE | Generic     |            |     | Mexico      |
| 33 |  | Dynamizers             | Generic     |            | X   | Germany     |
| 34 |  | Dynamic ADE            | Generic     |            | X   | Spain       |
| 35 |  | Geodata Join ADE       | Generic     |            |     | Germany     |
| 36 |  | Topo ADE               | Generic     |            |     | China       |
| 37 |  | Transport ADE          | Generic     |            |     | Netherlands |
| 38 |  | Traffic Sign ADE       | Generic     |            |     | Spain       |
| 39 |  | 3D-GEM                 | Generic     |            | X   | Netherlands |
| 40 |  | New LoD ADE            | Generic     |            | X   | Netherlands |
| 41 |  | Semantic City Model    | Generic     |            | X   | China       |
| 42 |  | GeoBIM                 | Generic     | X          | X   | Netherlands |
| 43 |  | PANTURA ADE            | Generic     |            |     | Netherlands |
| 44 |  | 3D Metadata ADE        | Generic     | X          | X   | Netherlands |

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