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GIS (geospatial) / BIM interoperability

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 59, *Buildings and civil engineering works*, Subcommittee SC 13, *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The complexity of information needed to support decisions relating to built assets by the public and private sectors as well as by citizens, require digitally enabled practices based upon interoperable systems. Indeed, the decisions that are needed over a built asset's life cycle and across its different stages rely on these complex sets of information. Moreover, these decisions are made by a multitude of actors that perform information-processing activities such as data creation, capture, transformation, and analysis, and are embodied in project and asset management practices as defined in existing and emerging standards.

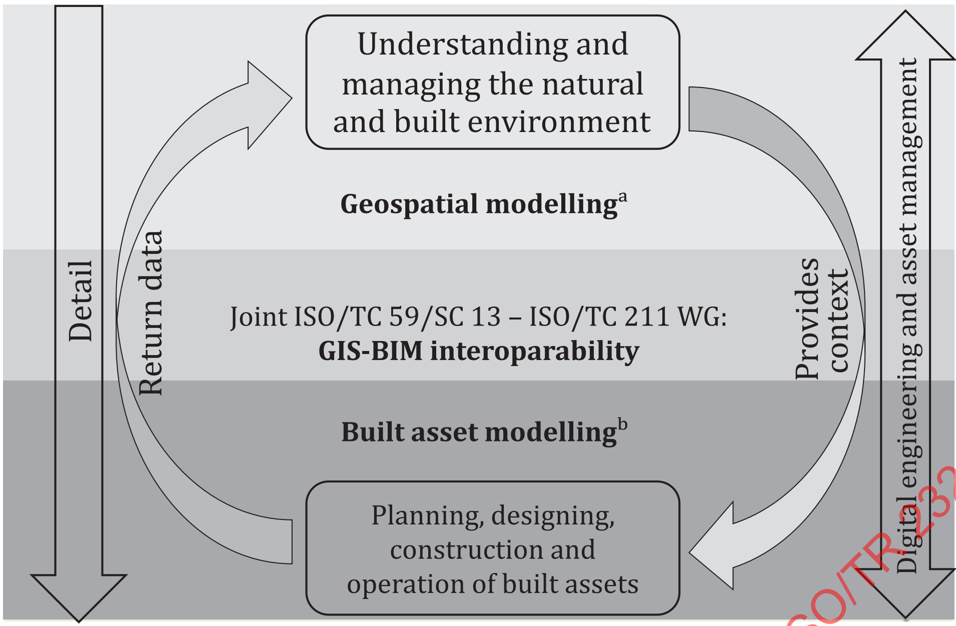
Consequently, several initiatives aimed at the digitalization of built assets at regional, national and international levels have spurred considerable investments around the globe. A key component of these initiatives concerns the need for collaboration and interoperability between information processing systems. These systems rely on digital practices that support digital engineering and asset life cycle management, which rely heavily on different domains of information modelling. These domains include both the observed natural environment and built structures. They also span many scales, from the fabricated asset to its territorial and contextual setting. In this case, the domain of geographic information, "maps", and geomatics, is encompassed with the concept of geographic information systems (GIS), whereas the built asset and its parts is encompassed by the concept of building information modelling (BIM). Traditionally these two information systems have been viewed as separate domains. From a digital engineering and asset management perspective however, there is an increasing overlap and need for interoperability between the two, as illustrated in Figure 1.

The two domains can also be viewed as two different sets of tools, used by several disciplines/domains.

The geospatial domain with its many professions (e.g. land management, engineering surveying, geodata management, remote sensing and cartography) uses GIS tools to acquire, manage, analyse, distribute and present geospatial information.

The geospatial domain handles (most of the time) descriptive models that are designed for many purposes and long-term use and were formerly presented on maps in scale 1:100 to 1:100 000 000. But as the need for geospatial applications varies greatly between actors, the main standardization committee for geomatics, ISO/TC 211, focuses on enabling the development of application schema. The main focus has been on a set of common rules for the development of application schemas (ISO 19109). However, there are applications schemas provided in other organisations, like OGC's CityGML standard for urban environments (including buildings). Buildings (and their urban environment) and the data specification for buildings in the European INSPIRE directive, both based upon ISO/TC 211 standards, including ISO 19109.

The AECO (architecture, engineering, construction and operations) domain with its many professions (e.g. project development, architecture, civil engineering, contractor, facility management) related to planning, designing, building and operating built assets (buildings, infrastructure, etc.) uses the evolving BIM method for collaborative and digital processes in construction projects and for asset management. The models are (most of the time) prescriptive models, designed for a specific purpose and project phase and were formerly presented on drawings in scale 10:1 to 1:1 000, including landscape drawings, rail and road geometrics. These AECO disciplines have at least one thing in common: the building.



a ISO/TC 211: ISO 19101 (all parts), ISO 19103, ISO 19104, ISO 19105, ISO 19106, ISO 19107, ISO 19108, ISO 19109, ISO 19110, ISO 19111, ISO 19136 (all parts), ISO 19150 (all parts).

b ISO/TC 59/SC 13: ISO 16739-1, ISO 29481 (all parts), ISO 19650 (all parts), ISO 12006 (all parts).

Figure 1 — Standards that relate to the cycle of information flow between geospatial and BIM domains (adapted from a diagram developed by the Joint OGC / bSI IDBE Working Group)

To date, the interaction between the BIM and the GIS domains has not been intuitive or seamless. In its simplified form the GIS, or geospatial modelling, domain has traditionally focused on modelling at the territorial scale and has adopted a large perspective of the observed environment which includes a multitude of distributed assets. The BIM domain has focused more on modelling the components of a single built asset. With the move towards integrated information environments, the differences in focus and scale between the two domains are diminishing. Arguably, use cases and perspectives in both domains are converging and overlapping. Indeed, and as mentioned, decisions pertaining to built assets typically require data and information that span both domains. Therefore, information models from both domains are becoming increasingly bound to each other: every built asset has a location and is situated within a context relative to the existing environment. Conversely, the existing environment incorporates all built assets.

With this move towards integrated information environments, use cases will increasingly require seamless transitions between both domains and their information models, from the bird's eye perspective to the manufactured component found within a built asset, to support the various asset life cycle practices and requirements within a specified context as illustrated in Figure 1. A key challenge in achieving this seamless transition or movement between both domains is ensuring the interoperability in systems used for geospatial information modelling and built asset information modelling. Currently, state-of-the-art modelling of geospatial information is based upon international standards developed and maintained by ISO/TC 211 and Open Geospatial Consortium, Inc. (OGC), whereas state-of-the-art modelling of built assets is based upon standards developed and maintained by ISO/TC 59/SC 13 and buildingSMART International (bSI).

This document aims to identify measures to enable interoperability between the two domains. These measures are expected be developed in either ISO/TC 211, ISO/TC 59/SC 13 or as a joint work between the two committees. To achieve this the enterprise interoperability framework (EIF) defined in ISO 11354 (all parts) has been used, focusing on the need for interoperability in data, services and processes to ensure seamless exchanges and transitions between both domains. First this document focuses on identifying standards within the two aforementioned interoperability levels. Barriers, or incompatibilities, between the two domains are then exposed and discussed. Lastly, specific work packages aimed at eliminating these barriers are identified and suggestions for future work aimed at streamlining interoperability between the two domains are made.

GIS (geospatial) / BIM interoperability

1 Scope

This document investigates barriers and proposes measures to improve interoperability between geospatial and BIM domains, namely, to align GIS standards developed by ISO/TC 211 and BIM standards developed by ISO/TC 59/SC 13.

Where relevant this document takes into account work and documents from other organizations and committees, such as buildingSMART, International (bSI), Open Geospatial Consortium (OGC) and Comité Européen de Normalisation (CEN). The focus is to identify future topics for standardization and possible revision needs of existing standards.

This document investigates conceptual and technological barriers between GIS and BIM domains at the data, service and process levels, as defined by ISO 11354 (all parts).

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
application schema
conceptual *schema* (3.13) for *data* (3.5) required by one or more applications

[SOURCE: ISO 19101-1:2014, 4.1.2]

3.2
conceptual model
data (3.5) model that represents an abstract view of the real world

Note 1 to entry: A conceptual model represents the human understanding of a system.

[SOURCE: ISO/IEC 11179-1:2015, 3.2.5, modified — The preferred term "conceptual data model" has been removed.]

3.3
conceptual schema
formal description of a *conceptual model* (3.2)

[SOURCE: ISO 19101-1:2014, 4.1.6]

3.4
conceptual schema language
formal language based on a conceptual formalism for the purpose of representing *conceptual schemas* (3.3)

EXAMPLE UML, EXPRESS, IDEFX1.

Note 1 to entry: A conceptual schema language may be lexical or graphical. Several conceptual schema languages can be based on the same conceptual formalism.

[SOURCE: ISO 19101-1:2014, 4.1.7]

3.5
data
reinterpretable representation of *information* (3.9) in a formalized manner suitable for communication, interpretation, or processing

Note 1 to entry: Data can be processed by humans or by automatic means.

[SOURCE: ISO/IEC 2382:2015, 2121272, modified — Notes 2 and 3 to entry have been removed.]

3.6
dataset
named collection of *data* (3.5)

3.7
data template
schema (3.13) providing a standardized *data* (3.5) structure used to describe the characteristics of objects

3.8
implementation
realization of a specification

[SOURCE: ISO 19105:2000, 3.18, modified — Note 1 to entry has been removed.]

3.9
information
meaningful *data* (3.5)

[SOURCE: ISO 9000:2015, 3.8.2]

3.10
interoperability
capability of two or more functional units to process *data* (3.5) cooperatively

[SOURCE: ISO/IEC 2382:2015, 2120585, modified — The domain "<distributed data processing>" and notes to entry have been removed.]

3.11
metamodel
model that specifies one or more other models

[SOURCE: ISO/IEC 11179-3:2013, 3.2.80]

3.12
ontology
formal, explicit specification of a shared conceptualization

Note 1 to entry: An ontology typically includes definitions of concepts and specified relationships between them, set out in a formal way so that a machine can use them for reasoning.

Note 2 to entry: See also ISO/TR 13054:2012, 2.6; ISO/TS 13399-4:2014, 3.20; ISO 19101-1-2014, 4.1.26; ISO 18435-3:2015, 3.1; ISO/IEC 19763-3:2020, 3.1.1.1.

[SOURCE: ISO 5127:2017, 3.1.2.03, modified — References in note 2 to entry have been editorially updated.]

3.13
schema
formal description of a model

[SOURCE: ISO 19101-1:2014, 4.1.34]

3.14
semantic interoperability
capability of two or more systems to communicate and exchange *data* (3.5) through specified data formats and communication protocols

[SOURCE: ISO 18308:2011, 3.48]

3.15
service
distinct part of the functionality that is provided by an entity through interfaces

[SOURCE: ISO 19119:2016, 4.1.12]

4 Abbreviated terms

API	application programming interface
AECO	architecture, engineering, construction, and operations
AIM	asset information model
ARM	application reference model
BAT	BIM authoring tools
BIM	building information modelling
BOM	business object model
CDE	common data environment
CEN	Comité Européen de Normalisation
CRS	coordinate reference system
GIS	geographic information system
GFM	general feature model (in ISO 19109)
GML	Geography Markup Language
ICT	information and communications technology
IFC	Industry Foundation Classes
IFD	International Framework for Dictionaries
IDM	information delivery manuals

MDA	model driven architecture
OMG	Object Management Group
OWL	Web Ontology Language
OGC	Open Geospatial Consortium
PDT	product data templates
STEP	standard for the exchange of product model data
SQL	Structured Query Language
UML	Unified Modeling Language
XML	Extensible Markup Language

5 Specification of BIM and GIS interoperability issues

5.1 General

According to ISO 11354 (all parts), enterprise interoperability can be implemented at 4 different levels, going from the simplest to the most complex e.g. data level, service level, process level and business level. In addition, the framework identifies three categories of interoperability, conceptual, technological and organizational.

Business and operational processes can give rise to interoperability barriers between enterprises, and this is also the case between enterprises across the geospatial and BIM domains. Figure 1 highlights the fact that while both domains share a focus on digital engineering processes and asset management, they inherently rely on different approaches to the management of information to support those processes at the service and data levels. This is the key consideration addressed in this document.

It is this common focus on information modelling in the built environment, albeit from differing perspectives, that creates both the requirement and opportunity to integrate information flows across both domains. While the processes do introduce interoperability challenges, it is the specific use cases or services where those processes intersect that introduce the biggest interoperability barriers. These barriers manifest themselves principally at the service and data levels. Hence, the focus is put on the data and service levels in this document from a conceptual and technological perspective, as listed in Table 1.

ISO 11354 (all parts) is designed for analysing enterprises. As explained above, GIS and BIM can be viewed as different domains, alternatively as different set of tools. Due to this difference between the enterprise approach and the domain/tool approach, not all the perspectives of ISO 11354 (all parts) are relevant, ending up with focusing on the need for interoperability in data, services and processes to interoperate between the domains. The concept of “process” is understood differently in the BIM domain and in the GIS domain. While several BIM processes have been specified using languages such as BPMN (business process modelling notation), there are no equivalents in GIS.

Table 1 — Interoperability levels considered for this document

	Conceptual	Technological
Service	Refers to the expressions, definitions and understanding of exchange information, and how that affects the ability to request, provide and utilize each other's services.	Refers to the use of ICT to communicate and exchange information, and how that affects the ability to request, provide and utilize each other's services.
Data	Refers to the expressions, definitions and understanding of exchange information, and how it affects the ability to exchange data items between the (GIS-BIM) domains.	Refers to the use of ICT to communicate and exchange information, and how it affects the ability to exchange data items between the (GIS-BIM) domains.
NOTE Reproduced from ISO 11354-1.		

5.2 BIM and GIS interoperability levels

5.2.1 General

In this subclause the service and data interoperability levels are explored and compared through analysing the relevant standards targeting these categories in both domains e.g. ISO/TC 59/SC 13 for BIM and ISO/TC 211 for GIS.

5.2.2 Data level

5.2.2.1 General considerations

This subclause aims at describing existing schemas in standards used in BIM and in GIS.

The overview of GIS schemas is based on the model driven architecture (MDA) approach as defined in ISO 19103:2015, 5.2.2.3. Open BIM schemas follow the STEP architecture, defined in ISO 10303 (all parts) and are presented in 5.2.2.4. The only common concept to both approaches is the concept of "conceptual schema language". Therefore, the languages as used in BIM and in GIS for describing conceptual schemas are listed in 5.2.2.2.

5.2.2.2 BIM and GIS Conceptual Schema Languages

Conceptual schema languages are commonly used for formal representations of conceptual models. Table 2 lists the different languages used for schemas in GIS and BIM standards.

Table 2 — Conceptual schema languages

Domains	Name	Reference
GIS	UML Unified Modeling Language	ISO/IEC 19505-2
BIM	EXPRESS modelling language.	ISO 10303-11
Note 1: ISO/IEC 19505-2 has been developed by the Object Management Group (OMG) and standardised by ISO.		
Note 2: The EXPRESS data modelling language is specified in ISO 10303-11, a standard for the computer-interpretable representation and exchange of product manufacturing information.		
Note 3: ISO 10303-11 also specifies a graphical representation for a subset of the constructs in the EXPRESS language. This graphical representation is called EXPRESS-G.		

5.2.2.3 GIS data schemas

5.2.2.3.1 General

GIS schemas are structured according to a model driven architecture (MDA) as defined in ISO 19103. The founding principle in MDA requires schemas to be defined for different levels of abstraction. ISO 19103 defines four levels of abstraction, as illustrated in Figure 2:

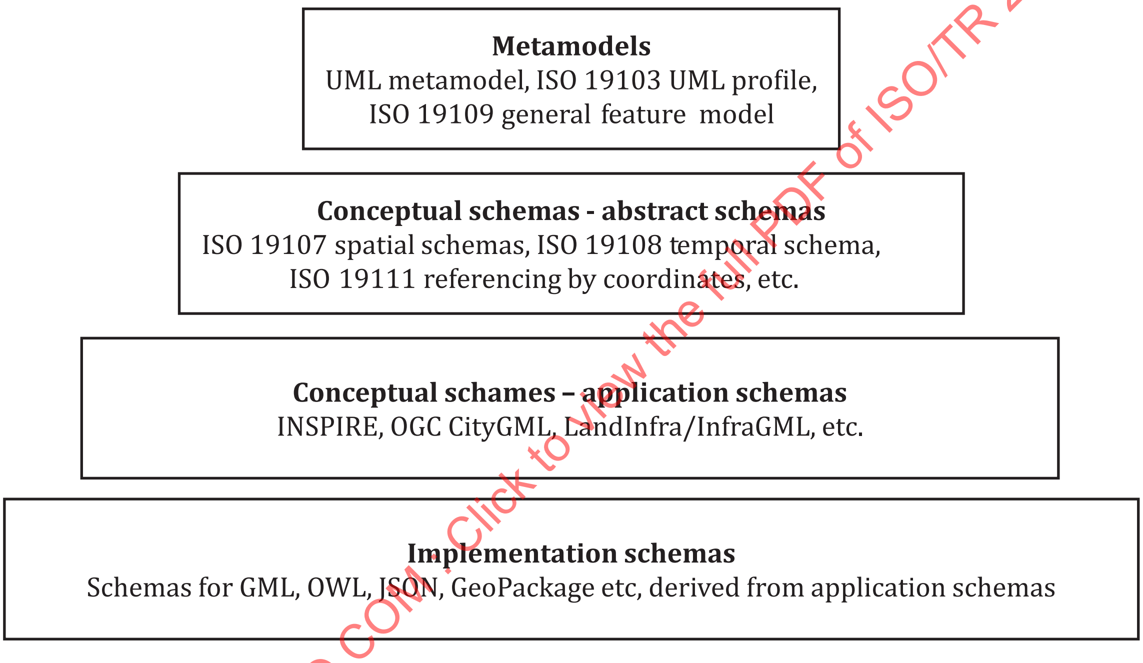
— metamodels: the fundament for defining other models;

— abstract conceptual schemas: abstract schemas describing concepts for reuse in other schemas;

— conceptual application schemas: conceptual schemas defined for specific applications;

— implementation schemas: schemas for implementation in databases and exchange formats.

The conceptual schemas are required to be independent of specific implementation technologies.



NOTE Adapted from Reference [62].

Figure 2 — Levels of abstraction

5.2.2.3.2 to 5.2.2.3.5 further detail the specific elements and items as specified by the standards for each of the levels of abstraction.

5.2.2.3.2 GIS metamodel standards

Table 3 lists metamodels defined in GIS standards.

Table 3 — GIS metamodel standards

Name	Reference	Description
Geographic information - Reference model	ISO 19101	Model that defines concepts of a universe of discourse.
Core UML profile	ISO 19103	Formalised UML profile and rules for the use of UML for modelling geospatial information.

Table 3 *(continued)*

Name	Reference	Description
UML profile for application schemas	ISO 19109	Rules for the use of UML for modelling geospatial information in an application schema.
General feature model	ISO 19109	The general feature model is the metamodel for ISO/TC 211 GIS standards, with concepts for FeatureType, PropertyType (AttributeType, Operation and FeatureAssociationRole) and FeatureAssociatonType.

5.2.2.3.3 GIS abstract conceptual schemas

Table 4 lists abstract conceptual schemas defined in GIS standards.

Table 4 — GIS abstract conceptual schemas

Schema name	Reference	Description
Core data types	ISO 19103	Specifies core data types for use in UML models of geographic information.
Spatial schema	ISO 19107	Specifies UML classes for representing the spatial characteristics of features as composites of geometric and/or topological primitives.
Core profile of the spatial schema	ISO 19137	Provides a profile of ISO 19107 that is limited to describing features as simple geometric primitives of 0, 1, or 2 dimensions.
Schema for coordinate referencing	ISO 19111	Concepts for coordinate references systems, coordinate systems, datums and operations.
Temporal schema	ISO 19108	Concepts for temporal characteristics of features and classes for describing relevant temporal reference systems.
Schema for referencing by identifiers	ISO 19112	Concepts for describing spatial locations by reference to identifiers.
Schema for moving features	ISO 19141	Extends ISO 19107 to support the description of moving spatial objects.
Schema for linear referencing	ISO 19148	Concepts for describing spatial locations by referring to locations in a linear network.
Schema for data quality	ISO 19157	Concepts for describing data quality.
Feature cataloguing	ISO 19110	Concepts for feature cataloguing.
Metadata	ISO 19115-1	Concepts for metadata.
Schema for coverage geometry and functions	ISO 19123	Schema for an alternative representation of spatial information as a coverage, in which non-spatial attributes are assigned directly to geometric objects rather than to features composed of such objects.

5.2.2.3.4 GIS Conceptual application schemas

Table 5 lists conceptual application schemas defined in GIS standards.

Table 5 — GIS Conceptual application schemas

Standard	Reference	Description
OGC Land and Infrastructure Conceptual Model Standard (LandInfra)	http://docs.opengeospatial.org/is/15-111r1/15-111r1.html	OGC® Land and Infrastructure Conceptual Model Standard (LandInfra) presents the implementation-independent, concepts supporting land and civil engineering infrastructure facilities, projects, alignment, road, railway, survey (including equipment, observations, and survey results), land division, and condominiums.
OGC CityGML Application schema	https://www.ogc.org/standards/citygml	OGC® CityGML is an open data model and XML-based format for the storage and exchange of virtual 3D city models. It is an application schema for the Geography Markup Language version 3.1.1 (GML3), the extendible international standard for spatial data exchange issued by the Open Geospatial Consortium (OGC) and the ISO/TC 211. The aim of the development of CityGML is to reach a common definition of the basic entities, attributes, and relations of a 3D city model.
OGC IndoorGML Application schema	https://www.ogc.org/standards/indoorgml	OGC® IndoorGML standard specifies an open data model and XML schema for indoor spatial information in support of indoor navigation. IndoorGML is an application schema of OGC® GML 3.2.1. While there are several 3D building modelling standards such as CityGML, KML, and IFC, which deal with interior space of buildings from geometric, cartographic, and semantic viewpoints, IndoorGML intentionally focuses on modelling indoor spaces for navigation purposes.
INSPIRE Data specifications	https://inspire.ec.europa.eu/data-specifications	Common data models to be used when exchanging spatial datasets in Europe. For example, Buildings; Transportation Networks; and Utilities and Government Services.

5.2.2.3.5 GIS Implementation schemas

Table 6 lists implementation schemas and encoding rules defined in GIS standards, limited to GML, XML and OWL. There exist a long range of other implementation schemas like JSON, geoJSON, Geopackage. Strictly, INSPIRE GML schemas are not GIS standards, but are important in Europe as it is part of European legislation.

Table 6 — GIS implementation schemas

Schema/format name	Reference	Description
Geography Markup Language (GML)	ISO 19136 (all parts)	Encoding in the GML Exchange format, including rules for conversion from UML to GML.
ISO/TC 211 XML schemas	https://schemas.isotc211.org/	Official XML schemas derived from the ISO/TC 211 UML models.
Rules for developing ontologies in the Web Ontology Language (OWL)	ISO 19150-2	Rules for conversions from UML to OWL.
ISO/TC 211 ontologies	https://def.isotc211.org/	Official ontologies derived from the ISO/TC 211 UML models.
OGC CityGML GML schemas	http://schemas.opengis.net/citygml/2.0/	Official OGC CityGML 2.0 schemas.
OGC InfraGML GML schemas	http://schemas.opengis.net/infragml/	Official OGC InfraGML 1.0 schemas.

Table 6 *(continued)*

Schema/format name	Reference	Description
OGC IndoorGML GML schemas	http://schemas.opengis.net/indoorgml/1.0/	Official OGC IndoorGML 1.0 or 1.0.3 schemas.
INSPIRE GML schemas	https://inspire.ec.europa.eu/schemas/	Official INSPIRE GML Schemas.

5.2.2.4 BIM data schemas

For all intents and purpose, there currently exists no overarching architecture driving the development of BIM based implementations, processes and technologies. In other words, there is no core architecture to frame the development of BIM data and process standards that is comparable to the MDA approach as described in ISO 19103. That being said, the past 20+ years has seen the development of ISO 16739-1 – IFC as a core schema for open BIM principles and was initially based on, but then developed along its own path, the STEP architecture and information model, as described in ISO 10303-201 to ISO 10303-242, which specify the application protocols and can be considered as “conceptual application schemas” for BIM. Due to the absence of this core architecture, there exist no framework describing how the different BIM standards, e.g. ISO 12006, ISO 29481 (all parts) and ISO 16739-1, relate to each other. The absence of this framework of common architecture makes it hard to compare the two domains at this level. IFC- and data templates are described further in Annex B. For the purpose of this document, comparison is based on the existing STEP modular architecture which is illustrated in Figure 3.

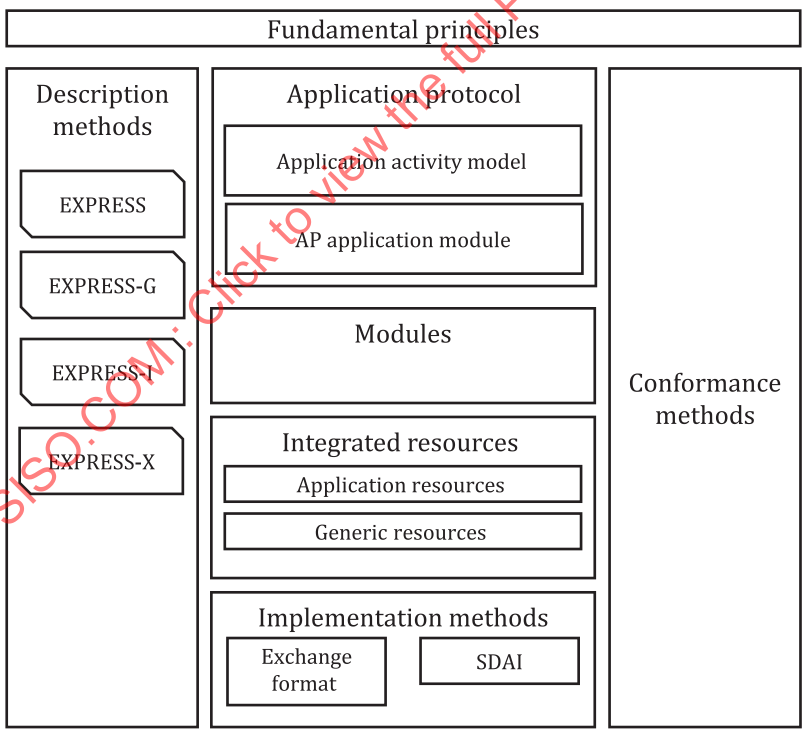


Figure 3 — Existing STEP architecture (ISO 10303-1)

BIM standards rely on two specific implementation technologies:

a) STEP P21 file format EXPRESS (implementation format for BIM data, also intended for AIM-based exchange especially for authoring tools containing geometry);

b) XML.

The existing combinations are shown in Table 7.

Table 7 — BIM implementation schemas, schema languages and data languages (ISO 10303-1)

Information model	Modelling language	Implementation schema	Schema language for implementation	Data language for implementation
AIM	EXPRESS	AIM Long Form	P11 EXPRESS	STEP P21 file format
ARM	EXPRESS	none	none	none
Business object model (BOM)	EXPRESS	BO Model XML (STEP AP242 edition 1 Business Object)	XML schema	XML

In the context of BIM, the standard data format for file exchange is defined by the schemas in ISO 16739-1 Industry Foundation Classes (IFC). IFC considers the four conceptual layers, as illustrated in Figure 4:

— domain layer: specific schemas for individual domains;

— interoperability (shared) layer: schemas that define concepts common for several domains;

— core layer: schemas that define the basic concepts;

— resource layer: abstract schemas for geometry, date and time, measures, etc.

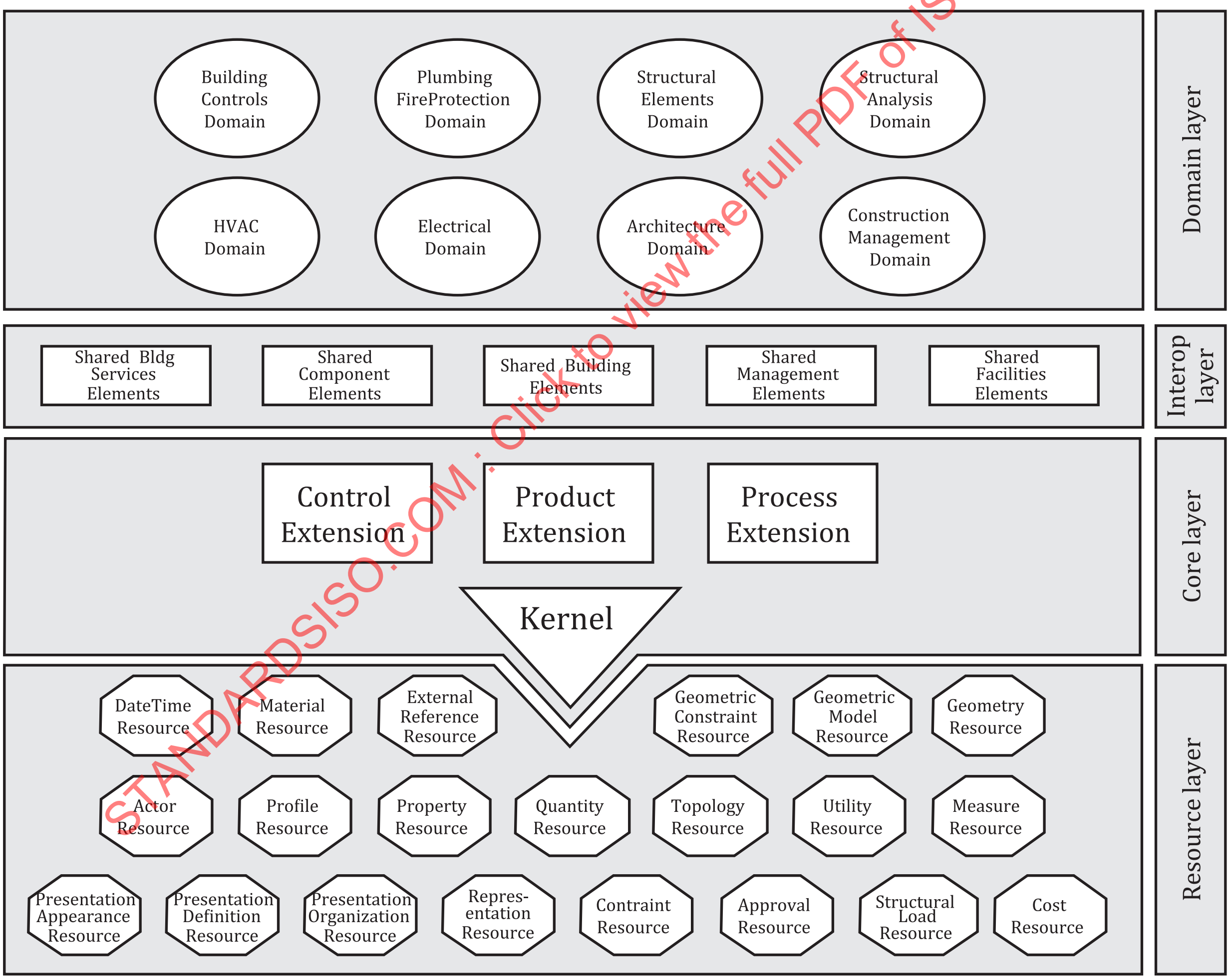


Figure 4 — IFC data schema architecture with conceptual layers

Table 9 lists data languages considered for schema implementation, as defined in BIM standards (ISO 10303-11).

Table 9 — BIM data schemas

Data schema name	Reference	Description
STEP	ISO 10303-21	Implementation methods: clear text encoding of the exchange structure.
IFC XSD schema	ISO 10303-28	XML representations of EXPRESS schemas and data, using XML schemas.
OWL	W3C OWL	Web Ontology Language (OWL) representation of the Industry Foundation Classes (IFC) schema e.g. ifcOWL reference[a].

[a] https://technical.buildingsmart.org/standards/ifc/ifc-formats/ifcowl/.

Table 10 further specifies the subparts defined in IFC (ISO 16739-1).

Table 10 — Schemas defined in ISO 16739-1 (IFC)

Schema name	Reference	Description
IFC Kernel Schema	ISO 16739-1:2018, 5.1	Defines the most abstract part or core part of the IFC specification. Captures general constructs, that are basically founded by their different semantic meaning in common understanding of an object model, like object, property and relationship.
IFC Control Extension Schema	ISO 16739-1:2018, 5.2	Declares basic classes for control objects and assignment of these to any object derived from IfcObjectDefinition. Also, it declares the classes to associate resource level objects of controlling nature to any subtype of IfcRoot.
IFC Product Extension Schema	ISO 16739-1:2018, 5.4	Specialises the concepts of a (physical) product, i.e. a component likely to have a shape and a placement within the project context.
IFC Process Extension Schema	ISO 16739-1:2018, 5.3	Provides the primary information that expands one of the key ideas of the IFC Model. This is the idea of 'process' which captures ideas about the mapping of processes in a logical sequence or planning and scheduling of work and the tasks required for its completion. It is important to understand that process information can be expressed by classes in exactly the same way as product information.
IFC Resource Schemas	ISO 16739-1:2018, Clause 8	The resource definition data schemas consist of supporting data structures. Entities and types defined in this layer can be referenced by all entities in the layers below. Unlike entities in other layers, resource definition data structures cannot exist independently, but can only exist if referenced (directly or indirectly) by one or more entities deriving from IfcRoot.
IFC DateTime Resource Schema	ISO 16739-1:2018, 8.5	Defines generic date and time specific concepts that can be used to identify context within calendars, schedules, and time series.
IFC Measure Resource Schema	ISO 16739-1:2018, 8.11	Specifies units and defined measure types that can be assigned to quantities.
IFC Quantity Resource Schema	ISO 16739-1:2018, 8.17	Defines a set of basic quantities that can be associated with products.
IFC Utility Resource Schema	ISO 16739-1:2018, 8.21	Deals with the general concepts of Ownership and Change.

Table 10 *(continued)*

Schema name	Reference	Description
IFC Geometric Model Resource Schema	ISO 16739-1:2018, 8.8	Defines the resources used to determine the placement of the shape representation of a product within the geometric representation context of a project.
IFC Geometry Resource Schema	ISO 16739-1:2018, 8.9	Defines the resources used for geometric representations. The primary application of this resource is for representation of the shape or geometric form of an element.
IFC Geometric Constraint Resource Schema	ISO 16739-1:2018, 8.7	Defines the resources used to determine the object placement used for the shape representation of the object, and determine the constraints applied to the connectivity between two shapes of objects.
IFC Topology Resource Schema	ISO 16739-1:2018, 8.20	Defines the resources used for topological representations.
IFC Representation Resource Schema	ISO 16739-1:2018, 8.18	Defines the representation of shape and topology as important definitional properties for products defined within the IFC Object Model. The schema defines two ways to represent definitional properties of products: topological representation and geometric shape representation.
IFC External Reference Resource Schema	ISO 16739-1:2018, 8.6	Provides the means to access or use information from external sources.
IFC Material Resource Schema	ISO 16739-1:2018, 8.10	Contains the types and entities that are used to define materials.
IFC Property Resource Schema	ISO 16739-1:2018, 8.16	Defines a basic set of property types that can be associated with occurrence objects and type objects through Property Sets.
IFC Profile Resource Schema	ISO 16739-1:2018, 8.15	Defines the two-dimensional profiles or cross sections, used to define geometric shape representations.
IFC Actor Resource Schema	ISO 16739-1:2018, 8.1	Enables representation of information concerning a person or an organization that will undertake work or hold responsibility.

Table 11 shows the framework for object-oriented information about construction work defined in ISO 12006-3.

Table 11 — BIM abstract conceptual schemas

Schema name	Reference	Description
Building construction – organization of information about construction works – Framework for object-oriented information	ISO 12006-3	The main part of ISO 12006-3 consists of the specification of a taxonomy model, which provides the ability to define concepts by means of properties, to group concepts, and to define relationships between concepts. Objects, collections and relationships are the basic entities of the model. The set of properties associated with an object provide the formal definition of the object as well as its typical behaviour. Properties have values, optionally expressed in units.

Table 12 shows application protocols (or conceptual application schemas) defined in ISO 10303 (all parts), for the BIM domain

Table 12 — BIM application protocols (or conceptual application schemas)

Schema name	Reference	Description
IFC Shared Schemas: Shared Bldg Services Elements Shared Component Elements Shared Building Elements Shared Management Elements Shared Facilities Elements	ISO 16739-1:2018, Clause 6	Contain intermediate specializations of entities. Entities defined in this layer can be referenced and specialized by all entities above in the hierarchy. The shared element layer provides more specialized objects and relationships shared by multiple domains.
IFC Domain Schemas: Building Control Domain PlumbingFireProtectionDomain StrucutralElementsDomain StructuralAnalysisDomain HVAC Domain Electrical Domain Architecture Domain Construction Management Domain	ISO 16739-1:2018, Clause 7	Contain final specializations of entities. Entities defined in this layer are self-contained and cannot be referenced by any other layer. The domain specific layer organizes definitions according to industry discipline.

5.2.2.5 Comparing Schemas

5.2.2.5.1 General

5.2.2.5.2 to 5.2.2.5.5 contain comparisons of schemas from GIS and BIM according to the MDA levels of abstraction, as defined in ISO 19103.

5.2.2.5.2 Metamodels and core elements

Table 13 lists and compares schemas and metamodels used as the foundation for BIM and GIS schemas.

Table 13 — Metamodels in BIM and GIS

BIM	GIS	Comment
IFC Kernel Schema	ISO 19103 UML profile ISO 19109 GFM	Further comparisons of concepts from GFM and the kernel schema is needed.
IFD (ISO 12006-3) – Framework for object-oriented information ISO 23387	ISO 19109 GFM ISO 19126 – feature concept dictionary ISO 19110 methodology for feature cataloguing	Further comparisons of the concepts in GIS and BIM are needed.

Table 14 lists basic concepts in the IFC Kernel Schema compared to ISO 19109 GFM.

Table 14 — IFC Kernel concepts compared to ISO 19109 GFM

BIM	GIS	Comment
IFC Kernel	ISO 19109 GFM	
ifcObjectDefinition	Realization of FeatureType	
ifcObject	Realization of FeatureType	

Table 14 *(continued)*

BIM	GIS	Comment
ifcTypeObject	Realization of FeatureType	ISO 19109 GFM does not define separate concepts for Objects and TypeObjects.
ifcPropertyDefinition	AttributeType	
ifcProperySet	Not defined	
ifcRelationship	FeatureAssociationType	Relationships in IFC are EXPRESS entities and can have their own properties. Feature associations according to the ISO 19109 GFM cannot have individual attributes.

There are some differences between concepts defined in the IFC Kernel schema and the ISO 19109 GFM. The entities ifcObjectDefinition, ifcPropertyDefinition and ifcRelationship are concepts that can be directly compared to the GFM classes FeatureType, AttributeType and FeatureAssociationType. However, there is one major difference between relationships based on ifcRelationship and associations based on FeatureAssociationType: Relationships in IFC are EXPRESS entities that inherit from the main entity ifcRoot and can have their own properties; those inherited from ifcRoot, as well as specific properties for each relationship entity. UML associations based on FeatureAssociationType cannot have individual attributes, only five predefined characteristics (name, definition etc.). IFC Relationships with individual properties can be compared to UML association classes, which are rarely used in GIS schemas. Relations with attributes are usually modelled as FeatureType with feature associations in GIS schemas. They can also be compared to the GIS concept FeatureType with mandatory feature associations.

The ifcObjectDefinition, ifcObject and ifcTypeObject entities can be compared to realizations of the GFM metaclass FeatureType, as superclasses that carry the common characteristics for all instantiable classes in the model. The classification of objects (ifcObject) and type objects (ifcTypeObject) is not commonly used in GIS schemas. The type object in IFC is used for handling common properties for all occurrences of a set of type objects.

In addition to the Kernel schema, the IFC Core layer consists of abstract conceptual schemas for Control Extension, Process Extension and Product Extension. The latter is the most relevant for this work, with the concepts for describing (physical) products to be implemented as individual products or as common product types. The main entity of the Product Extension schema - ifcProduct is subclassed to a range of entities representing product classifications, where two are of main interest for this work: ifcElement and ifcSpatialElement. Figure 5 shows the inheritance from IfcRoot to IfcProduct and subclasses of IfcProduct.

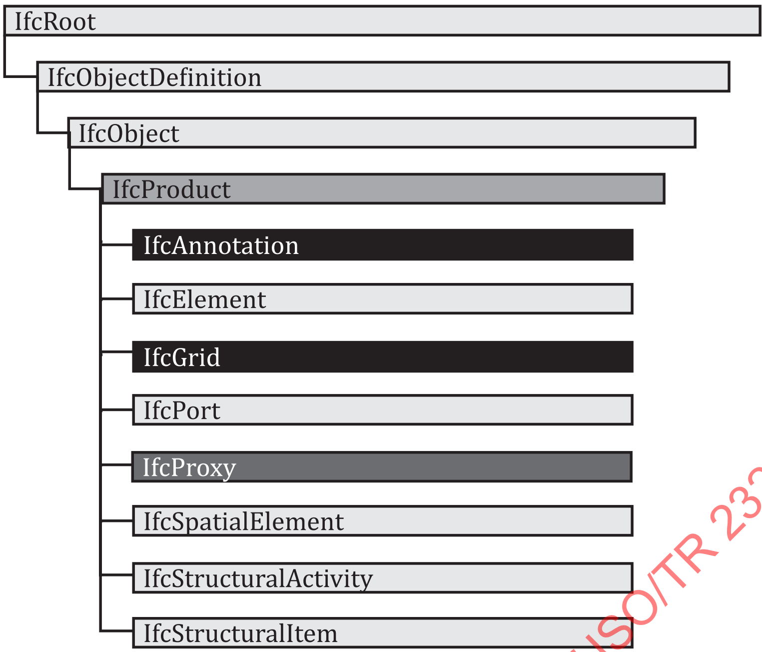


Figure 5 — Subclasses of ifcProduct

The entity ifcSpatialElement contains entities such as ifcProject; ifcSite; ifcBuilding; ifcBuildingStorey; and ifcSpace, i.e. entities that describe the spatial structure elements. While the entity ifcElement contains entities for components ("building materials"), i.e. the building pieces to be mounted together to build the house. Entities in these two "structures" are connected using the relationship IfcRelContainedInSpatialStructure. This kind of classification is not commonly used in GIS Schemas.

5.2.2.5.3 Abstract conceptual schemas

The IFC resource schemas consists of basic schemas for date and time, geometry, topology, quantity, measure etc. The entities defined in these schemas are not subtypes of the core entity ifcRoot and cannot exist independently. They are abstract entities that can only exist through references from other entities that are subtypes of ifcRoot.

Similar concepts for abstract conceptual schemas are defined in GIS standards such as ISO 19103 (data types, including date and time, measure etc.), ISO 19107 (spatial schema with geometry models), ISO 19108 (temporal schema) and ISO 19111 (coordinate reference systems), in the conceptual schema level of MDA.

Table 15 lists some of the IFC resource schemas and possible comparable GIS schemas.

Table 15 — Heading IFC resource schemas and possible comparable GIS schemas

IFC resource schemas	GIS schemas
IFC DateTime Resource	ISO 19103 CSL DateTime ISO 19108 temporal schema
IFC Measure Resource	ISO 19103 CSL measure
IFC Geometry Resource IFC Geometric Model Resource IFC Geometric Constraint Resource IFC Profile Resource	ISO 19107 spatial schema ISO 19137 core profile of the spatial schema

Table 15 *(continued)*

IFC resource schemas	GIS schemas
IFC Representation Resource	ISO 19111 referencing by coordinates
IFC Product Extension	ISO 19148 linear referencing

5.2.2.5.4 Conceptual application schemas

The ISO 191xx standards are mainly concerning basic concepts, with a few exceptions. They do not define domain specific models, which are rather defined in national, regional or discipline specific models based on ISO 19100 standards. Examples of such domain models are the INSPIRE models in Europe and the OGC Specifications InfraGML and CityGML.

The IFC schemas goes much further in defining domain specific models, in particular in schemas in the domain layer. The Product Extension schema defines the basic concepts for products, including the classification based on spatial and functional structure. The main entities in the Product Extension schema are abstract supertypes of entities that are defined in schemas in the Interoperability layer or the domain layer. The schemas in the Interoperability layer describes instantiable entities that are common to several domains, while the schemas in the domain layer describe the most domain specific instantiable entities.

The structure of main abstract entities and domain models in IFC schemas can be compared to the rules for defining application schemas in ISO 19109 and for feature cataloguing in ISO 19110.

5.2.2.5.5 Implementation schemas

As stated in 5.2.2.1, the only common concept to both approaches (MDA and STEP architecture) is the concept of “conceptual schema language”. Thus, implementation schemas are not a common concept for BIM and GIS.

5.2.3 Service level

5.2.3.1 General

This subclause aims at describing service models as used in BIM and in GIS. This subclause addresses services implemented in an electronic form identifying existing services of:

— service models in the domains of BIM and GIS;

— service interoperation in the domains of BIM and GIS.

5.2.3.2 GIS service model standards

Table 16 lists GIS service model standards.

Table 16 — GIS service model standards

Service model name	Reference	Providing (Operation)
Services	ISO 19119	Defines and identifies the architecture patterns for service interfaces.
OGC Catalog Service	12-168r6/ 12-176r7	Supports the ability to publish and search collections of descriptive information (metadata records) for geospatial data, services, and related information.
Web Map Service	ISO 19128	Specifies the behaviour of a service that produces spatially referenced maps dynamically from geographic information.

Table 16 *(continued)*

Service model name	Reference	Providing (Operation)
Web Feature Service	ISO 19142	Specifies discovery operations, query operations, locking operations, transaction operations and operations to manage stored parameterized query expressions.
Location-based services Reference model	ISO 19132	Defines reference model and framework location-based services.
Location-based services — Tracking and navigation	ISO 19133	Used for implementing of tracking and navigation services.
Metadata	ISO 19115-1	Description of a data set or a service.
OGC 3D Portrayal Service 1.0	15-001r4	Geospatial 3D content delivery implementation specification. It focuses on what is to be delivered in which manner to enable interoperable 3D portrayal.
OGC Web Processing Service	05-007r7	Provision of rules for standardizing how inputs and outputs (requests and responses) for geospatial processing services, such as polygon overlay. The standard also defines how a client can request the execution of a process, and how the output from the process is handled.
Geodetic register	ISO 19127	Geodetic register.
Geospatial API for features	ISO 19168-1	Core geospatial API for features.

5.2.3.3 BIM service model standards

In the context of BIM, there is no equivalent to services as defined in the GIS world. The understanding of the concept of “service” is also different than in GIS or in computer science in general. In the domain where BIM is currently applied, “service” generally refers to “building service” or “building services”, both related semantically to the concept of “process” (as understood in computer science).

When considering “service models” as those defined for GIS, there are no BIM service models specified so far. Table 17 lists some documents describing procedures and approaches that can be further adapted into BIM service models. But if one sticks to the GIS interpretation of “service model”, there are no equivalents in BIM.

Table 17 — BIM procedures that can be adapted into service models

Service model name	Reference
Common data environments (CDE) for BIM projects – Function sets and open data exchange between platforms of Part 1: Components and function sets of a CDE; with digital attachment (See further explanation below the table)	CEN/TC 442 WI00442032 “Common Data Environments (CDE) for BIM projects – Open data exchange between platforms of different vendors via an open CDE API”
Building information models — Information delivery manual — Part 2: Interaction framework ISO 29481-2 specifies a methodology and format for describing ‘coordination acts’ between actors in a building construction project during all life cycle stages. It therefore specifies: — a methodology that describes an interaction framework, — an appropriate way to map responsibilities and interactions that provides a process context for information flow, — a recommended format to specify the interaction framework.	ISO 29481-2

Table 17 *(continued)*

Service model name	Reference
ISO 29481-2 is intended to facilitate interoperability between software applications used in the construction process, to promote digital collaboration between actors in the building construction process, and to provide a basis for accurate, reliable, repeatable, and high-quality information exchange.	

CEN/TC 442 WI00442032 address the use of common data environments (CDE) in the collaborative creation of information in BIM projects. Requirements for collaboration and the information to be provided are typically defined in so-called exchange information requirements (EIR) and BIM execution plan (BEP).

ISO 19650 (all parts) specifies good principles and already shapes out some general advantages of a CDE for the container-based management of information. This includes the reduction of time and cost efforts, the traceability of information deliveries and responsibilities, and the unique identification of intellectual property.

In CEN/TC 442 WI00442032 the benefits of a common data environment for the model-based collaborative work in BIM projects will be further detailed and set out down to the functional level. The basic components of a CDE, their tasks and use cases and the minimal viable function set for the operation of a CDE will be specified. Further optional features and functions are referenced. This is to help clients in the assessment and contracting of CDEs.

CDEs are employed during any project phase along the life cycle of a building. Therefore, a parallel or consecutive use of platforms from different vendors is common. In the interest of a seamless data exchange during the course of a project, CDEs need to be able to mutually exchange data without losses. In CEN/TC 442 WI00442032, therefore, a concept for an open protocol for the exchange of data between two platforms is specified. Compliant interfaces enable platform users and operators to exchange BIM data, as well as other project data between CDEs or applications legally secure and without data loss.

ISO 15686-1 defines structures for capturing and exchanging service life cycle information based on IFC and on COBie (Construction Operations Building Information Exchange).

5.2.3.4 Query languages

Query language is a language used to access information stored in a database (ISO/IEC/IEEE 24765).

Table 18 lists GIS query languages.

Table 18 — GIS query languages

Service model name	Reference
GeoSPARQL - A Geographic Query Language for RDF Data	https://www.opengeospatial.org/standards/geosparql
Filter encoding	ISO 19143
NOTE ISO 19143 gives a neutral syntax for expressing projections, selection and sorting sections collectively called a query expression.	

There are no BIM query languages.

5.3 GIS/BIM incompatibilities

5.3.1 General

This subclause aims at identifying the shared elements and the possible barriers for achieving interoperability among BIM and GIS systems. According to ISO 11354-1, these barriers are classified in two main categories:

1) Conceptual barriers address:

   a) Different concepts for entity representation (incompatibilities in geometries, syntaxes, semantics and semiotics).

   b) Differences in expressing / defining / understanding exchanged items at various levels of abstraction.

2) Technological barriers concern:

   a) Discontinuities in the entity exchange path (incompatible interfaces, exchange protocols, services, and data storage devices).

   b) Different choices among different standards that prohibit sharing & exchanging information between systems.

5.3.2 lists conceptual and technological barriers identified in the document.

5.3.2 Incompatibilities

5.3.2.1 General

This subclause aims to list and classify incompatibilities as conceptual and/or technological incompatibilities. According to ISO 11354, conceptual incompatibilities can arise from different concepts for entity representation (incompatibilities in geometries, syntaxes, semantics and semiotics) and from differences in expressing, defining and understanding the exchanged items at various levels of abstraction. Technological incompatibilities can arise from discontinuities in the entities exchange path (incompatible interfaces, exchange protocols, services, and data storage devices) and different choices among standardization technologies that prohibit sharing and exchanging information between systems.

In a general sense, information modelling in GIS and BIM are based on different conceptual modelling languages and different modelling approaches. Schemas at different levels of abstraction describe concepts differently in the two domains. This is seen as a key difference that introduces many of the incompatibilities discussed below.

5.3.2.2 [Conceptual] Differences in underlying software design approach

GIS relies on MDA, IFC relies on its own architecture derived from STEP modular architecture, and even then, the BIM domain is broader in scope that what is covered in the IFC schema. In addition to this, IFD has its own language independent information model. To obtain a set of accommodated concepts common to all approaches, the following steps need to be considered:

— Listing related concepts in both domains e.g. “application schema”, “information model”, “data specification language” and “metamodel”.

— Identifying standard definitions for those concepts as specified in related standards.

— Defining natural language links / mappings / relations among concepts with the same meaning / interpretation. For example, following the definition of “application schema” in ISO 10303-22, one can map this as an equivalent BIM concept for “conceptual application schema” as understood in the GIS world.

— Adapting the above-defined relations into some formal language, processable by machines.

Mappings between MDA concepts and aspects of IFC concepts need to be defined.

5.3.2.3 [Technological] Differences in underlying architectures

Today BIM and GIS platforms are connectable by means of specific APIs or code. As such, one cannot seamlessly exchange data and information from one domain to the other. Information exchange also undergoes specific adaptations and developments. Subsequent to work undertaken addressing [Conceptual] differences among architectures, the [Technological] differences among them also need to be addressed. Implementing full semantic interoperability among the different architectures is a non-trivial task. Fundamentally, a consistent approach to developing interoperability that would be best suited to both domains need to be developed (e.g. federation, unification or integration).

— Federation can be reached by formally defining sets of links among architecture parts and/or modules.

— Unification would consider defining a common metamodel.

— Integration would result in a new architecture, e.g. fusion of MDA and STEP.

5.3.2.4 [Technological] Differences in the geometric/topological dimension

Geospatial data are essential for design and planning in BIM. Therefore Geodata (Terrain, Utilities, Topographic Objects, Boundaries) are loaded into/linked to the BIM authoring tools (BAT), model checking tools or common data environments (CDE). Geospatial features are mostly represented as points, lines or surfaces. Points, lines, and surfaces are typically not supported (visualised, selectable, analysed) by BIM authoring or collaboration tools. Most solids in building models, representing a building, are collections of polygons.

Primitive and complex geometry types for GIS as points, curves, surfaces or solids are defined in ISO 19107. BIM schemas define swept solids and constructive solids in addition. Incompatibilities have been found due to different geometry models. GIS applies the B-Rep (boundary representation) vs BIM (or more precise, IFC's) CSG (constructive solid geometry) representation, though IFC seems to also allow for B-Rep model. The transformation between these representation forms is not trivial.

5.3.2.5 [Technological] generation of watertight B-Reps for BIM

Buildings in city models are not necessarily watertight: CityGML has no general requirements of being watertight. Reusing CityGML buildings to visualize the geographic context and for BIM/geospatial analysis, such as visibility analysis or calculations for building permits, requires watertight geometry. Ensuring water tightness is not straight forward. Most solids in building models, representing a building, are collections of polygons. There are no standards that ensure, that the generation of watertight B-Reps for BIM is possible. See Annex D.

5.3.2.6 [Technological] Diversity in spatial representation

Spatial representation diversity in BIM: The diversity of possible geometric representations in BIM makes it difficult to transform objects completely to GIS. Even deriving a footprint of a BIM model for GIS is not a trivial task. See also Annex D.

5.3.2.7 [Conceptual] Semantic incompatibility regarding the concept of "service"

The concept of “service” is understood differently in the BIM domain and in the GIS domain while the GIS interpretation follows the computer science meaning associated with “service” (something that has inputs, outputs, preconditions and effects), it is not the case for the BIM domain. No BIM services have been specified following the computer science interpretation. A potential work item for the future can address adapting existing GIS services for BIM, while investigating which BIM services can also be needed (especially in the context of the advent of digital twins, security related services can be defined e.g. encoding of information, identifier formats, merging different IFC datasets).

5.3.2.8 [Conceptual] Semantic incompatibility regarding the concept of "product"

The concept of “product” is understood differently in the BIM domain and in the GIS domain. There are some relations established between product in a GIS sense and product in a BIM sense, but it needs to be further investigated and developed. In BIM a product is often understood as a “sellable” physical product, whereas in GIS information can be understood as a “data product”. For further information of product in BIM, see Annex A.

5.3.2.9 [Conceptual] Differences between conceptual schemas

Conceptual schemas are described differently in GIS and BIM standards. There are different schema languages and differences in schemas at the four levels of abstraction as described in 5.2.2.3, which is a key conceptual barrier between the domains. Furthermore, there are key conceptual incompatibilities in the abstract conceptual schemas between the domains.

5.3.2.10 [Conceptual] Differences in entity definition and interpretation

There are differences in definition and interpretation of terms used in the two domains. Both domains also have different methods of defining terminology. The BIM domain also lacks a consistent approach for handling terminology and extensions. For instance, some terminology is defined as part of ISO 16739-1 whereas ISO 12006-3 defines language independent information model to create dictionaries with the purpose of defining concepts and their relations. BIM terminology is defined by ISO/TC 59/SC 13/TF 01; its last version gathering 2 950 BIM terms gathered from several standards published by ISO/TC 59 "Buildings and civil engineering works". Several ISO/TC 59/SC 13 standards define BIM terms, among those: ISO 12006-3, ISO 19650 (all parts), ISO 22386 and ISO 29481 (all parts).

At the level of buildingSMART, the bSDD (buildingSMART Data Dictionary) is an implementation of ISO 12006-3, containing concepts and relations relevant for the BIM domain.

Definitions in ISO 191xx standards are available as an excel file according to ISO 19104. In addition, a web-based register (Geolexica) for multi-lingual terminology on geographic information technology is freely available. In addition, ISO/TC 211 definitions (in ISO 191xx standards) are incorporated in ISO terminology (accessible via https://www.iso.org/obp).

5.3.2.11 [Technological] Differences in extensions of the underlying architectures for addressing semantic interoperability issues

As described earlier there are incompatibilities in the underlying architectures between the domains. Some work is being done in both domains to improve this through bringing the core “closed domain” data models into semantic web ontologies, through generation of OWL from the underlying models (Express and UML). However, semantic web technologies do not solve the semantic interoperability barriers all together or by itself. Indeed, if ontologies are developed in silos, without being aligned, they are only raising the level of semantic heterogeneity. Furthermore, special attention is paid to ontology design best practices as defined by the W3C. Researchers have also proven that ontologies that are automatically generated from closed world languages like EXPRESS and UML models have weaknesses. Such automatically generated ontologies have been pushed in both fields (e.g. ifcOWL automatically generated from EXPRESS for BIM, and automatic generation of ontologies from TC 211 published standards in GIS).

5.3.2.12 [Conceptual] and [Technological] Differences regarding how coordinate systems are used and specified

The use of coordinate systems in BIM and GIS are conceptually very different. While the many relative Cartesian coordinate systems in BIM can be converted (translated, rotated) by 6 parameters, coordinate conversion in GIS needs to take account of the curvature, the Earth’s gravity field, cartographic projections and the precision of the realisation (benchmarks) in a useable geodetic reference frame. More details are given in the discussion on coordinate systems from the OGC/BSi IDBE discussion paper OGC 19-091 pages 9 and 12.

In IFC4, a local/engineering CRS (coordinate reference system) is implemented so there is no longer such a difference. GIS applies geographic CRS (geodetic, geographic and projected). In most cases, it would be a projected CRS (the local legal one). And the need to ensure proper georeferencing by provision of the base / reference point(s). See Annex C for further details.

5.3.2.13 [Conceptual] and [Technological] Differences in usage and specification of object geometry and topology (features)

The use of geometric and topological forms of representation in BIM and GIS are conceptually similar but adapted to the respective domain of expertise. While geographic information systems (GIS) map many structures with reduced complexity, highly complex shapes of individual components are stored in the digital model (BIM) during construction. The interoperability barriers that arise when transferring the information from one to the other conceptual model are usually at the application level. So far there is no clear opinion as to whether any (ISO) standardized transformation or linking rules (concerning the geometric and topological representation) bring added value to the construction industry and the geospatial industry.

5.3.2.14 [Conceptual] and [Technological] The use and understanding of metadata is different between the domains

5.3.2.14.1 General

The use of metadata in GIS allows important information about a dataset to be recorded, i.e. data history, data definition, extents, suitability. When exchanging data this information is essential to inform users.

Metadata is handled differently in GIS and BIM domains. Metadata is a key concern in the GIS domain, when exchanging data. ISO/TC 211 provides standards for metadata (including quality); however in the BIM domain this is not the case. Metadata is to some extent covered by ISO 16739-1, but not easily comparable. In addition, there are technological incompatibilities in how metadata is implemented and used. This also affects the exchange of information inside the domain, and obviously between the domains.

5.3.2.14.2 [Technological] Lack of consensus on information management practices

When going through an exchange process there is a high potential for decline of data quality, the loss of information either through limitations of software or incorrect/misinterpretation of process. This needs to be addressed to ensure information management (IM) process and assurance of quality is delivered.

In GIS, the ISO 191xx standards have strict requirements to be fulfilled and an abstract test suite (ATS) to ensure that the product is compliant to the standard. However, lack of sufficient detailed requirements can lead to incorrect/misinterpreted process in the exchange between the two domains, which is not necessarily the case within the GIS domain.

5.3.2.15 [Technological] Different techniques to spatially represent information

The process of spatially referencing BIM information container to a terrestrial reference frame is called georeferencing.

Georeferencing is addressed by the following entities in IFC:

— IfcCoordinateReferenceSystem;

— IfcProjectedCRS;

- IfcCoordinateOperation (Abstract supertype of IfcMapConversion);
- part of resource IfcRepresentationResource.

Georeferencing is addressed by the following entities in GIS:

- ISO 19111 referencing by coordinates;
- ISO 19112 referencing by geographic identifiers;
- ISO 19148 linear referencing.

Missing or inadequate georeferencing is a vital challenge for interoperability between the two domains.

5.3.2.16 Limitations on type of object available within GIS

ISO 19107 defines primitive and complex geometry types for GIS as points, curves, surfaces or solids. BIM includes swept solids and constructive solids in addition.

Incompatibilities have been found due to different geometry models. GIS applies the B-Rep (boundary representation) vs BIM (or more precise, IFC's) CSG (constructive solid geometry) representation, though IFC seems to also allow for B-Rep model. The transformation between these representation forms is not trivial.

6 GIS/BIM interoperability opportunities

6.1 General

This clause identifies elements from the BIM domain and the GIS domain that need to be shared. According to the incompatibilities identified and characterised in Clause 5, this clause proposes opportunities to resolve them. Specifically, this clause lists relevant opportunities for GIS/BIM interoperability from the following viewpoints: data interoperability opportunities (6.2) and service interoperability opportunities (6.3).

In Tables 19 and 20, indications are made whether the opportunity gives basis for further standardization work, which is further explained in Clause 7.

6.2 Data interoperability opportunities

Table 19 lists the interoperability opportunities at the data level, by categorizing them into the direction of exchange between the domains (FROM and TO), with a description of the process and the opportunity identified. It further lists existing standards that are impacted and at the end classifies whether the opportunity gives a basis for further standardization work.

Table 19 lists data exchange opportunities.

Table 19 — Data exchange opportunities

FROM	TO	Description	Opportunity	Standards impacted	Further work (Y/N)
GIS/BIM (1)	GIS/BIM	Different conceptual schema languages and metamodels lead to fundamental differences between schemas and instance data based on the schemas.	Specify differences and similarities between conceptual schema languages and metamodels. Investigate possibilities for mapping or linking at metamodel level. Mapping or linking can be used to transform or link schemas and instances.	ISO 16739-1 ISO 19103 ISO 19109 ISO 12006-3 ISO 23387	Yes
GIS/BIM (2)	GIS/BIM	Differences in conceptual models lead to fundamental differences between schemas and instance data based on the schemes. The differences include that concepts appear to have the same meaning, while they are actually different, as well as schemas that describe the same concepts differently.	Specify differences and similarities between conceptual models. Investigate possibilities for mapping or linking schemas and instances. Mapping or linking can be used to transform or link schemas and instances.	ISO 16739-1 ISO 19103 ISO 19107 ISO 19137 ISO 19111 ISO 19108 ISO 19112 ISO 19141 ISO 19148 ISO 19157 ISO 19110 ISO 19123	Yes
GIS/BIM (3)	GIS/BIM	Naming conflicts are related to differences in the designation of concepts related to the presence of synonyms, homonyms, etc.	Technical report that specifies terms and synonyms and translations between the two domains.	TC 211 TMG and TC59 SC2 WG 4	Yes
BIM (4)	GIS	Different concepts of Georeferencing IFC models lead to incorrect coordination of spatially distributed building models. With a common terms of/way of georeferencing, integration of BIM models directly into GIS can be eased / improved. Survey points (tie points for transformation) need to be included.	Technical report to provide guidelines for proper georeferencing of BIM models.	ISO 19111 ISO 19148 ISO 16739-1 (IFC) IFC Project Setup Information Deliveral Manual (IDM) (bSI)	Yes

Table 19 *(continued)*

FROM	TO	Description	Opportunity	Standards impacted	Further work (Y/N)
BIM (5)	GIS	The BIM2GIS requirements for spatial representation have not yet been (ISO) standardized. There are no formal agreements, which means that individual objects can be incorrectly transformed in practice. A standard that restricts the diversity of geometrical representational forms would help software companies to bring faster functional implementations to the marketplace.	"International Standards on how to transfer BIM information to GIS systems can provide the industry with (very general) information requirements. These geospatial Exchange Information Requirements (geoEIR) are a human readable specification for BIM export. geoEIR will help in many BIM2GIS use cases because different BIM software will uniformly export the georeferencing, geometry, and topology of the built assets. Based on the "buildingSmart Model Setup IDM" an ISO policy can make management agreements about which geometrical presentation types in the geoEIR can or cannot be exported. Later, also machine-readable model definitions can be implemented". See also Annex D.	ISO 16739-1 (IFC) Spatial schema/ISO 19107 Metadata/ ISO 19115 IFC Project Setup IDM (bSI)	Yes
GIS (6)	BIM	In practice it is difficult to import and make use of GIS geometrical data in BIM domain software. This relates to the use of models and the quality management in the process of exchange. CityModels are not easy to import in BIM software, because the models contain geometric-topological errors (e.g. selfintersecting polygons) that are not explicitly forbidden in the GIS standard but lead to problems in BIM software.	Create quality management procedures required for exchange between GIS and BIM ensuring geometric and topological quality and consistency in exchange, to ease implementation.		Yes
GIS/BIM (7)	GIS/BIM	When exchanging data between domains, metadata (e.g. provenance, quality etc.) needs to be considered. Metadata is a large component of Geospatial for handling provenance on the data, but it has a different meaning when utilised in BIM.	Opportunity for BIM to benefit from how GIS utilises Metadata. Work required to better understand how GIS style metadata can be prepared and used in BIM.	ISO 19115 (all parts) ISO 19157 CSW (OGC) (ISO 23386) ISO 16739-1 (IFC)	Yes

Table 19 *(continued)*

FROM	TO	Description	Opportunity	Standards impacted	Further work (Y/N)
(8)		Need to investigate and report on how the quality of information has the potential to change during the exchange process and how this information on change is reported to the actors.	During the exchange process the quality has the potential to change, this change can lead to a reduction in quality. From an Information Management aspect where source data contains assurance it is essential this change is either maintained or reported.	ISO 19650 (all parts)	Yes

6.3 Service interoperation opportunities

6.3.1 General

6.3.2 and 6.3.3 concern interoperability opportunities at the service level for the respective direction of interaction of the service.

In 5.3.2.7 under incompatibilities it is stated that the concept of "service" is understood differently in the BIM domain and in the GIS domain.

A potential service interoperation opportunity can address adapting existing GIS services for BIM, while investigating which BIM services can also be needed (especially in the context of the advent of digital twins, security related services need to be defined e.g. encoding of information, identifier formats, merging different IFC datasets)

However, testing and adapting GIS services for BIM is not really a standardization work.

6.3.2 GIS-to-BIM

Table 20 represents interoperability opportunities at the service level where GIS domain have a need to be served from the BIM domain.

Table 20 expresses services, where the GIS domain has a need to be served from the BIM domain.

Table 20 — GIS to BIM service interoperation opportunities

Service use			Service response			Involved in complex service + list of interconnected services	Further work (Y/N)
Description	By [Service Requestor]	From [Service Provider]	Description	From [Service Provider]	To [Service Requestor]		
Data Templates for construction objects/ geo-entities	Land surveyor, geodata-provider	Domain specific data dictionaries, property template server	Data templates for geo entities provides means to a) align the semantics (name, attribute set, classification); b) provide detailed exchange information requirements as human readable document and web service for geo-objects/ entities/feature used in BIM projects. Geo-objects are mainly needed for the "as-is" model.	Data template server	Surveying software (field-to-BIM); GIS; BIM-authoring tools and model checker	Data templates are based on ISO 12006-3 (bsDD) which has to compared to ISO 19109 (GFM). ISO 23386 specifies the expert process to describe author and maintain properties. The scope of ISO WI 442008 is how the Data Templates have to be designed. ISO WI 442018 will standardise the IFC structure for data templates.	NA Wait for the standardization to mature
CDE API for geo-feature	Geodata manager	BIM manager, offering the CDE	A CDE is an agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process. A CDE workflow describes the processes to be used and a CDE solution can provide the technology to support those processes. (ISO 19650-1:2018, 3.3.15) Geospatial data in the CDE (information container with geospatial content) are Created, Read, Update, Deleted by Geodata manager using GIS software.	CDE (BIM management)	Geodata manager (GIS)	Check compatibility CDE API (CEN preliminary WI WI=00442032) with OGC API – Features (Part 1: Core) Check whether Links/Requests to geospatial services are possible in CDE or within a linked container structure (ICDD)	NA Wait for the standardization to mature

6.3.3 BIM-to-GIS

Table 21 represents interoperability opportunities at the service level where BIM domain has a need to be served from the GIS domain.

Table 21 expresses services where BIM domain has a need to be served from the GIS domain.

Table 21 — BIM to GIS service interoperation opportunities

Service use			Service response			Involved in complex service + list of interconnected services
Description	By [Service Requestor]	From [Service Provider]	Description	From [Service Provider]	To [Service Requestor]	
Use existing services for maps (web map service), vector data (web feature service or core OGC API features), raster data (web coverage service) or meta data services	BIM user, BIM author and BIM coordinator	Any geospatial service provided in spatial data infrastructure (SDI)	The web service delivers geospatial data (map as background, vector e.g. cadastre, raster e.g. terrain or aerial image, metadata) to software clients, that are used in BIM projects, such as BIM authoring tools or model checker.	WMS, WFC, WCS or OGC API feature	Any BIM software	This opportunity can be reached on the service level by implementing BIM-clients. Specific problems will arise on the data level. In the long term it can be useful to equip OGC API feature (neutral to encoding) with IFC output, if this is useful.

7 Suggestions for further work

7.1 General

7.2 to 7.4 identify areas for further standardization work.

7.2 Linking abstract concepts in BIM and GIS standards (opportunity 1 and 2)

It would be appropriate to define similarities and differences in order to establish links and transformations between abstract concepts in BIM and GIS standards.

Different conceptual schema languages, metamodels and the use of these for describing the real world in BIM and GIS standards has led to differences between conceptual schemas and implementations based on the schemas. Furthermore, conceptual schemas from the two domains have defined separate but equivalent abstract concepts for time, measures, geometries and more.

Schema crosswalks and ontology linksets can define links and transformations between equivalent concepts. Links and transformations between UML and EXPRESS at a metamodel level – as well as on the use of the conceptual schema languages in IFC and ISO/TC 211 standards – will enable improved interoperability between information models. Links and defined transformations between abstract concepts will contribute to the use of information models and information across domains.

7.3 Geospatial and BIM dictionary (opportunity 3)

It would be appropriate to specify terms and synonyms and translations between terms in the two domains.

Naming conflicts are related to differences in the designation of concepts related to the presence of synonyms, homonyms, etc.

Similar terms or function definitions will exist both in BIM and GIS. The categorisation of them can be graded in relation to how complex the comparison is.

a) unique to either BIM or GIS;

b) attached within BIM and GIS;

c) variant, in both but having a variance in definition;

d) new requirement, creation of new terms specific to an action or requirement adopted by the exchange process.

e) complex, additional work required to improve understanding of terms.

A dictionary of terms in the two domains will bridge the gap between the two domains.

Schema crosswalks and ontology linksets can define links and transformations between equivalent concepts.

The level of detail in definition of terms will increase to accommodate a potential for reduced understanding in the terminology of either BIM or GIS. Investigation is required to better understand if current terminology for BIM and GIS meets the required levels of this standard.

7.4 Information exchange guidelines between BIM and GIS

Related to opportunities:

(4) Georeferencing BIM models

(5) Reduced complexity and restricted data types for BIM2GIS processed (GeoEIR)

(6) GIS quality model to achieve high numerical/geometric and semantic demands for BIM

(7) Metadata to support bidirectional GIS/BIM information exchange

(8) Change of quality in the process

It would be appropriate to provide guidelines for information exchange using open standards between the construction and the geospatial domain. Domain specific aspects are: georeferencing, spatial representation (2D/3D), semantic alignment and metadata. Geodata manager and BIM manager will use the guidelines for quality management, to specify information requirements, organize information exchange and check data deliveries. IT professionals are provided with cross-domain conceptual guidelines to design software interfaces.

During its work the "Joint ISO/TC 59/SC 13 - ISO/TC 211 WG: GIS-BIM interoperability" recognized that many barriers for interoperability arise only because existing standards are unknown or used improperly by professionals. This applies particularly to the standards of the other domains. This suggested work item does not aim to develop new standards but provide guidelines on how to use existing standards adequately so that the other domain can provide and request information properly. ISO standards are in focus, but to maximize the usefulness of the guidelines considered in this context, the latest developments from OGC and buildingSMART also need to be considered.

Georeferencing of BIM models is as a major base task for almost every use case. With the ISO 16739-1 (IFC) the alphanumerical and numerical values that describe the position and orientation of the building related to a geodetic CRS are redundant: The information is distributed over several entities and can be stored in an ambiguous manner in IFC4. Therefore, the guidelines will explain how to store transformation parameters consistently in IFC. The guidelines will be based on, but go beyond the buildingSMART model set up IDM, also considering engineering surveying control points, GIS conform WKT/proj4 strings for datum transformation, proper explanation of scale and meridian convergence as well as the visualisation of the project base point.

A major practical challenge is the immense diversity of geometric representation types within the IFC. standard guidelines that restricts the diversity of geometrical representational types would help software companies to bring faster functional implementations to the marketplace. A concept for a geospatial exchange information requirements (geoEIR) can be prepared as practical guideline. This formal / computer-readable specification for restricted BIM-export e.g. to B-Rep can be useful in many

BIM2GIS use cases. With a geoEIR, different BIM software will uniformly export the georeferencing, geometry, topology and semantics of the objects and thus deliver standardised output, ready to be imported or linked to GIS.

Along the geospatial standard ISO 19157, relevant quality measures need to be selected and described quantitatively in the guidelines. Quality testing routines need to be conceptualised, so that geodata can be imported adequately and quality assured in BIM software.

The aspect "semantic alignment" is very much related to 7.2. However, practical guidelines need to be provided to the geospatial community, how they can plug-in to the evolving standard family for data templates, namely: ISO 12006-3 as general taxonomy to describe objects, ISO 23387 principles for data templates for construction objects, ISO 23386 the expert process to describe, author and maintain properties and the relates IFC data exchange (WI 442018). These standards are complementary to IFC, because they address dynamic semantics (rather than strict semantic models) and information requirements (rather than data exchange). However, besides being designed to manage product data specification, this ISO standard family can also be used to semantically align information of existing geo-objects. The aim is to align the concept to describe semantics also for geographic information and measured surveys with the construction domain.

Metadata give great opportunities to find, evaluate and manage information. Practical guidelines help to select the most relevant types of metadata from ISO 19115, ISO 16739-1 and ISO 19650 (all parts). Furthermore, it need to be explained how the metadata data from one domain are transferred practically to the other domain.

Annex A

Handling of information about construction objects (product handling)

A.1 Introduction

Construction projects involve assembling "externally produced units" (construction objects) into a built asset. Construction objects and product catalogues are essential in this activity. Geospatial information consists of digital representations of "natural objects" typically not involving fabricated construction objects. Built assets are embedded within a geospatial context, and information about construction objects come from data sheets following a data template for construction objects. The concepts and principles of data templates, and the processes of how to create properties and data templates for construction objects is being standardized in CEN/TC 442 and ISO/TC 59/SC 13.

This annex provides information for construction objects and aims to identify opportunities for interoperability between building information modelling and geospatial information modelling. In addition, it provides suggestions on future work to overcome these barriers.

Is the concept of PDT suitable for dissolving interoperability barriers between geospatial and building information models when it comes to "as-is" BIM, describing the existing buildings and near-by topography? What are the implications, if the term "product" is extend to "geospatial feature"? The suggestions on future standardization work are outlined.

Table A.1 shows schemas applicable for product handling in BIM and GIS standards.

Table A.1 — Product handling in BIM and GIS standards

Schema name	Reference	Description
Organization of information about construction works –Framework for object-orientation information	ISO 12006-3	Specifies a language -independent information model which can be used for the development of dictionaries used to store or provide information about construction works.
Data template specification based on ISO 12006-3	ISO 23387	Sets out the principles and structure for data templates for construction objects.
Property attributes modelling	ISO 23386	
Data product specifications	ISO 19131	Specifies requirements for the specification of geographic data products. The term data product in ISO 19131 is not pointing to the information about construction objects (products), instead it points to the requirement for data delivery. It is a precise technical description of the data product in terms of the requirements that it will or can fulfil.
Industrial automation systems and integration—Integration of life-cycle data for process plants including oil and gas production facilities	ISO 15926	
IFC exchange of product data	WI 00442018 (CEN/TC 442 work item, no official reference code yet)	

Table A.1 *(continued)*

Schema name	Reference	Description
Data structures for electronic product catalogues for building services	ISO 16757 (all parts)	Enables building services system designers to import the product data of different manufacturers into their design software.
Enabling use of environmental product declarations (EPD) at construction works level using building information modelling (BIM)	ISO 22057	

A.2 Use cases

GIS to BIM use case:

— Providing "as-is" data such as parcels, roads, city furniture, terrain. GeoPDTs, describing the characteristics of geo- entities, will be established for specific deliverables in the BIM process. Together with geospatial exchange Information Requirements (geoEIR)s the receiving BIM-software has a unique machine-readable structure and set of attributes for geo-objects.

BIM to GIS use case:

— After construction: uploading "as-built" IFC-models with unique semantic structure.

— A "geoPDT for measured surveys" can be used in a digital information exchange for specifying the basic requirements (demands) on the digital description of measured topographic objects, e.g. CRS, geometric representation (point, line, face, solid) and well-defined attributes (ISO 23386) related to the object.

— A "geoPDT for geodata products" can be used in a digital information exchange for specifying the basic requirements (demands) on the digital description of geo data products, as described in ISO 19131. Geodata products in a BIM context are models of the existing build environment (parcels, streets, utilities, terrain…) in the surrounding of the planned building.

Example on digital terrain models:

The property Server defines the properties to describe the product delivery "digital terrain model":

— Raster/TIN

— Data Provider

— Resolution

— Number of points

— Outer boundary

— Break lines yes/no

These properties are collected as PDT and sent as "empty forms" to the geodata manager or land surveyor reviews. They then have a structure to describe all the desired metadata on their product "digital terrain model".

The terrain model including the "filled form" as PropertySets are sent as IFC dataset and added to the collaboration model (BIM).

Data templates for aligning semantics as standardised in ISO 12006-3, ISO 23386 and ISO 23387 that can be used for product data and geospatial data in the same system architecture is described in Figure 6, e.g. using the same taxonomy for property sets will bridge the gap between BIM and geospatial"

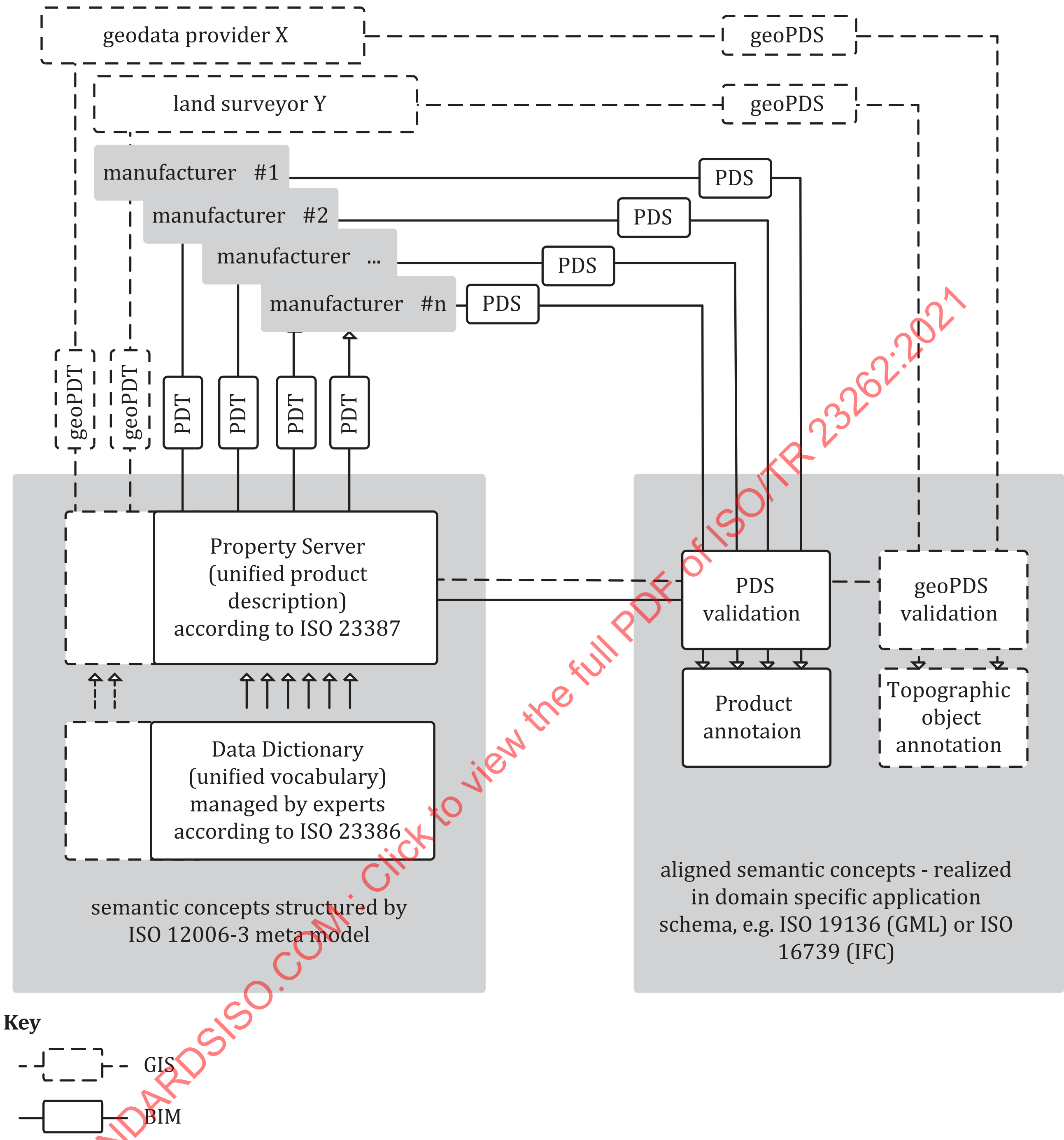


Figure A.1 — Data templates for aligning semantics

A.3 Comparison of concepts and vocabulary

Table A.2 compares concepts and vocabulary in the BIM and GIS domains.

Table A.2 — Table A.2 Comparing concepts and vocabulary in BIM and GIS

EN ISO 12006-3	ISO 16739-1	ISO 19131/Other source
xtdBag	IfcProject	potentially core:CityModel
xtdSubject	IfcLibraryReference	the application schema potentially serves similar demands
xtdProperty	IfcPropertyTemplate	-
xtdNest	IfcPropertySetTemplate	-
xtdMeasureWithUnit	IfcMeasureWithUnit	-
xtdUnit	IfcUnitOfMeasure	unit of measure that goes with each coordinate (GML 3.0)

Annex B

IFC and data templates

B.1 General

IFC is a common data schema that makes it possible to hold and exchange relevant data between different software applications. Even though IFC is mainly used for buildings today, there are several initiatives working on expanding the schema to cover other user needs within infrastructure, airports, rail, bridges etc. For all these domains, exchange of geospatial information is essential.

B.2 Challenges with IFC

Many actors in BIM require the use of open international standards to exchange information about the construction objects. For a growing number of projects, the delivery of digital product information is required to be based on ISO 16739-1 (IFC).

For an industry that is in digital change, where most actors are uncertain of how to relate to the existing delivery requirements for product information within BIM, it is essential with an unambiguous way of communicating project requirements between the project stakeholders. Different geographical locations will generate different markets and authorities. This is not possible to support using IFC schema as per today.

IFC is a common data schema that makes it possible to hold and exchange relevant data between different software applications. The schema represents a building or construction object, which in IFC is called an entity, down to a certain level of detail. Each entity has a property set where a list of properties has been defined. However, there are three major challenges with the properties in IFC:

a) The number of IFC properties only covers a small part of the information requirement for construction objects.

b) IFC properties apply to a generic level of construction objects, not to product level.

c) IFC properties are designed to meet a generic global level, not the requirements of national regulations, and of ISO standards, CEN / CENELEC standards, and national standards.

IfcPropertySets though provides a mechanism for adding user-defined properties to any IfcObject (and though IfcProduct). These user-defined IFC properties will then only syntactically conform to IFC but not approvable conform any semantic domain standard. This enables the IFC to exchange information on products that meet local requirements and needs. There are standards under development in ISO/TC 59/SC 13 covering this topic where a data dictionary based on ISO 12006-3 is the source to describe the local business needs for construction objects. IFC can exchange this information without the use of IFC properties.

B.3 Lack of machine-readable information for objects

There are no standardized digital means for object-related description of the information exchange requirements of individual measured or modelled real world objects to be measured or modelled by geospatial engineers. Experts can only exchange this information with human-readable, but not machine-readable documents.

B.4 Lack of exchange standards for single geo-objects

There are no standardized digital means to exchange single geo-objects with agreed geometric representation and attributes in order to make them readable by BIM-software and ready for automated validation.

B.5 Lack of BIM-ready geo-web services

Geo-web-services are not BIM-ready, because the geo-objects delivered by WFSs are not using IFC but GML. ISO 19168-1 geospatial API for features does not mandate any specific exchange format, the initial application of this standard for IFC needs to be explored in a testbed in order to identify best practices and consider requirements for a standardization project.

Annex C

Georeferencing

C.1 General

Georeferencing is a major base-task for many use cases that acquire, manage, analyse or visualise the geometric information of buildings (BIM) and topography (GIS) as combined or linked information. Georeferencing is performed through a coordinate transformation (ISO 19111) from one coordinate system to another where at least one of the coordinate systems is related to a geodetic datum.

A building model is geo-referenced if enough meta-information (IS0 19115-1, MD_Georeferenceable) is given to apply a coordinate transformation from the coordinate system of the building or construction site to a geodetic coordinate system like a national grid. The method and quality of the transformation depends on the use case and the desired accuracy.

For interoperability, it is essential to establish mutual understanding of georeferencing of both, BIM and geospatial domain experts. The BIM and geospatial domain have different concepts, standards, algorithms and technologies for georeferencing.

In ISO/TC 211 conceptual models and ISO 19136 (all parts) (Geographic Markup Language GML) encoding, the georeferencing is provided by the SRS, documented by the srsName attribute, and also (and even more) identified by its SRS identifier, such as an EPSG code or any other geodetic register identifier, which is the basis for all GML geometry elements. Therefore, each geometry element that provides location information needs to carry the srsName attribute. For examples a Point <gml:Point srsName="utm27n">. The srsName can determine the CRS by name or by explicit definition. The conceptual model to define CRS is given by ISO 19111.

Using ISO 16739-1 (IFC) only to geo-reference building models is an important base-task for many use cases, when BIM and geospatial data are shared.

With the ISO 16739-1 (IFC) the alphanumerical and numerical values that describe the position and orientation of the building related to a geodetic CRS are redundant: The information is distributed over several entities and can also be stored redundantly in IFC4 (or previously in IFC 2x3, which is presently supported by most tools). Therefore, this document gives an overview on how georeferencing can be stored in IFC.

Figure C.1 illustrates how an IFC building model can be connected to CRSs, as handled by GIS domain.

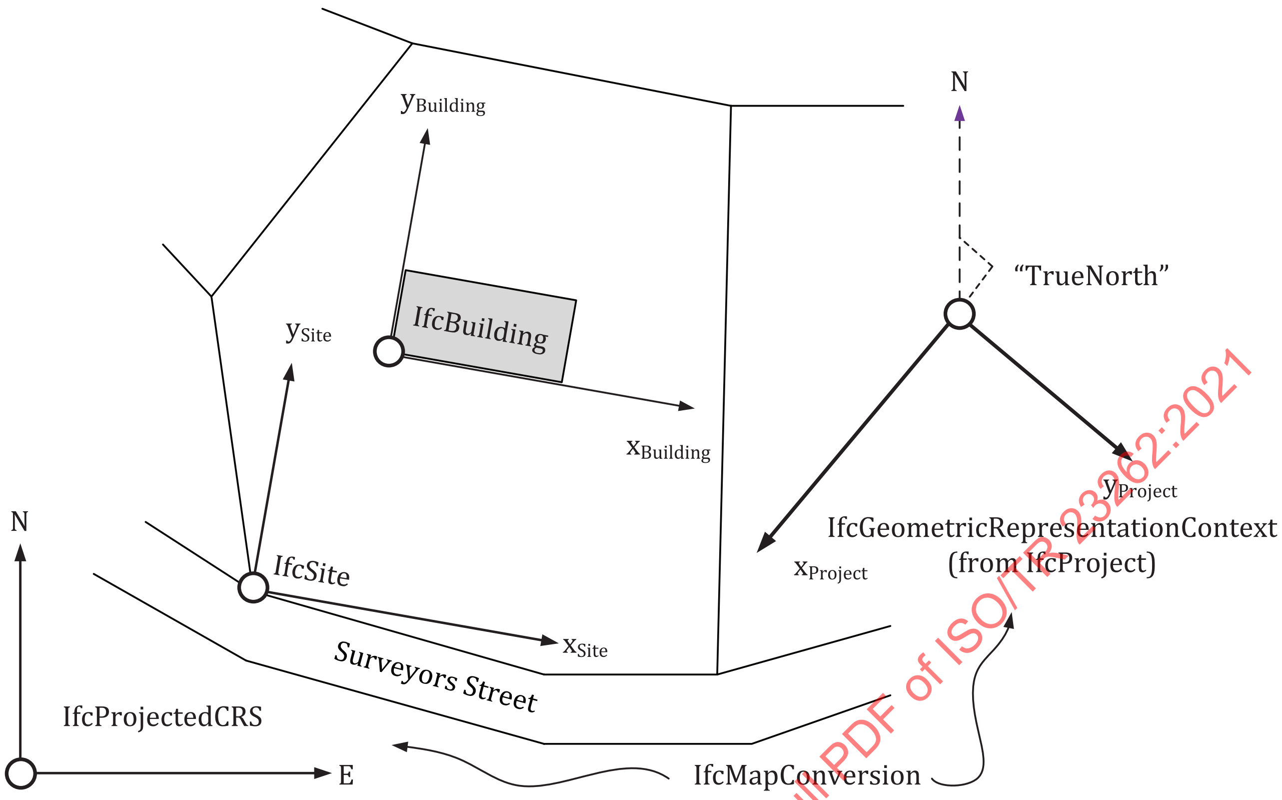


Figure C.1 — Cascading relative CRS for a BIM Project (for a BIM building model)

Practical experience shows that BIM authoring software writes the georeferencing very differently. To have a common language (used in exchange information requirements (EIR), BIM execution plan or information delivery manuals (IDM)) this document proposes a LoGeoRef concept under the following "Metric": The higher the LoGeoRef is, the higher quality of georeferencing is. Higher levels do not automatically include information out of lower levels. Each level comprises its own IFC-schema attributes and is standing on its own. The metric is designed with decimal steps to allow intermediate steps e.g. for elevation, quality of attribute values, project-specific extensions.

C.2 LoGeoRef 10 (postal address, project management)

The simplest way to describe a site or a building location is to add an address to the BIM project. Postal addresses are easy human readability and semi-structured for machines. For georeferencing purposes, it is only a rough approximation for setting the location of the site or the building. Nevertheless, it can be helpful for integrating GIS data like adding data of surrounding city models.

The IFC schema provides an entity for storing address data in an IFC-file. The entity IfcPostalAddress contains multiple attributes including address lines, postal code, town, region and country. For a correct assignment to a spatial structure element, the IfcPostalAddress object has to be referenced by either IfcSite or IfcBuilding. Both entities include a certain attribute for address referencing.

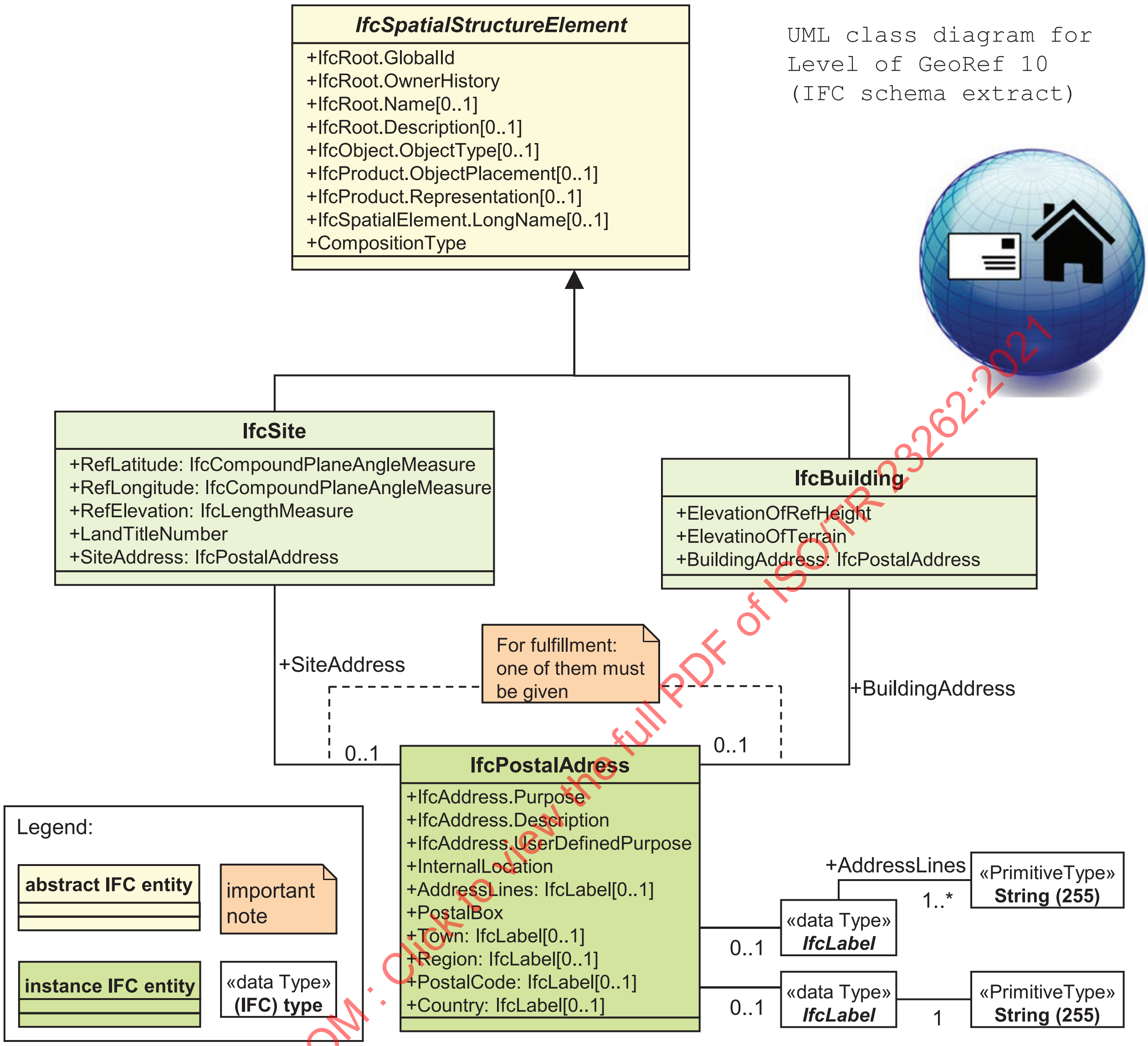


Figure C.2 — IFC entities to specify a postal address (LoGeoRef10)

The file contains an instance of IfcPostalAddress with information for georeferencing highlighted in the green frame (see Figure C.2). In this case, the address is referenced by an instance of IfcSite and an instance of IfcBuilding (red frames). Please note that for fulfilling LoGeoRef 10 the IfcPostalAdress does not has to be referenced in both entities.

The following file extract shows a simple georeferencing example with geographic coordinates and postal address.

```
#445= IFCSITE('0x4O8ugOrDO9QL8HjLBpak',#41,'SiteName',$,'',#444,#437,$,.ELEMENT.,
                  (51,2,2,346496),(13,44,2,95184),115.10,$,#106);
#110= IFCBUILDING('2jdRbanYj5W8hjkAXSMLMz',#41,'',$,$,#32,$,'',.ELEMENT.,$,$,#106);
#106= IFCPOSTALADDRESS(.SITE.,'Address of HTW Dresden, Faculty of Spatial Information ','',$,
                  ('Reichenbachstrasse 1'),$,'Dresden','Saxony','01069','Germany');
```

C.3 LoGeoRef 20 (geographic coordinate, point on map)

There is another simple way for georeferencing IFC-files. For compliance with LoGeoref 20, instances of IfcSite need to contain values for their attributes RefLatitude and RefLongitude. As their names suggest an IFC model is able to store one single point coordinate with longitude and latitude directly in IfcSite. According to the IFC schema definition its values are geographic coordinates with respect to the World Geodetic System (WGS84 with EPSG:4326). Besides that, it is also possible to store a value for the elevation in the corresponding attribute RefElevation. By definition, RefElevation needs to have a metric value related to a locally used datum relative to the sea level. However, there is no possibility to specify the datum´s name explicit in the file, see Figure C.3.

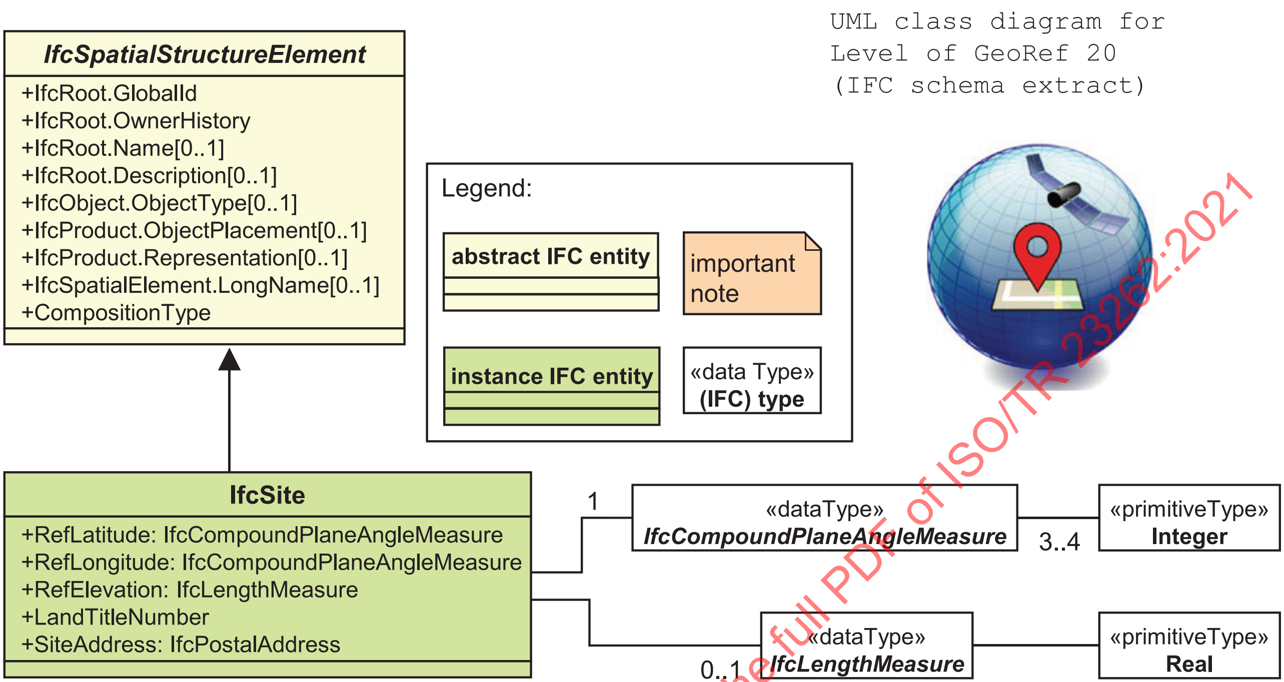


Figure C.3 — IFC Entities to specify geographic coordinates of the site (LoGeoRef20)

The below example shows a corresponding IFC-file extract with numerical and syntactical example for geographic coordinates related to IFC site (LoGeoRef 20).

```
#445= IFCSITE('0x4O8ugOrDO9QL8HjLBpak',#41,'SiteName',$,'',#444,#437,$,.ELEMENT.,
                           (51,2,2,346496),(13,44,2,95184),115.10,$,$);
```

Latitude and longitude are stored as comma-separated integers fulfilling the conditions of the IFC-type IfcCompoundPlaneAngleMeasure. There can be three or four integers describing the required angle. The first value stands for the degree, the second for the minutes, the third for the seconds and the optional fourth for the millionth-seconds part of the angle. This shows that it is possible to set a point coordinate for IfcSite in a very accurate way. LoGeoRef20 does not include possibilities to store any rotation parameters, though. Although the numerical precision for lat/lon can be high, proper CRS for engineering surveying and cadastre need better geodetic datums than WGS84. WGS does not take regional/local shifts (e.g. continental drift) into account.

C.4 LoGeoRef 30 (3+1-parameter for IfcSite placement)

LoGeoRef 30 describes the possibility to store the location of any IfcSpatialStructureElement directly in its LocalPlacement-object. Subclasses that can be instantiated in an IFC-file are IfcSite, IfcBuilding, IfcBuildingStorey or IfcSpace. As an important constraint, LoGeoRef 30 applies only to those spatial structure elements that do not have a relative placement to another spatial structure element. Therefore, the attribute PlacementRelTo of the IfcLocalPlacement-object belonging to the IfcSpatialStructureElement needs to be empty (“$”). Usually this is the same spatial element which is also the uppermost element in the spatial hierarchy. According to the IFC schema definition this always needs to be an IfcSite-object.

The attribute RelativePlacement is of type IfcAxis2Placement3D, so X-, Y- and Z coordinates for the location can be stored together with vector components for an angle specification for a rotation of the X-axis and the Z-axis.

This makes it possible to store placement for the translation to an arbitrary coordinate reference system (CRS) in the Location attribute and the rotation (true north) as vector of the specific axis respectively RefDirection attribute, see Figure C.4.

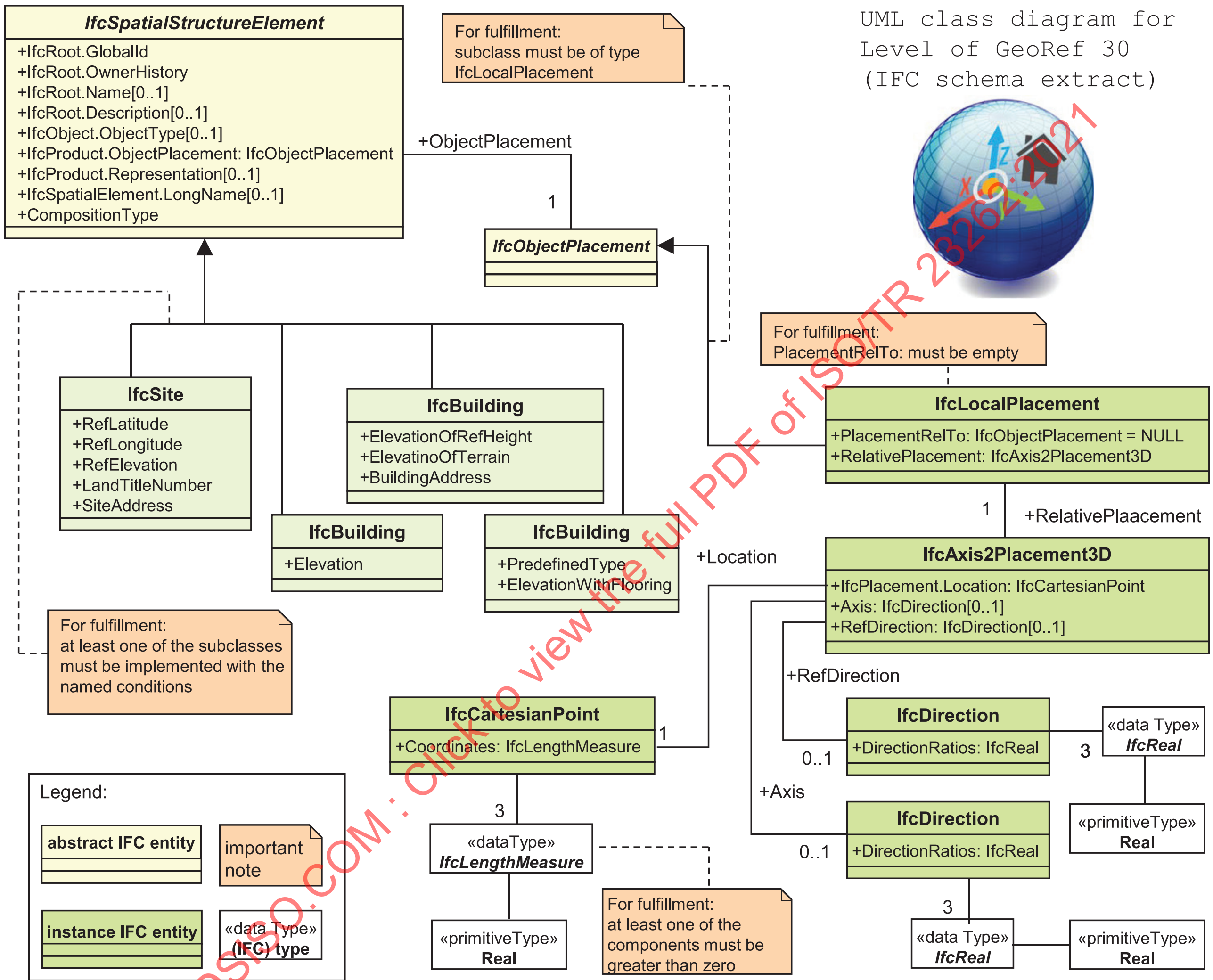


Figure C.4 — IFC Entities to specify translation (offset, Easting/Northing) and rotation of a building or a site (LoGeoRef 30)

The below example shows a corresponding IFC-file extract for satisfying this level (simple 3-Parameter-Transformation as Placement of IFC Site):

```
#69182= IFCCARTESIANPOINT((5656243.561,5411838.574,0.));
#69183= IFCDIRECTION((0.,0.,1.));
#69184= IFCDIRECTION((0.94640939062909,0.322969449529013,0.));
#69186= IFCAXIS2PLACEMENT3D(#69182,#69183,#69184);
#69187= IFCLOCALPLACEMENT($,#69186);
#69188= IFCSITE('1fhWSaVqX4OwpLiY3_CNsN',#41,'SiteName',$,'',
        #69187,#69180,$,.ELEMENT.,(48,8,20,852966),(11,34,48,669204),0.,$,$);
```

In this example, the IfcGeometricRepresentationContext contains a geo-referenced location in IfcCartesianPoint. Its directions are optional and not explicitly given. That means they use their default directions for X-axis (1/0/0) and Z-axis (0/0/1). The rotation (true north angle) is given in IfcDirection (#91).

This example shows the possibility to store geo-referenced coordinates and rotations for the whole project context and not only for a certain (spatial) element. Furthermore, the TrueNorth attribute provides the option to set a distortion directly relative to the north direction.

However, those options can be confusing and redundant when direction attributes are set at WorldCoordinateSystem and TrueNorth as it can happen when LoGeoRef 50 is fulfilled.

C.5 LoGeoRef 40 (3+1-parameter using GeometricRepresentationContext of IfcProject)

LoGeoRef 40 provides two main attributes to store georeferencing attributes in an IFC-file. Both WolrdCoordinateSystem and TrueNorth are part of the IfcGeometricRepresentationContext of an instantiated IfcProject. According to the IFC schema defintion every IFC-file contains an IfcProject and also a referenced IfcGeometricRepresentationContext with the attribute ContextType given as “Model”. It is also possible to set up a coordinate system for the 3D-model context of the project via the attribute WorldCoordinateSystem.

The other attributes follow the same rule as mentioned in previous LoGeoRef 30. A location stored in an instance of IfcCartesianPoint and optional directions for X- and Z-axis, stored in instances of IfcDirection.

As a second main attribute there is the TrueNorth attribute. This attribute is used in case that the Y-axis of the given WorldCoordinateSystem does not point to the global northing. That means that this is another way to set a rotation for the XY-plane. In consequence, the corresponding IfcDirection can only store two vector components.

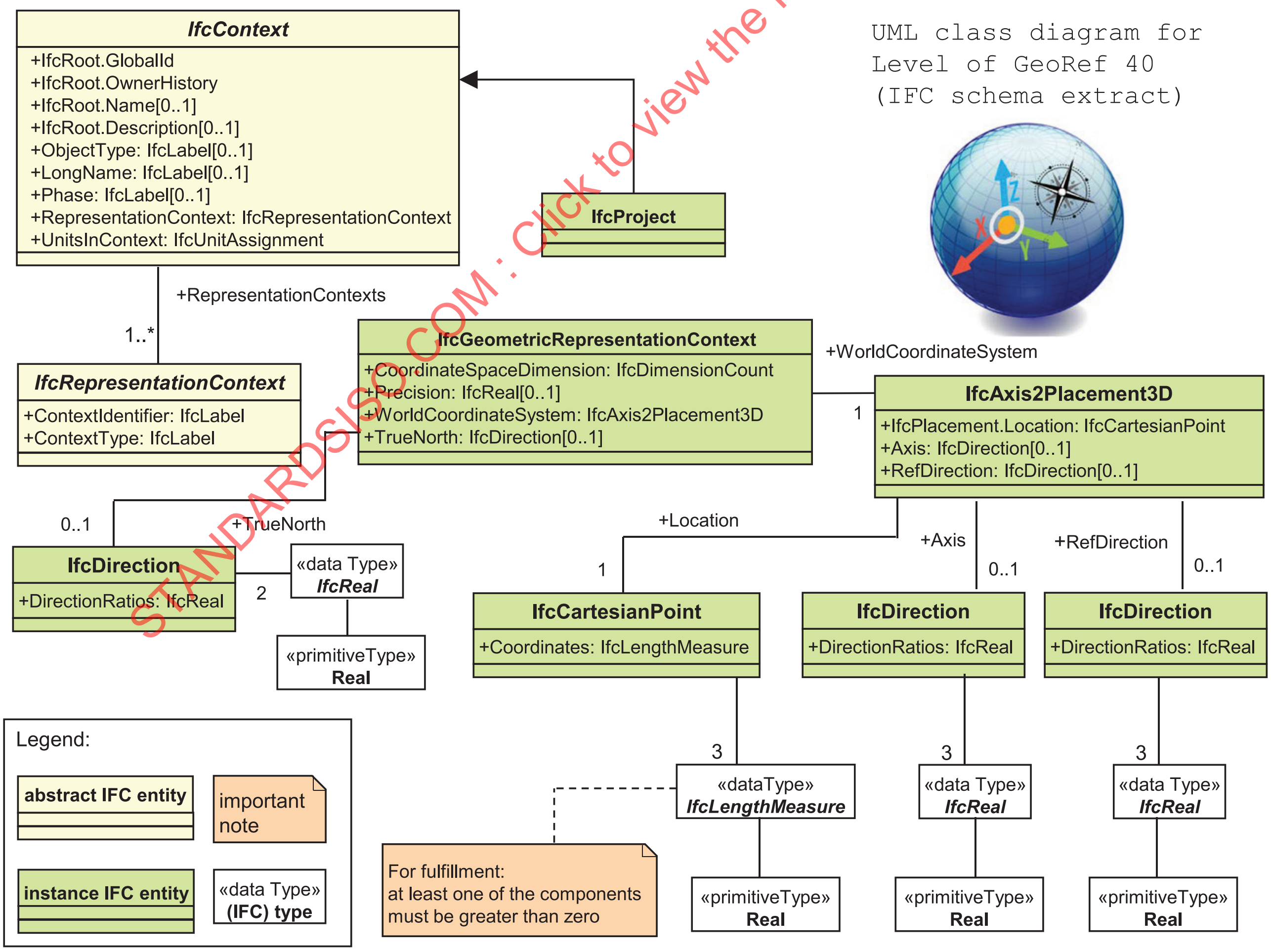


Figure C.5 — IFC entities to specify the geometric representation context of a project (LoGeoRef 40)

```
#89= IFCCARTESIANPOINT((5656243.561,5411838.574,115.1));
#90= IFCAXIS2PLACEMENT3D(#89,$,$);
#91= IFCDIRECTION((0.322969449529013,0.94640939062909));
#93= IFCGEOMETRICREPRESENTATIONCONTEXT($,'Model',3,1.00000000000000E-5,#90,#91);
#104= IFCPROJECT('3I$EzliEjENBTAsc55oSMB',#41,'ProjectName',$,$,
                 'BIM project example','phase1',(#93,#101),#88);
```

Numerical and syntactical example for geo-referencing the geometric representation context of a project (LoGeoRef 40)

In the example (Figure C.6) the IfcGeometricRepresentationContext contains a geo-referenced location in IfcCartesianPoint. Its directions are optional and not explicitly given. That means they use their default directions for X-axis (1/0/0) and Z-axis (0/0/1). The rotation (true north angle) is given in IfcDirection (#91).

The example (Figure C.5) shows the possibility to store geo-referenced coordinates and rotations for the whole project context and not only for a certain (spatial) element. Furthermore, the TrueNorth attribute provides the option to set a distortion directly relative to the north direction.

However, those options can be confusing and redundant when direction attributes are set at WorldCoordinateSystem and TrueNorth as it can happen when LoGeoRef 50 is fulfilled.

C.6 LoGeoRef 50 (3+1 parameter and CRS metadata)

This level provides the highest quality regarding the georeferencing of an IFC-file. It is only available in IFC-files since IFC schema version 4. So, it is important to note that no IFC-file previous to IFC4 can fulfil this level.

With IFC schema version 4 buildingSMART introduced some entities especially for georeferencing purposes. In particular, the entity IfcMapConversion stores the offset between project coordinate system and the global origin of a coordinate reference system with the attributes Eastings, Northings and OrthogonalHeight for global elevation. The rotation for the XY-plane will be stored using the attributes XAxisAbscissa and XAxisOrdinate. Each attribute stores one vector component of the resulting angle (unlike the TrueNorth attribute with both vector components, see LoGeoRef 40). With the attribute Scale a distortion of distances can be introduced.

The connection to the project is made by the attribute SourceCRS that inherited from IfcCoordinateOperation. As a constraint of LoGeoRef50 the SourceCRS needs to be of type IfcGeometricRepresentationContext. TargetCRS is consequently the coordinate reference system that needs to apply to the project. For describing these systems, IFC4 is able to store data regarding the CRS via an instance of IfcProjectedCRS. By schema definition it is recommended to specify the CRS with an EPSG-code. However, it can also be specified via the other attributes of this entity.

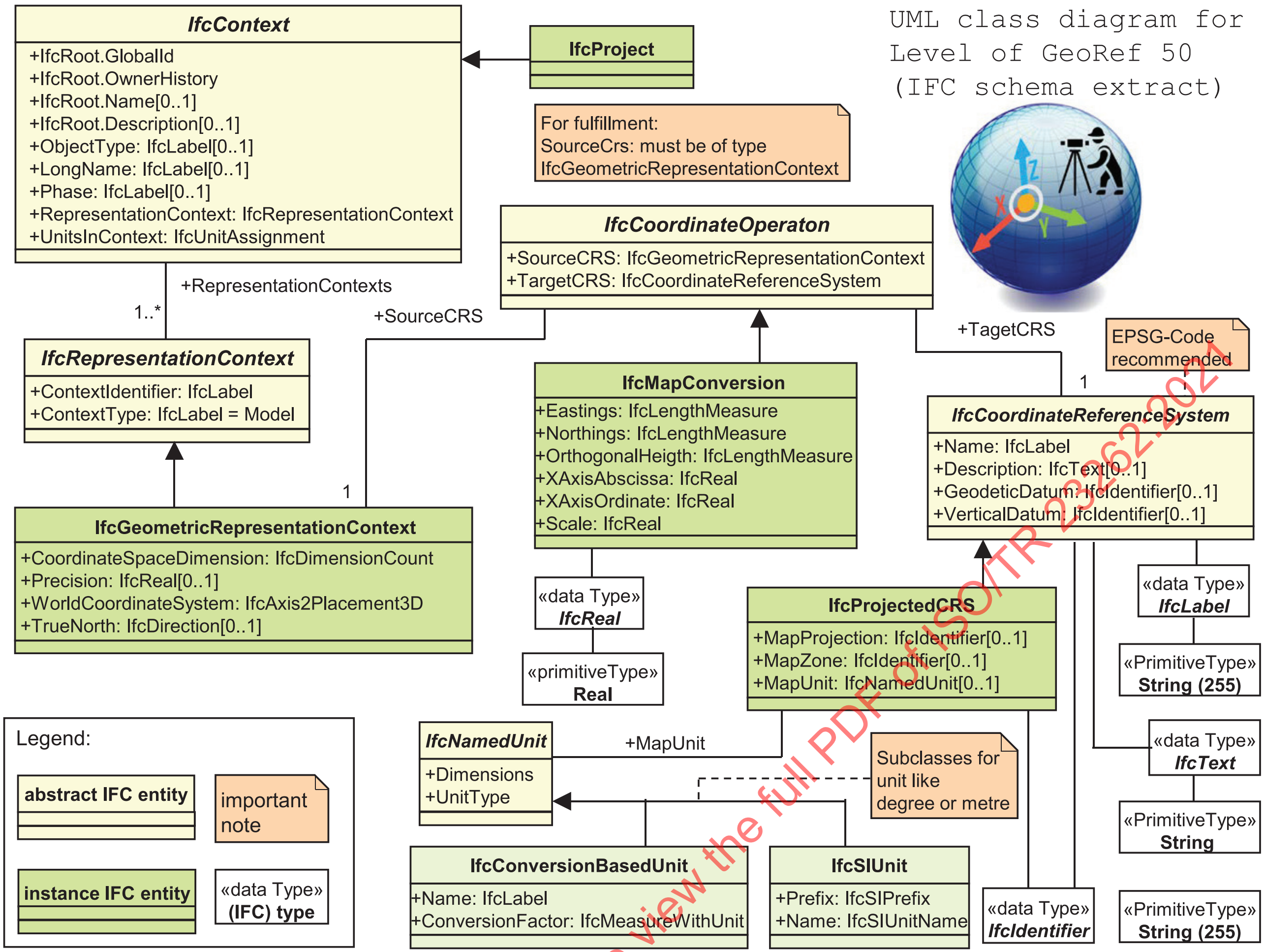


Figure C.6 — IFC entities to specify georeferencing with metadata in IFC4 (LoGeoRef 50)

The below example shows a corresponding IFC-file extract for georeferencing and meta data using IfcMapConversion (LoGeoRef 50)

```
#101= IFCPROJECT('01JwSt5ycUHvKFlMZUleKS',#105,'GeoRef50Example',$,$,$,$,(#111),#160);
#102= IFCMAPCONVERSION(#111,#112,3458715.92,5439966.65,113.7,0.270600,0.962691,$);
#111= IFCGEOMETRICREPRESENTATIONCONTEXT($,'Model',3,1.0E-5,#140,$);
#112= IFCPROJECTEDCRS('EPSG:31467','DHDN / 3-Degree Gauss-Krueger Zone 3',
                'ETRS89',$,'Gauss-Krueger','3',#120);
#120= IFCSIUNIT(*,.LENGTHUNIT.,$,.METRE.);
```


C.7 LoGeoRef60 (set of common points in BIM and geospatial)

C.7.1 General

At present, there is no possibility to store any transformation between local or engineering system of the building project to any global CRS in IFC. Level50 handles only the conversion between those. Transformation is needed if CRS is e.g. any global geodetic reference system and a change of datum is required. The presumptive most reliable option to apply a transformation is the use of control points. Control points need to have coordinate values in on one hand the local project/site/building system and on the other hand in the global CRS system. It is up to the software manufacturers to provide functionality for transforming of BIM models into global geodetic systems. Possible data e.g. calculated transformation parameters can be stored -without extending IFC schema- through generic property sets.

C.7.2 Comparison of concepts — Synthesis

Table C.1 summarizes the comparison of concepts related to georeferencing BIM and GIS data.

Table C.1 — Comparison of concepts related to georeferencing BIM and GIS

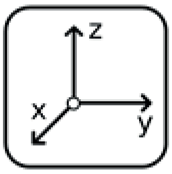
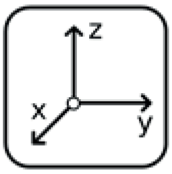
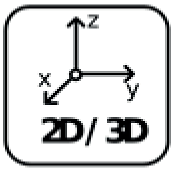
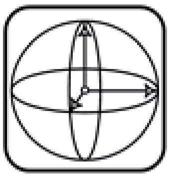
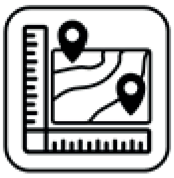
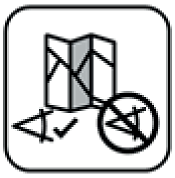
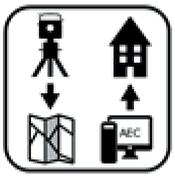
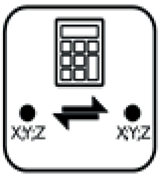
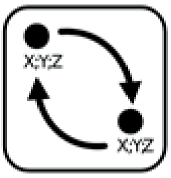
	Geospatial	BIM
Absolute vs. relative 	One coordinate system (CS) for all features.	One base (project) CS, representations with cascading CSs relative to other representations or the base CS.
	Geometry (B-Rep) is based connections of points with absolute positions in CRS (plus vertical component).	Relative positioning (IfcLocalPlacement with attribute PlacementRelTo) of geometric representation origins with different geometric concepts (B-Rep, CSG, Extrusion).
Separation between location and elevation vs. Cartesian 3D 	Combined 2D (projected cartesian or geographic) CS on the surface of a spheroid or ellipsoid and 1D vertical CS as height above the surface or independently physically defined.	All CS are 2D or 3D Cartesian CS.
Geodetic datum 	Point coordinates are related to named geodetic datum. The physically defined Height relates to named vertical datum.	Every CS has a defined translation and rotation against the context CS.
	The type of 2D CS, the geodetic Datum, and surface dimensions together defines a named coordinate reference system (CRS).	Possibility to set Coordinate in engineering system, map conversion to named CRS (since IFC4), or WGS84 reference latitude and longitude at project or site origin. Reference elevations (above sea level) at sites or buildings definable. The possibility to define reference elevations and rotations against true north implies that the Z-axis at origin of the base CS needs to be either parallel to the local plumb line, or perpendicular to the surface of the CRS.
natural vs. scaled distances 	The Pythagorean theorem is not valid for distances between points in projected CRS. To obtain the natural distance a scale factor needs to be applied. This factor depends on the heights above surface and the cartographic projection (e.g. UTM).	No scaling needed. However, for stake out Earth's curvature and gravitation need to be considered, dependent on project extent and position of origin.

Table C.1 *(continued)*

	Geospatial	BIM
	Angles between lines can be distorted depending on the map projection and location.	Angles between lines are not distorted (do to the small project size).
Stochastic measurement vs. deterministic modelling 	Geospatial coordinates are always a result of measurements. The stochastic nature of geo-coordinates leads to limited and diverse accuracy/precision. The measured "as is" model does not perfectly map the geometry on site. Note: The quality / accuracy is documented in metadata associated to the dataset and/or to the individual feature/object.	Coordinates are deterministic (= not stochastic). Coordinates are not the result of measurements but of planning. The building model can represent the geometry "as to be" perfectly, at least within the computational accuracy of the software.
coordinate operations 	Coordinate conversion (no change of datum) vs. coordinate transformation (change of datum, control points).	No datum dependent transformation necessary. Only conversions from (the many) relative CS to absolute/project CS needed.
	Determining the transformation parameters.	Geodata are georeferenced by metadata (telling in which CRS the coordinates are given) and known transformation parameters (WKT/proj4) between two CRS. The transformation parameters are given by public authorities. BIM COLUMN: The correct numerical values for the transformation from the project coordinate system (BIM) to the higher-level geo-system (GIS) are specified using identical points, distances to borders or by constraint to topographic objects. The transformation parameters are saved in the project base point or in the geometric context. A land surveyor needs to do this.
R conv Linear referencing / alignment	Linear referencing allows locations relative to a one-dimensional object as measurement along (and optionally offset from) that object. Alignment (defined in OGC LandInfra) is a linear referencing system associated to linear facilities and their constructions, such as roads, railways, and bridges, used to position elements, such as road, railway or bridge elements or other physical elements, positioned along the alignment. Alignment can be horizontal, vertical, 3D.	Alignment has been incorporated in IFC 4.1 (consistently with LandInfra alignment).

Annex D

Spatial representation

The complexity of adopting the geometric representation type is often underestimated[61]. The transformation from BIM to GIS and vice versa is not a simple 1:1 schema-mapping. The diversity of used geometric representation types (mathematical models and computer representation) in BIM and also in GIS results out of the different model intentions. The geometric representation type of a single object (feature/entity) depends on the modelled planned/real-world object, the model intension, and the level of abstraction.

Table D.1 gives an overview of spatial representations in BIM and GIS schemas.

Table D.1 — Spatial representations in BIM and GIS schemas

Schema name	Reference	Description
Spatial schema, conceptual schemas for describing, representing and manipulating the spatial characteristics of geographic entities. Vector data	ISO 19107	Uses coordinate reference systems to describe positions in (global/local) context Defines geometric primitives such as GM_Point, GM_Curve, GM_Surface, GM_Solid Defines geometric representation of objects as Primitives, Complex/Composite (GM_CompositePoint, GM_CompositeCurve, GM_CompositeSurface, GM_CompositeSolid) and Aggregates (GM_MultiPoint, GM_MultiCurve, GM_MultiSurface, GM_MultiSolid) uses only BoundaryRepresentation for representing of geometry, coordinates of every vertex are necessary
CityGML	OGC/NON-ISO	Uses a subset of ISO 19107 Identificators (gml:id) for semantic parts (e.g. bldg.:WallSurface) as well as for geometric elements (e.g. gml:Polygon) GM_Curve: linear GM_Surface: planar TP_xxx not implemented (but topology is sometimes realized as XLink between topological elements, href with unique ID)
ISO 10303-42 (STEP) Industrial automation systems and integration -- Product data representation and exchange -- Part 42: Integrated generic resource: Geometric and topological representation)	ISO 10303-42	The standard describes the resources (data structures) for geometry and topology. Any product in STEP context can have diverse geometry and topology representations. — Designed for complex CAD modelling with high demands on numerical stability and modelling flexibility — STEP (ISO 10303-21) has two identifier types: a) The instance identifier in ISO 10303-21 requires that files are unique within a single file. b) User-defined identifiers that are a part of the product data. These ids do not require to be unique, neither globally nor within a single physical file. In IFC the identifiers of type b) are used as IfcGloballyUniqueID.

Table D.1 *(continued)*

Schema name	Reference	Description
		— uses Cartesian coordinate systems for representation — Representation context defines cascading coordinate transformations — many Geometric primitives (geometric_representation_item) for dimension 1,2 and 3 — diverse possibilities to describe geometric connection: BRep, CSG, Extrusion, Sweep — many topological representation items (diverse solid model representations!) — gives (pseudo code) algorithms for calculations and operations in geometric items — Schema is given with Express(G)
Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries	ISO 16739-1	The definitions taken from ISO 10303-42 have undergone an adaptation process, characterised by: — adaptation of the IFC naming convention (inner majuscules and Ifc prefix) — adaptation of the STEP entities, where multiple inheritance or non-exclusive inheritance (i.e. AND or ANDOR subtype constraints) are used — selection of a subset of the IR, using subtype and select pruning — dimensionality of geometric representation items defined at each item (not through the representation context) — omission of pcurves, use of simple 2D curves for the generation of swept surfaces — omission of the name attribute at the representation item

Table D.2 gives a comparison of spatial representations.