



OGC INDOORGML PART I - CONCEPTUAL MODEL

STANDARD
Conceptual model

CANDIDATE TC VOTE DRAFT

Version: 2.0

Submission Date: 2024-10-15

Approval Date: 20xx-xx-xx

Publication Date: 20xx-xx-xx

Editor: Sisi Zlatanova, Abdoulaye Diakite, Taehoon Kim, Ki-Joune Li

Notice for Drafts: This document is not an OGC Standard. This document is distributed for review and comment. This document is subject to change without notice and may not be referred to as an OGC Standard.

Recipients of this document are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

License Agreement

Use of this document is subject to the license agreement at <https://www.ogc.org/license>

Suggested additions, changes and comments on this document are welcome and encouraged. Such suggestions may be submitted using the online change request form on OGC web site: <http://ogc.standardstracker.org/>

Copyright notice

Copyright © 2024 Open Geospatial Consortium

To obtain additional rights of use, visit <https://www.ogc.org/legal>

Note

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. The Open Geospatial Consortium shall not be held responsible for identifying any or all such patent rights.

Recipients of this document are requested to submit, with their comments, notification of any relevant patent claims or other intellectual property rights of which they may be aware that might be infringed by any implementation of the standard set forth in this document, and to provide supporting documentation.

CONTENTS

I.	ABSTRACT	vii
II.	KEYWORDS	vii
III.	PREFACE	viii
IV.	SECURITY CONSIDERATIONS	ix
V.	SUBMITTING ORGANIZATIONS	x
VI.	SUBMITTERS	x
1.	SCOPE	2
2.	CONFORMANCE	4
3.	NORMATIVE REFERENCES	6
4.	TERMS AND DEFINITIONS	8
5.	CONVENTIONS	11
5.1.	Symbols (and abbreviated terms)	11
5.2.	UML Notation	12
5.3.	Identifiers	14
6.	OVERVIEW OF INDOORGML	16
6.1.	Motivation for developing the IndoorGML Standard	16
6.2.	Modularization	17
7.	GENERAL CONCEPTS OF INDOORGML	20
7.1.	Space	20
7.2.	Cellular space	21
7.3.	Poincaré Duality	25
7.4.	Structured space model	27
7.5.	Semantics	28
7.6.	Thematic layers	29
8.	DATA MODEL	36
8.1.	IndoorGML Core Module	36
8.2.	Navigation Extension Module	48
8.3.	Requirements	56

9. DATA DICTIONARY AND REQUIREMENTS	61
9.1. Feature Types in Core Module	61
9.2. Feature Types in Navigation Module	67
ANNEX A (NORMATIVE) ABSTRACT TEST SUITE	73
A.1. Introduction	73
A.2. General Tests	73
A.3. Conformance Class	73
BIBLIOGRAPHY	79

LIST OF TABLES

Table 1 – Symbols and abbreviated terms	11
---	----

LIST OF FIGURES

Figure 1 – UML Notations	13
Figure 2 – IndoorGML in the overall application development ecosystem	16
Figure 3 – Modular organisation of IndoorGML	18
Figure 4 – A building (a) and the corresponding cellular space, containing all empty cells (b) and corresponding cells of a room, a corridor and their openings (c).	21
Figure 5 – Cellular space containing disconnected cells, i.e., all offices in a university building (Allatas et al., 2017)	22
Figure 6 – Three options to represent geometry in IndoorGML	23
Figure 7 – (a) A furnished indoor space. (b) Subdivision of the indoor space into two separate rooms with exclusion of furnishing elements' spaces. (c) Selection of specific CellSpaces (green) suitable for walking and rolling. (d) CellSpaces (green) suitable for flying.	24
Figure 8 – Principles of Poincaré duality. 3D Primal space case (a) and 2D case (b). (Mathematical definition of Poincaré duality in (Munkres, 1984))	26
Figure 9 – Poincaré duality on 3D cells of a building (a); Corresponding adjacency graph in the dual space (b); Combined primal and dual space view (c).	27
Figure 10 – Structured space model: mapping between Euclidean and Topological spaces, and Primal and Dual Spaces	28
Figure 11 – Cellular space for visitors (Alattas et al., 2017)	30
Figure 12 – Three different cellular spaces for the same physical space.	31
Figure 13 – Corresponding Primal and Dual spaces of different thematic layers.	32
Figure 14 – Inter-Layer relations between three different layers of a same environment.	33

Figure 15 – Inter-layer connection between two primal spaces. (a) furnished room. (b) cells of the room and door only. (c) cells of furnishing elements only represented by minmax boxes.	34
Figure 16 – UML diagram of the Core module.	37
Figure 17 – CellSpace and its related classes: PrimalSpaceLayer, CellBoundary, Node and InterLayerConnection	38
Figure 18 – CellBoundary and its related classes: PrimalSpaceLayer, CellSpace and Edge	40
Figure 19 – PrimalSpaceLayer and its related classes: CellSpace, CellBoundary and Thematic Layer	42
Figure 20 – Node and its related classes: CellSpace, Edge, DualSpaceLayer and InterLayerConnection	43
Figure 21 – Edge and its related classes: CellBoundary, Node and DualSpaceLayer	44
Figure 22 – DualSpaceLayer and its related classes: Node, Edge and Thematic Layer	45
Figure 23 – InterLayerConnection and its related classes: CellSpace, Node, ThematicLayer and IndoorFeatures	46
Figure 24 – ThematicLayer and its related classes: PrimalSpaceLayer, DualSpaceLayer, InterLayerConnection and IndoorFeatures	47
Figure 25 – UML diagram of the Navigation Extension Module (classes in green)	49
Figure 26 – Navigable and Non-navigable spaces (a) and boundaries (b) on a 3D model with walls and furniture (grey), indoor space (blue) and a door space (yellow).	50
Figure 27 – NavigableSpace and its related class: CellSpace	51
Figure 28 – GeneralSpace and its related class: NavigableSpace	52
Figure 29 – TransferSpace and its related class: NavigableSpace	52
Figure 30 – NavigableBoundary and its related class: CellBoundary	53
Figure 31 – NonNavigableSpace its related class: CellSpace	54
Figure 32 – ObjectSpace and its related class: NonNavigableSpace	54
Figure 33 – NonNavigableBoundary and its related classes: CellBoundary	55
Figure 34 – Route and its related classes: Node and Edge	56

LIST OF RECOMMENDATIONS

REQUIREMENTS CLASS 1	56
REQUIREMENT 1: UML CLASS DIAGRAM	56
REQUIREMENT 2: THEMATIC LAYER	57
REQUIREMENT 3: CELL SPACE	57
REQUIREMENT 4: CELL BOUNDARY	57
REQUIREMENT 5: NODE	58
REQUIREMENT 6: EDGE	58
REQUIREMENT 7: INTERLAYER CONNECTION	58

REQUIREMENT 8: OBJECTSPACE	58
CONFORMANCE CLASS A.1	73

ABSTRACT

The OGC IndoorGML Part I – Conceptual Model Standard (this Standard) specifies an UML model for indoor information. Part 2 of the standard specifies technical implementation schemas in GML, SQL and JSON. While there are several standards supporting 3D modelling concepts such as CityGML, KML, IFC, LADM and IMDF that deal with interiors of buildings from geometric, cartographic, and semantic viewpoints, IndoorGML focuses on modeling indoor spaces and their neighborhood relationships to support indoor location-based services. This document describes the conceptual model (Part 1) of IndoorGML that addresses spaces and networks for indoor navigation.

KEYWORDS

The following are keywords to be used by search engines and document catalogues.

OGCDoc, OGC documents, indoor, navigation, IndoorGML, GML, SQL, JSON

PREFACE

The goal of the OGC IndoorGML Standard is to represent and support interoperable exchange of geoinformation that is required to build and operate systems that rely on spaces and topological relationships between them such as path computation, sensor coverage, property accessibility, etc. Several standards such as CityGML (OGC, 2012), and IFC (ISO, 2018) have been published to describe 3D geometry and semantics of building features. However, these standards are not readily appropriate to derive spaces and their topological relationships. The OGC IMDF Community Standard (OGC, 2021) provides a comprehensive model to compute path(s) between features located on a map, but the derived network is application specific. The IndoorGML Standard aims to provide a unified, standardized and flexible approach for indoor spatial information required for space-graph based applications such as indoor navigation.

Version 2.0 of the IndoorGML Part 1 – Conceptual Model Standard consists of two components: 1) a core data model to describe topological connectivity and different contexts of indoor space, and 2) a data model for navigation in indoor space. While the core data model, as its name suggests, is the main conceptual model that IndoorGML is built upon, the navigation model extends it to support navigation applications. This allows illustrating the practical strength of the core model as well as how other application extensions could be built around it.

This version of IndoorGML covers geometric and semantic properties of indoor spaces relevant for indoor navigation. These indoor spaces may differ from the spaces described by other standards such as CityGML, IFC, LADM, and IMDF. In this respect, IndoorGML is a complementary standard to CityGML, IFC, LADM, and IMDF to support location-based services for indoor navigation.

OGC Declaration

SECURITY CONSIDERATIONS

No security considerations have been made for this Standard.

SUBMITTING ORGANIZATIONS

The following organizations submitted this Document to the Open Geospatial Consortium (OGC):

- The University of New South Wales
- Pusan National University
- Ordnance Survey
- University of Seoul
- CityGeometrix
- National Institute of Advanced Industrial Science and Technology

SUBMITTERS

Questions regarding this submission should be directed to the editor or the submitters:

NAME	AFFILIATION	CONTACT
Sisi Zlatanova	University of New South Wales	s.zlatanova at unsw.edu.au
Ki-Joune Li	Pusan National University	lik at pnu.edu
Abdoulaye Diakite	CityGeometrix	abdou at citygeometrix.com
Jeremy Morley	Ordnance Survey	Jeremy.Morley at os.uk
Taehoon Kim	National Institute of Advanced Industrial Science and Technology	kim.taehoon at aist.go.jp

1

SCOPE

SCOPE

The OGC IndoorGML Standard is for the representation and interoperable exchange of indoor navigation network models. IndoorGML Part 1 is a conceptual schema documented using UML and Part 2 is an implementation schema of the Geography Markup Language version 3.2.1.

IndoorGML Part 1 establishes a common schema for indoor space model and indoor navigation applications. Part 1 models topology and semantics of indoor spaces, which are needed for the components of navigation networks. The IndoorGML Standard defines a minimum set of generic, unified modelling concepts for indoor environments as follows:

- Spaces and space subdivision contexts;
- Geometric and semantic properties of spaces;
- Types of connectivity between spaces;
- Navigation networks (logical and metric) and their relationships.

2

CONFORMANCE

CONFORMANCE

Conformance targets of IndoorGML Part 1 are IndoorGML instance documents. Conformance with this Standard shall be checked whether IndoorGML instance documents achieve the criteria as defined in clause 7 to 9.

In order to conform to IndoorGML requirements and schema document implementations SHALL:

- a) Conform to the rules, specifications, and requirements in clauses 7 to 9; and
- b) pass all relevant test cases of the Abstract Test Suite (ATS) given in Annex A.

The framework, concepts, and methodology for testing, and the criteria to be achieved to claim conformance are specified in the OGC Compliance Testing Policies and Procedures and the OGC Compliance Testing web site¹.

¹https://portal.ogc.org/public_ogc/directives/directives.php

3

NORMATIVE REFERENCES

NORMATIVE REFERENCES

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO: ISO 8601-1, *Date and time – Representations for information interchange – Part 1: Basic rules*. International Organization for Standardization, Geneva <https://www.iso.org/standard/70907.html>.

ISO: ISO 19103, *Geographic information – Conceptual schema language*. International Organization for Standardization, Geneva <https://www.iso.org/standard/56734.html>.

ISO: ISO 19105, *Geographic information – Conformance and testing*. International Organization for Standardization, Geneva <https://www.iso.org/standard/76457.html>.

ISO: ISO 19107, *Geographic information – Spatial schema*. International Organization for Standardization, Geneva <https://www.iso.org/standard/66175.html>.

ISO: ISO 19109, *Geographic information – Rules for application schema*. International Organization for Standardization, Geneva <https://www.iso.org/standard/59193.html>.

ISO: ISO 19111, *Geographic information – Referencing by coordinates*. International Organization for Standardization, Geneva <https://www.iso.org/standard/74039.html>.

ISO: ISO 19115-1, *Geographic information – Metadata – Part 1: Fundamentals*. International Organization for Standardization, Geneva <https://www.iso.org/standard/53798.html>.

ISO: ISO 19136-1, *Geographic information – Geography Markup Language (GML) – Part 1: Fundamentals*. International Organization for Standardization, Geneva <https://www.iso.org/standard/75676.html>.

ISO: ISO/TS 19139-1, *Geographic information – XML schema implementation – Part 1: Encoding rules*. International Organization for Standardization, Geneva <https://www.iso.org/standard/67253.html>.

Cliff Kottman: OGC 99-108r2, *Topic 8 – Relationships Between Features*. Open Geospatial Consortium (1999).

Cliff Kottman: OGC 99-110, *Topic 10 – Feature Collections*. Open Geospatial Consortium (1999).

Clemens Portele: OGC 07-036, *OpenGIS Geography Markup Language (GML) Encoding Standard*. Open Geospatial Consortium (2007).

Cliff Kottman and Carl Reed: OGC 08-126, *Topic 5 – Features*. Open Geospatial Consortium (2009).

4

TERMS AND DEFINITIONS

TERMS AND DEFINITIONS

This document uses the terms defined in [OGC Policy Directive 49](#), which is based on the ISO/IEC Directives, Part 2, Rules for the structure and drafting of International Standards. In particular, the word "shall" (not "must") is the verb form used to indicate a requirement to be strictly followed to conform to this document and OGC documents do not use the equivalent phrases in the ISO/IEC Directives, Part 2.

This document also uses terms defined in the OGC Standard for Modular specifications ([OGC 08-131r3](#)), also known as the 'ModSpec'. The definitions of terms such as standard, specification, requirement, and conformance test are provided in the ModSpec.

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

4.1. Indoor Space

A space within one or multiple buildings.

4.2. Cellular Space

A cellular space S is a set of identifiable cells c_i grouped according to theme T and is noted S^T is $S^T = \{c_1, c_2, \dots, c_n\}$

4.3. Graph

A graph $G(V, E)$ where V is a set of nodes representing cells and E is the set of edges indicating topological relationships.

4.4. Adjacency Graph

A graph $G_{adj}(V, E_{adj})$ where V is a set of nodes representing cells and E_{adj} is the set of edges indicating the adjacency relationship.

4.5. Connectivity Graph

A graph $G_{con}(V, E_{con})$ where V is a set of nodes representing cells in indoor space and E_{con} is the set of edges indicating the connectivity relationship.

4.6. Logical Network

A graph $G(V, E)$, where node v in V and edge e in E do not contain any geometric properties.

4.7. Geometric Network

A graph $G(V, E)$ where node v in V and edge e in E contain both geometric properties.

4.8. Multi-Layered Space Model

A model representing multiple themes of cellular spaces and/or graphs and inter-layer connections between them.



5

CONVENTIONS

CONVENTIONS

This section provides details and examples for any conventions used in the document. Examples of conventions are symbols, abbreviations, use of XML schema, or special notes regarding how to read the document.

5.1. Symbols (and abbreviated terms)

The following symbols and abbreviations are used in this standard.

Table 1 – Symbols and abbreviated terms

ABBREVIATION	WORD OR PHRASE
BIM	Building Information Modeling
CityGML	City Geographic Markup Language
GPS	Global Positioning Systems
CRS	Coordinate Reference System
GML	Geographic Markup Language
IndoorGML	Indoor Geographic Markup Language
IFC	Industry Foundation Classes
IPS	Indoor Positioning Systems
ISO	International Organization for Standardization
KML	Keyhole Markup Language
LOD	Level of Detail
MLSM	Multi-Layered Space Model
OGC	Open Geospatial Consortium

RFID	Radio Frequency IDentifier
RTLS	Real-Time Locating Systems
UML	Unified Modeling Language
XML	eXtended Markup Language
1D	One Dimensional
2D	Two Dimensional
3D	Three Dimensional

5.2. UML Notation

The diagrams that appear in this standard are presented using the Unified Modeling Language (UML) static structure diagram. The UML notations used in this standard are described in the diagram below.

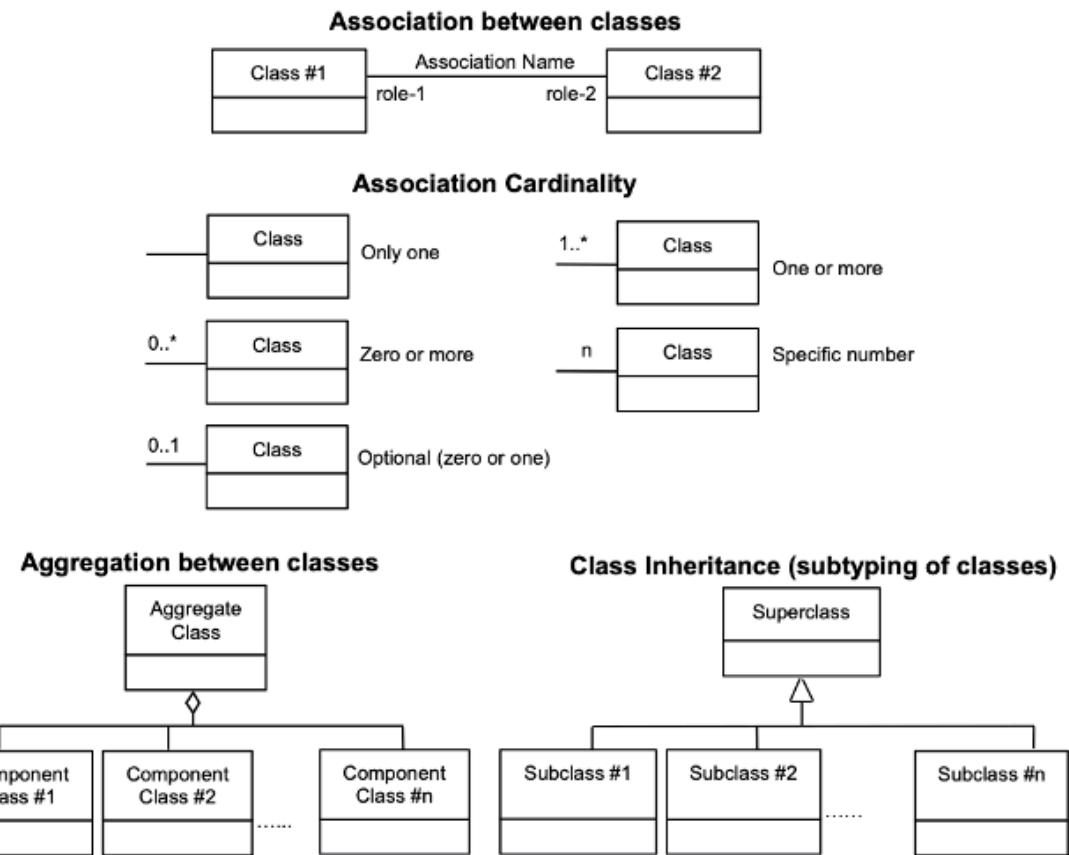


Figure 1 – UML Notations

In this standard, the following three stereotypes of UML classes are used.

- <<FeatureType>> is a feature as defined in ISO 19109. Features are abstractions of real-world phenomena and have an identity.
- <<DataType>> is a set of values that lack identity (independent existence and the possibility of side effects). A DataType is a class with no operations whose primary purpose is to hold the information.
- <<CodeList>> is a flexible enumeration that uses string values for expressing a list of potential values.

In this standard, the following standard data types are used:

- **CharacterString** – A sequence of characters;
- **Boolean** – A binary value of either 1 (true) or 0 (false);
- **Integer** – An integer number; and
- **Real** – A floating point number.

5.3. Identifiers

The normative provisions in this standard are denoted by the URI

<http://www.opengis.net/spec/indoorgml/2.0>

All requirements and conformance tests that appear in this document are denoted by partial URIs which are relative to this base.

6

OVERVIEW OF INDOORGML

OVERVIEW OF INDOORGML

The IndoorGML Conceptual Model is designed to support applications developers in providing Location-based services applications. Figure 2 illustrates the place of IndoorGML in an ecosystem of standards, models, and files formats and end-user applications. IndoorGML provides simplified yet standardized notations for indoor spaces and networks, which can be used in different application contexts such as navigation, monitoring, asset and property management. IndoorGML can be linked to and derived from any geometric model that a building owner may have (floor plans, CAD models, BIM models, laser scans, measurements). The semantics notations of IndoorGML are generic and therefore support protecting some sensitive building information.

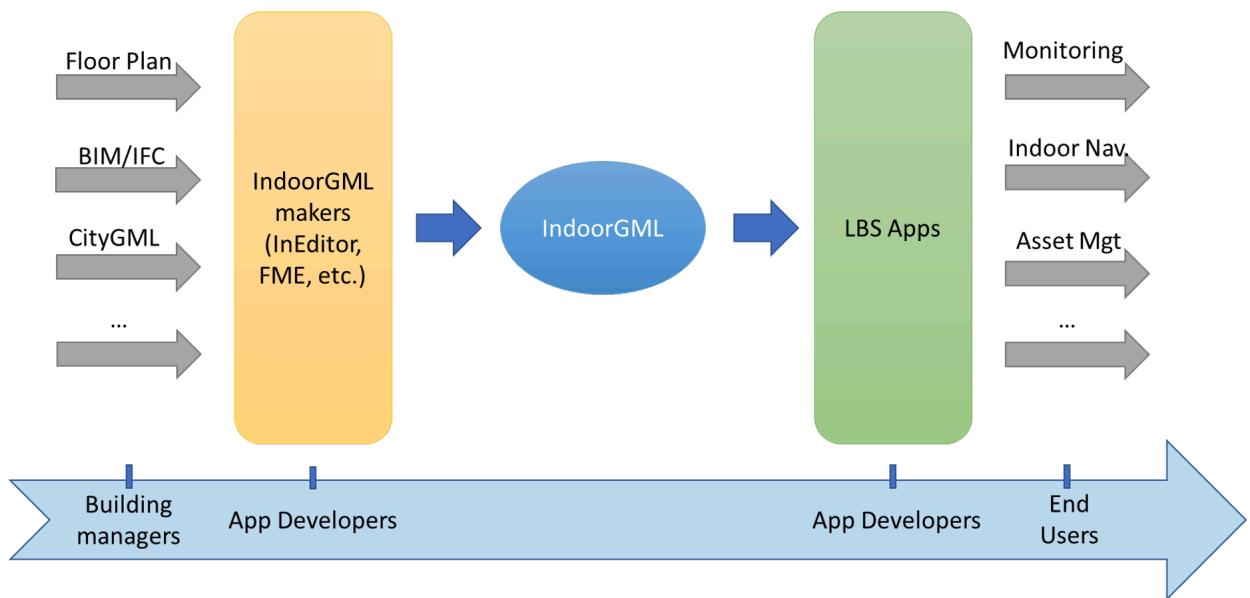


Figure 2 – IndoorGML in the overall application development ecosystem

6.1. Motivation for developing the IndoorGML Standard

Indoor environments differ from outdoor in many aspects. Indoor spaces have fewer structures, lanes, and directions to move. They are multi-levelled and reachable via different vertical connectors such as stairs, elevators, escalators, and ramps. They have large number of obstacles such as furniture columns, fences, decorations. Indoor spaces are enclosed and accessible via different types of openings (normal doors, emergency doors, sliding doors, one-way doors, portals). The height of the indoor spaces might vary to such an extent that some spaces are not accessible for certain type of users. This has led to the existence of a variety of approaches for modelling indoor environments and providing services. Therefore, well-known concepts, data models, and standards need to be refined and unified to reflect specifics of indoor environments.

In general, indoor spatial information can be classified into two large categories as follows:

- Architectural components (walls, stairs, slabs) and interior facilities (furniture).
- Cavities (rooms and corridors) or virtual subdivision (sensors coverage and legal spaces)

Building and facility management applications require mostly information from the first category. Indoor location-based services (LBS), indoor route analysis or indoor geo-tagging services require mostly information from the second category.

The IndoorGML Standard is intended to provide a unified modelling approach that is necessary to support indoor applications using information from those two categories. The leading concepts in the IndoorGML Conceptual Model are the Indoor spaces and the topological relationships between them (Clause 7.1), which are grounded in the Poincaré duality. The space notations are kept as generic as possible to reflect the variety and complexity of indoor environments. The entire indoor environment – objects and spaces – constitutes the Cellular space (Clause 7.2). Cells have properties, one of which is their geometry. The cell units can be subdivided or aggregated (Clause 7.2). The Cell Spaces are the basis for deriving an adjacency/connectivity/accessibility network (Clause 7.3). Cell Spaces of the same characteristics are non-overlapping and form a thematic layer (Clause 7.6). For example, architectural components (walls, slabs, stairs) and the corresponding cavities (rooms, corridors) form a Topographic thematic layer.

IndoorGML 2.0 follows a model-driven approach. All concepts are organized in a UML class diagram (Clause 8), from which the implementation schemas for GML are provided (Annex A).

6.2. Modularization

Following the OGC ModSpec guidance (OGC, 2009), IndoorGML Part 1 – Conceptual Model is organised into a Core module and Extension modules that have one or more mandatory dependencies on the Core (see Figure 3). The IndoorGML Core module defines generic aspects of Primal-Dual spaces (see below) and each extension module introduces thematic semantics for a specific application. IndoorGML 2.0 Part 1 contains one extension named *Navigation*. IndoorGML 2.0 Part 2 provides the implementation of IndoorGML 2.0 Part 1 Conceptual model in GML, JSON, and SQL.

The dependency relationships among IndoorGML's modules are illustrated in Figure 3. Each module is represented by a package in UML. The package name corresponds to the module name. A dash arrow in the figure indicates that the schema at the tail of the arrow depends upon the schema at the head of the arrow. In the following sections the modules are described in detail.

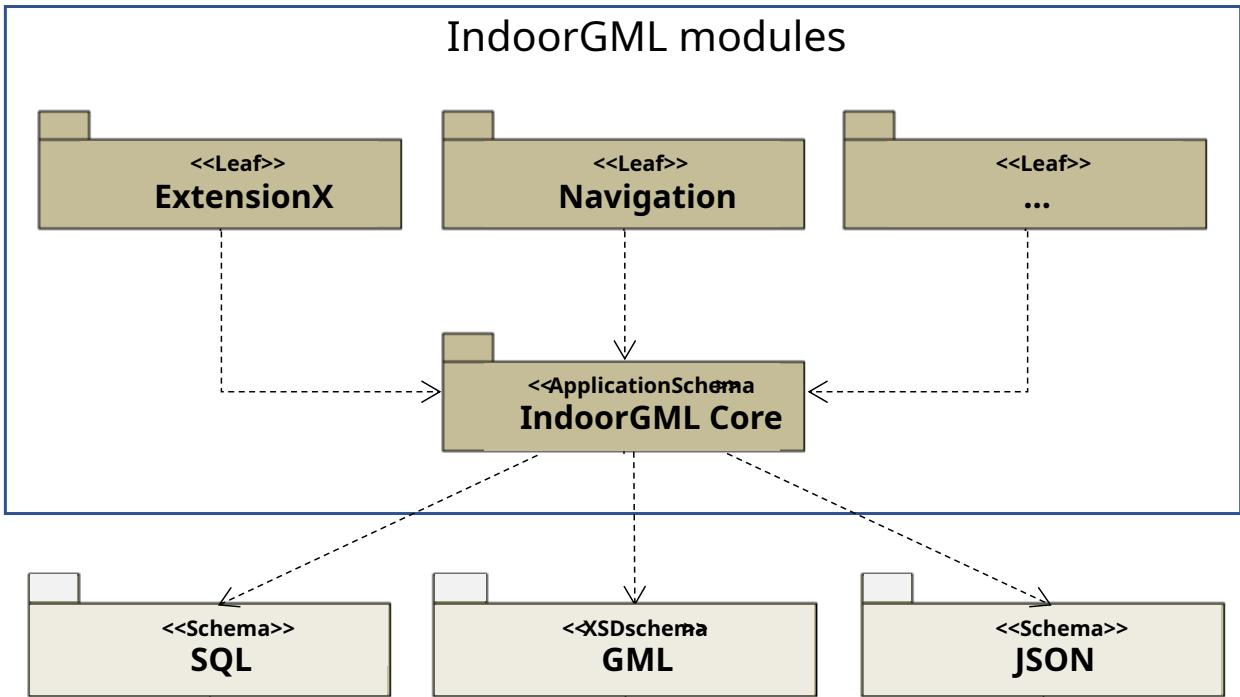


Figure 3 – Modular organisation of IndoorGML

7

GENERAL CONCEPTS OF INDOORGML

GENERAL CONCEPTS OF INDOORGML

IndoorGML is a space-centred standard. As such, it focuses on the three main types of information of spaces (2D or 3D): geometry, topology and semantic. To define the space and its suitable properties under the consideration of those three types of information, the Standard relies on the following concepts:

- Cellular space,
- Poincaré Duality,
- Semantic extension,
- Thematic layering.

The cellular space provides the geometric description of an IndoorGML model. The Poincaré duality describes the topological relations such as adjacency and connectivity between the spaces. Together, they form the key concept of the Primal-Dual model that defines the core part of the IndoorGML Conceptual Model. The semantic extension mechanism, as the name suggests, supports adding more details to the basic semantics of the core module. Thematic layering mechanism supports organizing an IndoorGML model as a collection of layers with different themes. Those concepts are elaborated in the following subsections.

7.1. Space

The notion of space is widely explored in spatial science and urban applications in general (Zlatanova, et al., 2020). Among the diverse definitions that can be found in dictionaries and related literature, one definition of the space encapsulates most of the concepts attached it:

“Space is either unlimited expand or an empty area usually bounded in some way between things (e.g., the architect left space in front of the building) or an area reserved for some particular purpose (e.g., the laboratory’s floor space)” (Princeton University, 2010).

That definition acknowledges three main aspects of the space: (a) its ability to expand infinitely, (b) its intuition to be generally empty and eventually bounded (particularly in the built environment) and © its functional property. In IndoorGML, the space is characterized by all those properties, except that an IndoorGML space is not necessarily empty. Depending on the IndoorGML extension (indoor navigation, sensors coverage, ownership, etc.) spaces can be empty, non-empty or partially empty.

Indoor space is commonly perceived as a space within a building. It incorporates architectural components such as walls, slabs, and doors, and furniture such as chairs, tables, desks, and the remaining empty spaces as in rooms, corridors, halls, etc. IndoorGML 2.0 Conceptual Model focuses on the empty spaces where objects can be located, and activities can be hosted

for indoor navigation or LBS. Consequently, the relationships between spaces are of critical importance.

Spaces in the built environment are not always sharply distinguishable. Many spaces cannot be strictly categorized as indoor or outdoor, but rather as semi-spaces often linking indoor and outdoor environments (Yan, Diakité, Zlatanova, 2019; Zlatanova, et al., 2020). For example, an inner court, a veranda, a balcony, or an open bridge can belong to a building, without being entirely enclosed within the shell of the building. Nevertheless, for a matter of completeness, the IndoorGML Conceptual Model can account for all types of space within the built environment, if they can be represented with the IndoorGML Cellular space concept (below).

7.2. Cellular space

A *cellular space* is a set of *cells* (or *CellSpaces*) defined as the smallest organizational or structural unit (Princeton University, 2010) and grouped according to thematic criteria (e.g. topographic space, sensor coverage space, etc.). A cellular space S of thematic layer T , noted S^T is defined as follows:

$$S^T = \{c_1, c_2, \dots, c_n\}$$

where c_i is i^{th} cell. Every cell in a cellular space can have the following properties:

- a unique identifier;
- a name (e.g., a room number);
- a geometry (e.g., solids in 3D or surfaces in 2D)

Figure 4 illustrates a cellular space consisting of cells, which represent rooms, corridors, doors and windows in a building.

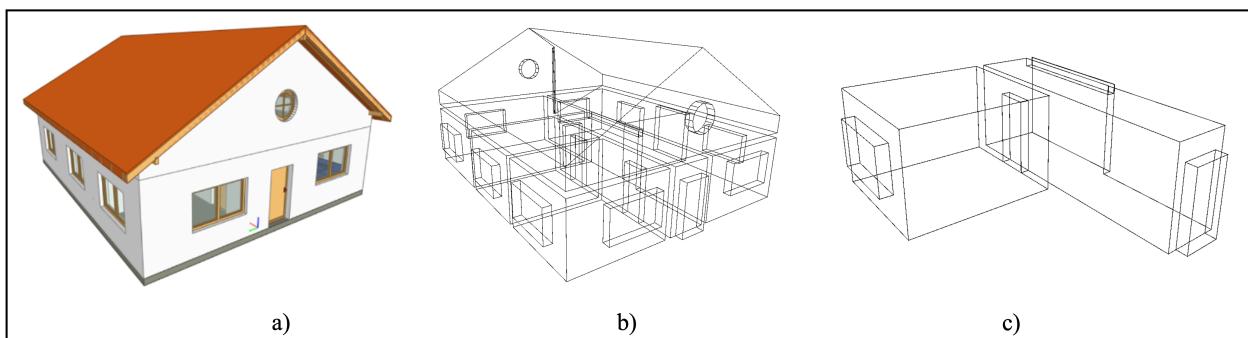


Figure 4 – A building (a) and the corresponding cellular space, containing all empty cells (b) and corresponding cells of a room, a corridor and their openings (c).

Within a cellular space, only the adjacency relationship is allowed between cells: No overlap may occur. Overlapping cells must be organized in a new cellular space. A cellular space may be incomplete coverage: There can be gaps between cells (Figure 5).

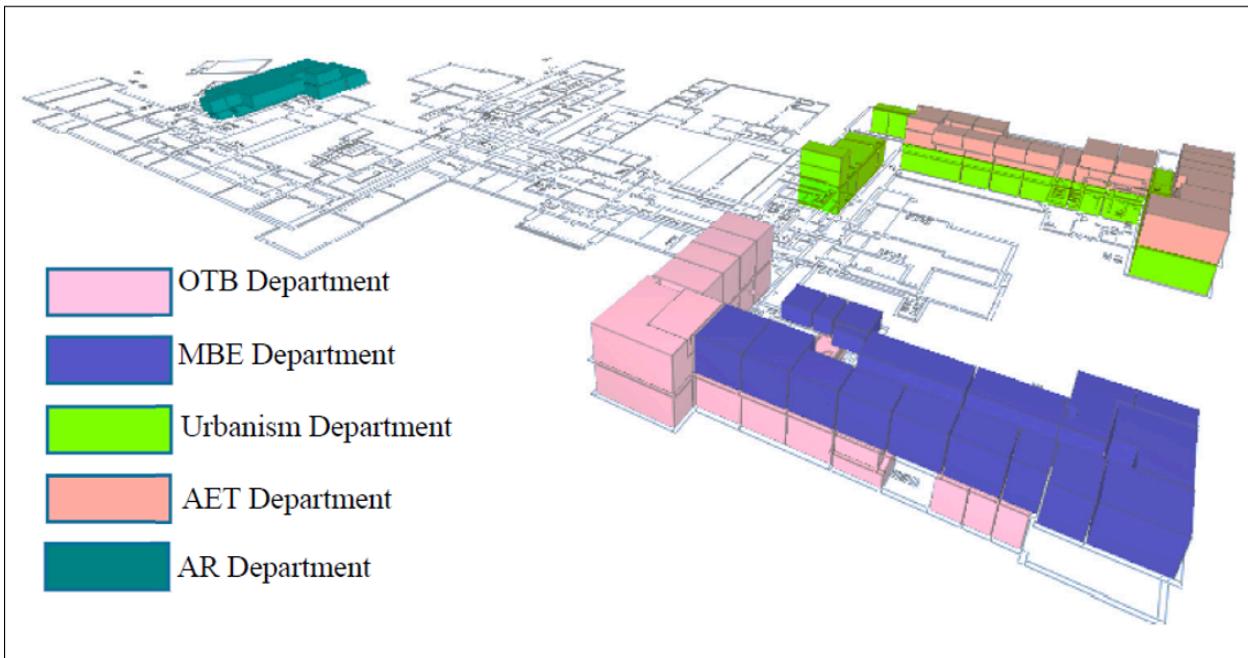


Figure 5 – Cellular space containing disconnected cells,
i.e., all offices in a university building (Allatas et al., 2017)

In the IndoorGML Conceptual Model, a cellular space can be subdivided into smaller cells or aggregated into larger ones. Those operations detailed in Clause 7.2.3 allow for both a tailored geometric granularity and functional specification of spaces.

7.2.1. Geometry

Every cell defining an item in indoor space owns a shape, size, and location that can be collected and modelled. Cell can represent physical features such as a room, door, wall, or virtual spaces such as legal rights and access or sensors coverages. Depending on the application, the geometry of a cell can be simplified and generalised into a polygon or rectangle. Such an approach can be applied when considering highly irregular shapes such as furniture. Geometric information can be included in an IndoorGML implementation instance either directly or via an external link. Geometry of cells can be omitted as well.

Cell geometry is defined in 2-dimensional or 3-dimensional Euclidean space and provides the means for the quantitative description of the spatial characteristics of cell. Metrics are defined as in (Morris, 2019). In the IndoorGML Conceptual Model, cells are modelled as features and conform with requirements as specified in ISO 19107 (Spatial Schema) (ISO, 2019). ISO 19107 provides conceptual schemas to describe and model real world objects as features.

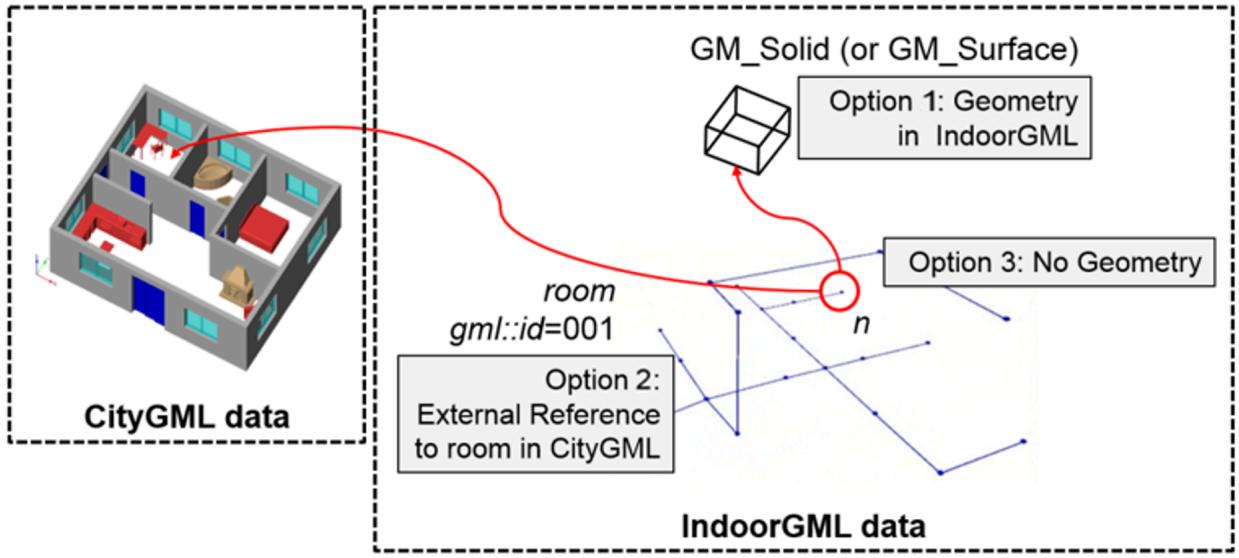


Figure 6 – Three options to represent geometry in IndoorGML

As illustrated in Figure 6, there are three options for representing geometry of a cell in indoor space:

1. Geometry in IndoorGML (Option 1): Geometric representation of a cell may be included within an IndoorGML document. As defined in ISO 19107 this is a GM_Solid in 3D space and GM_Surface in 2D space. Note that solid with holes or surface with holes are allowed in this standard.
2. External Reference (Option 2): Instead of explicit representation of geometry, an IndoorGML document can only contain external links to objects defined in data sets in some encoding/format such as IFC or CityGML, where the referenced objects in external data set include geometric information. Then there must be 1:1 or n:1 mapping from cells in IndoorGML to these corresponding objects in other datasets.
3. No Geometry (Option 3): No geometric information is included in IndoorGML. This means that the shape, extent and location are unknown. The cell is defined by its identifier.

Note that Option 2 can always be used in combination with the other options. When Option 1 is used, three fundamental operations can be applied to cell spaces: subdivision, aggregation, and selection.

7.2.2. Topology

Beside the geometry of a cellular space, cells can be represented in a topological model, which specifies the relationships between points, lines, polygons and solids constructing the geometry (Gröger and George, 2012). Such topological models are dedicated to representing spatial relationships. As such, their shape and size are not described (Egenhofer et al., 1989). This is to

say, geometric predicates such as volumes, areas, distances cannot be computed. As mentioned above, IndoorGML deals only with cells in 3D and 2D space, which are defined as solids or polygons. Consequently, the topological model contains only 3D and 2D objects in 3D cellular space and 2D and 1D objects in 2D cellular space. More information about topology of cells can be found in Clause 8.1.3.

7.2.3. Subdivision, aggregation, and selection

The indoor environment is complex and indoor spaces often have hierarchical structures. For several indoor applications, a careful decomposition of an indoor space is required to reflect these hierarchical structures. To support the representation of such configurations, the subdivision, aggregation, and selection processes on the CellSpaces can be applied.

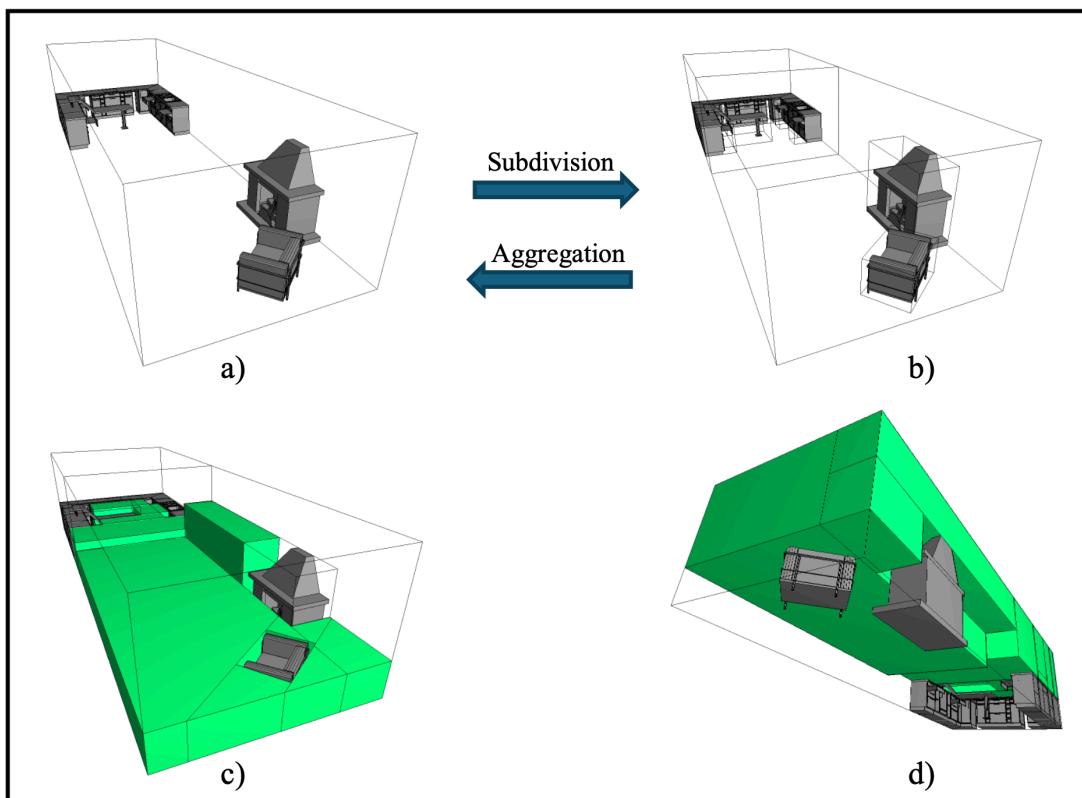


Figure 7 – (a) A furnished indoor space. (b) Subdivision of the indoor space into two separate rooms with exclusion of furnishing elements' spaces. (c) Selection of specific CellSpaces (green) suitable for walking and rolling. (d) CellSpaces (green) suitable for flying.

As illustrated in Figure 7, the subdivision is performed by splitting the original cells into several subspaces, according to the function of cell. For example, in Figure 7(b), the indoor space is subdivided into several cells according to their functions (e.g. as in Figure 7(a)) into a kitchen and a living room, as well as discriminating the spaces physically occupied by items. The subdivision process could be based on any application-based criteria and all resulting subspaces are CellSpaces of a cellular space. For navigation applications, subdivisions may be required due to:

- Geometry simplification such as working with spaces that have only convex shapes.
- Increase of granularity such as in for improving the localisation of people and items.
- Need to identify specific functional/perception spaces such as waiting or smoking areas.
- Defining free spaces such as spaces free of obstacles.

The aggregation process is the reverse of the subdivision process. An aggregation process results in subspaces being merged instead of being split. Therefore, the merging of all subspaces shown in Figure 7(a) allows retrieving the original cell spaces. Similarly, any new cell resulting from this process is a CellSpace of a cellular space. For the purpose of indoor navigation, aggregation may be required when:

- There are CellSpaces of no interest for an application, such as individual toilets or service areas in a building.
- There are CellSpaces, which are not accessible for specific users, such as restricted areas at hospitals and airports.

Finally, it is possible to discriminate CellSpaces of interest from the rest. Figure 7© and (d) illustrate a scenario where only CellSpaces that can support certain type of locomotion modes are considered in the cellular space (see the green CellSpaces). The selection of spaces for indoor navigation applications can take place for many different reasons:

- To reduce the overall number of spaces such as selecting only empty spaces, such as rooms and corridors and avoid non-empty spaces such as walls, slabs, or too crowded areas.
- To eliminate spaces, which will not be used for a specific user such as selecting only common spaces for someone visiting a public building.
- Eliminating spaces of danger such as in emergency cases, select only spaces which are still safe for users to be in.

7.3. Poincaré Duality

Topological relations between cells are crucial in the IndoorGML model. They allow establishing links between cells in the same or different thematic layers. This is critical information for several applications such as navigation, which relies on connectivity networks. As mentioned above, a topological model of cellular space is partial and represents only relations between cells and their boundaries. The Poincaré duality (Munkres, 1984) is further employed to explicitly describe the relationships between the cells. The Poincaré duality provides a theoretical background for mapping cellular space to a graph or network to represent allowed topological relationships. It simplifies the complex spatial relationships, which may occur in a 3D topological model (Lee, 2004).

The Poincaré duality refers to two spaces: Primal Space and Dual Space. A k -dimensional object in N -dimensional Primal Space is mapped to $(N-k)$ dimensional object in Dual Space. Thus, solid 3D objects in 3D Primal space, such as rooms within a building, are mapped to nodes (0D object) in dual space. A 2D surface shared by two 3D objects is transformed into an edge (1D) linking the two nodes in Dual space. The nodes and edges in Dual space form an adjacency graph. The nodes and the edges in Dual space represent abstractions of cells and their adjacency relationships in Primal space.

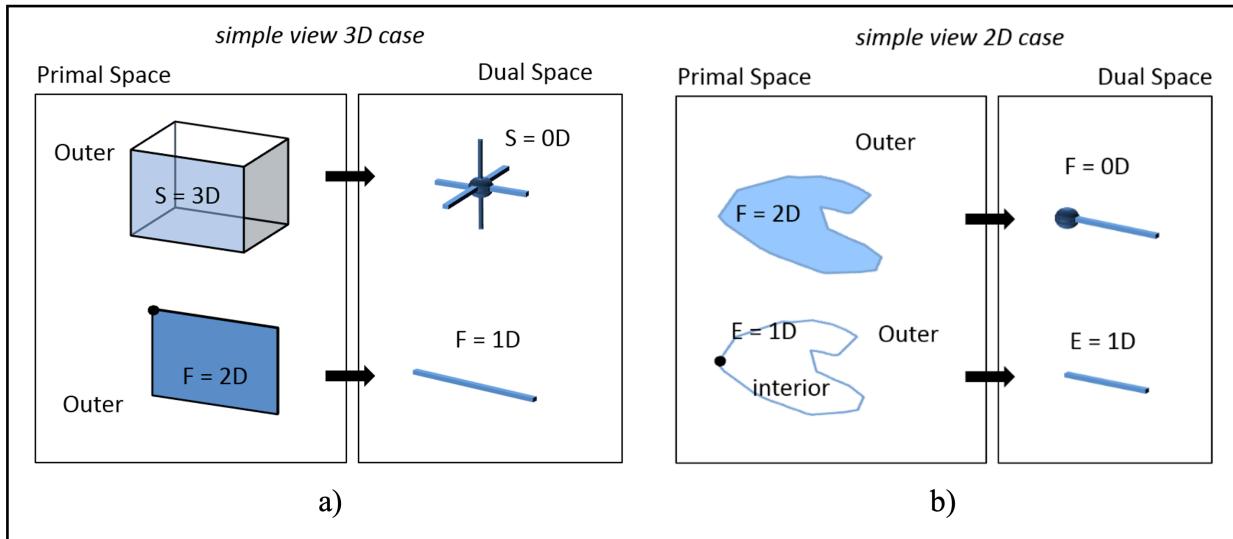


Figure 8 – Principles of Poincaré duality. 3D Primal space case (a) and 2D case (b). (Mathematical definition of Poincaré duality in (Munkres, 1984))

Figure 8 illustrates this duality transformation for the case where the primal space is 3D (a) and 2D (b) respectively. Note that the transformations from 1D object (curve) or 0D object (point) in 3D Primal space are not included in the IndoorGML model since they are not considered as cells in most applications. However, the transformation may be applied to 1D or 0D objects of 3D primal space in a similar way if it is required. Then the adjacency graph G_{adj} is defined as follows:

$$G_{adj} = (V, E_{adj})$$

where V and E_{adj} are sets of nodes and edges in dual space mapped from cells and surfaces in 3D primal space, respectively. The connectivity graph G_{con} is a subset of the adjacency graph and represents only adjacency that make the spaces connected. For navigation cases connectivity between spaces (i.e. room) is provided via the notion of doors between the rooms. Connectivity graph is defined as:

$$G_{con} = (V, E_{con})$$

where V and E_{con} are sets of nodes and edges in dual space mapped from cells and surfaces in 3D primal space, respectively. Figure 9 illustrates cellular space and its connectivity graph.

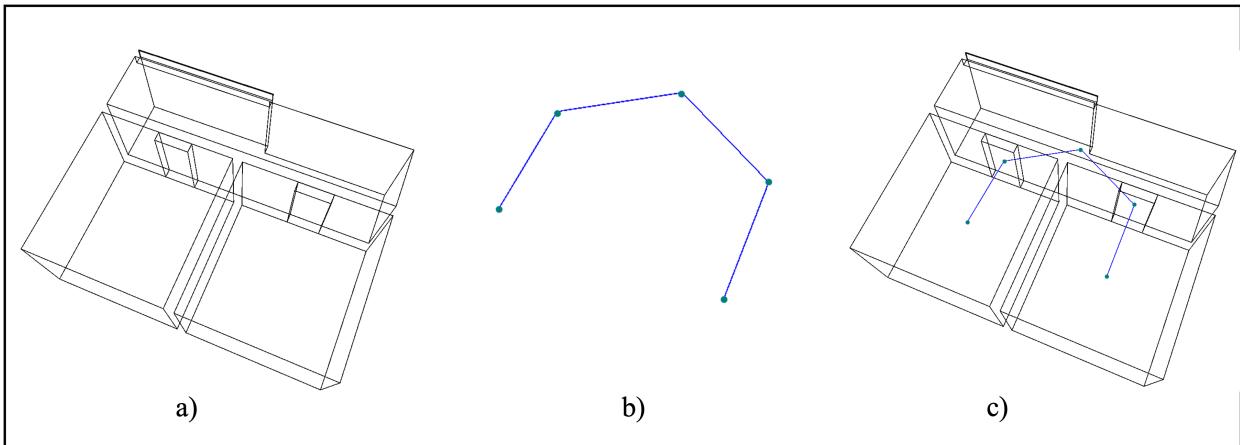


Figure 9 – Poincaré duality on 3D cells of a building (a); Corresponding adjacency graph in the dual space (b); Combined primal and dual space view (c).

The adjacency graph can be represented as a *logical network* or *geometric network*. While the logical network represents only the relationships between the cells, the geometric network holds geometry for nodes and edges.

7.4. Structured space model

The Primal and Dual spaces and the Euclidean and Topological spaces are interlinked in a Structured Space Model as illustrated in Figure 10. The Primal space refers to either Euclidean or Topological space and the Dual space refers to either the Geometric network or the Logical network. Geometry of Cellular Space and Geometric Network are embedded in the Euclidean space, while Topology of Cellular Space and Logical Network are defined in the Topological space. IndoorGML supports the Primal and Dual models in the Euclidean space and the Logical Network in the Topological space. As mentioned above, the Geometry for Cellular space is not compulsory, as the cellular space can be identified. An IndoorGML encoding is valid with at least one of the Primal spaces. See examples in Clause 9.

The Euclidean space (Geometry) is estimated to be the most useful for applications such as navigation and LBS. An IndoorGML encoding may then contain both Geometry and Geometry Network, or only Geometry, or only Geometric Network. Other types of applications, such as dealing with ownership or sensor coverage, may be better supporter by an IndoorGML encoding containing Geometry and Logical Network or Topology and Logical Network.

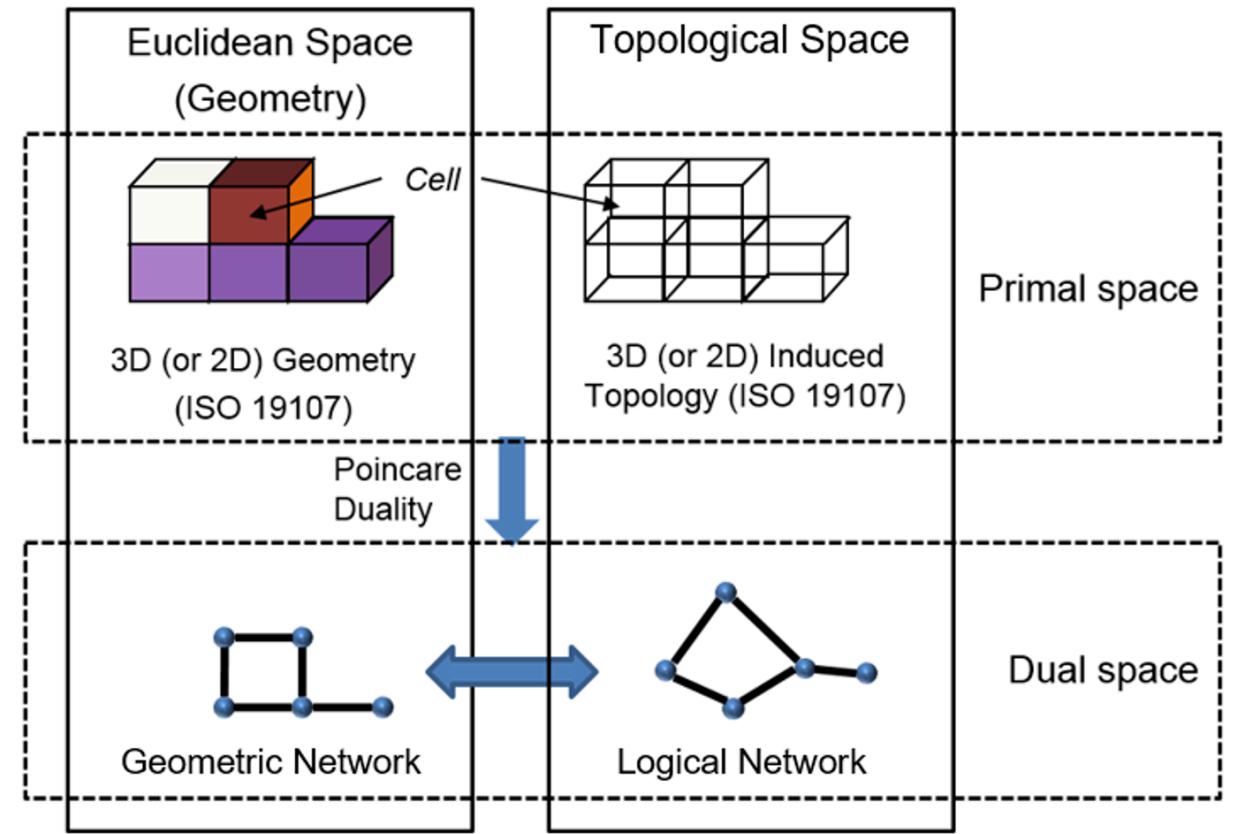


Figure 10 – Structured space model: mapping between Euclidean and Topological spaces, and Primal and Dual Spaces

7.5. Semantics

The IndoorGML model contains the semantic for the Primal and Dual spaces of the core module. The semantics of the core model are generic for all applications. It specifies only some characteristics such as name, level, and Point of Interest (Pol). If no extension module is involved, the cells carry the semantics of the core module only.

Further semantic specifications are provided via the Extension modules as explained in Clause 8.2. Every cell is further classified according to the semantics introduced by the extension module. The IndoorGML 2.0 Model defines semantics for Indoor navigation that are provided within the Navigation extension module. The semantics, defined in the Navigation extension module, are intended for two purposes to: 1) provide a classification of a cell, and 2) determine adjacency relationships that ensure connectivity between cells. Semantics thus supports defining cells that are important for navigation. Thus, a cell can be classified as navigable (room, corridor, hall), non-navigable (wall, slab, furniture), opening (door, window), etc. (see Clause 8.2). The subdivision and classification of Cellular space relies on the architectural layout of a building.

While this may be enough for some cases based on connectivity graph analysis, it can rapidly be limiting for more specialized applications such as sensor managements, legal aspects, or security. These latter applications require advanced, specific semantic needs to be associated to the geometric and topological elements. Examples can be a Legal Extension module, in which a cell might be classified as ‘ownership’, ‘restriction’, ‘responsibility’ etc. or a Security extension module that may offer semantics that would indicate ‘check-in’, ‘boarding’, ‘crew entrance’, etc.

The semantic extension mechanism enables adding more semantic on primal or dual spaces, as long as they follow the modularization principle. Cells can be organized in a hierarchical structure according to their semantics, corresponding properties, and semantic interrelations (specialization and generalization). For example, ‘room’ is a specialization of ‘navigable cell’ and ‘non-navigable cell’ is a generalization of ‘walls’ and ‘obstacles’. Cells created for one space representation may be aggregated or subdivided for the purpose of another one. More details about the Navigation extension module are given in Clause 8.2.

7.6. Thematic layers

A single indoor environment can be organized in many kinds of cellular spaces with distinct subdivision and semantic specifications. Within each Extension module, it is possible to have many different subdivisions and each cellular space is targeted towards specific applications and needs. A cellular space with a specific semantics and/or geometric subdivision, aiming to reflect a group of application can be organized in a *Thematic Layer*. Thematic layers can be defined using the Extension modules and/or Core module. Thematic layers making use of the semantics of Core module only, can be derived applying the principles of space partitioning, such as subdivision, aggregation and selection. Examples of such thematic layers are subdivision according to Wi-Fi or RFID coverage (see example below)¹. The Navigation extension module provides additional notions for navigability and connectivity. Therefore, thematic layers that rely of these properties should include the Navigation extension module. Navigation-based themes can be defined using a particular space partitioning with respect to:

- Tasks: visitor, staff, facility manager, emergency responder (see Figure 11)
- User characteristics: age, gender
- Mode: walking, driving, flying (see Figure 7© and (d))

IndoorGML 2.0 is organized as a collection of interconnected layers representing different themes of the same physical space. Figure 11 represents a thematic layer ‘Visitors’, which contains all cells, which are accessible to visitors in a university facility (Alattas et al., 2017). Similarly, cellular spaces can be created for students or facility management. All spaces use the semantics of the Navigation extension module, but a selection of spaces is made according to the user tasks. Similarly, cellular spaces from different extension modules can be organized into thematic layers.

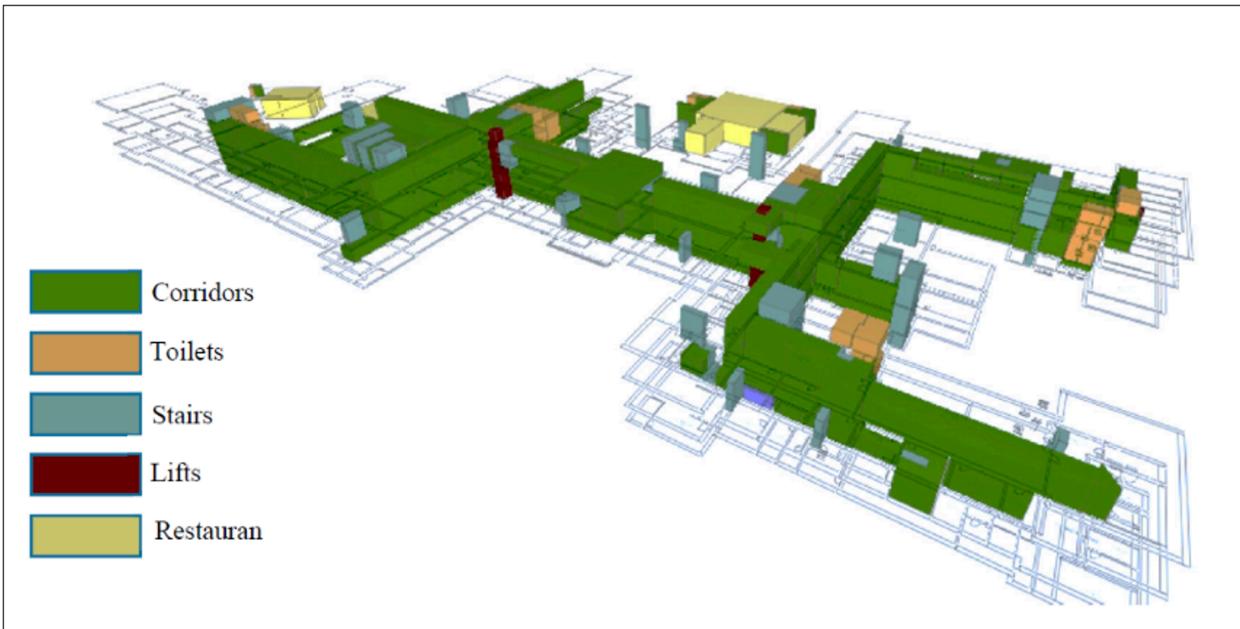


Figure 11 – Cellular space for visitors (Alattas et al., 2017)

In Figure 12, a physical indoor space named Topographic layer is organized according to the Navigation extension module. In addition, two thematic layers called Wi-Fi and RFID are specified, which rely on the semantics of the core model only. The Topographic layer, created under the Navigation extension module, follows the architectural layout of a building, and is composed of rooms, corridors, and stairs. Wi-Fi and RFID cells follow the outlines of the corresponding sensor coverages. The three cellular spaces, although related to subdivision approaches, each form a thematic layer. These three thematic layers may be appropriate for an application that provides tracking and navigation.

Following the modularization mechanisms, every layer in IndoorGML contains the core module, which is composed of Primal space and Dual space. A valid thematic layer should contain at least one of the four space representations: Geometry, Topology, Geometric network, or Logical network.

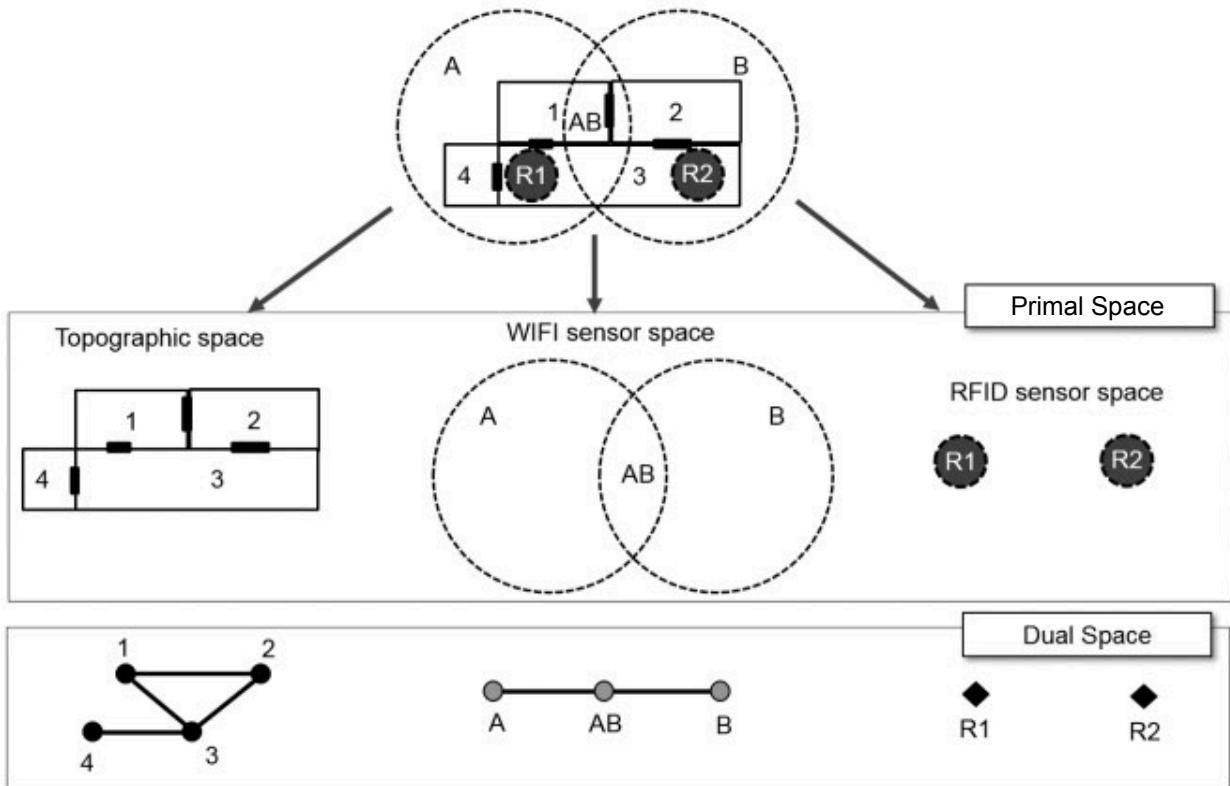


Figure 12 – Three different cellular spaces for the same physical space.

7.6.1. Multiple-Layered Space representation

The IndoorGML model provides mechanisms for maintaining and linking multiple Thematic layers for the same indoor environment. Figure 13 represents the three thematic layers discussed above.

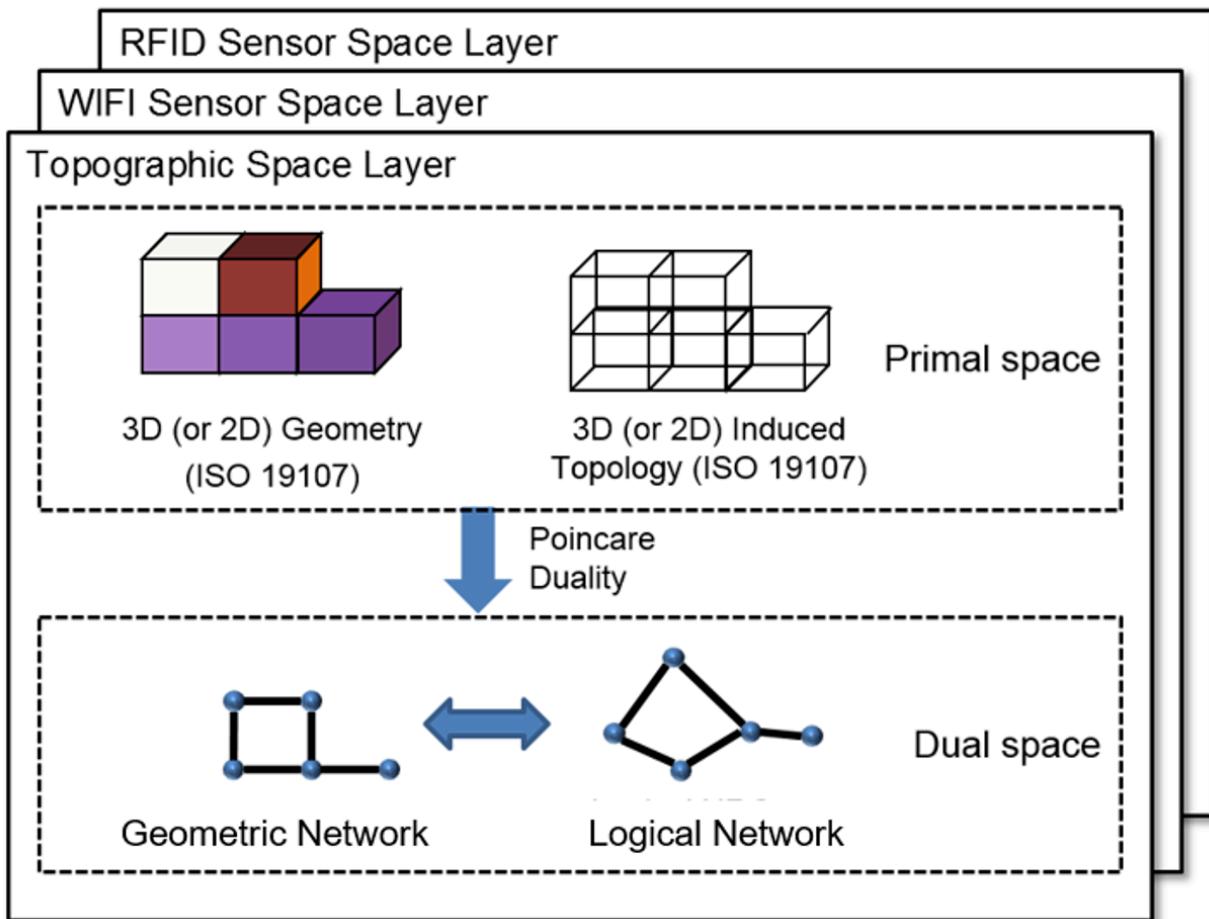


Figure 13 – Corresponding Primal and Dual spaces of different thematic layers.

This representation method with multiple cellular space layers is called *Multiple Layered Space Representation* (MLS Representation). The MLS representation is useful for many purposes. For example, representing the hierarchical structure of indoor space, where each floor level is a single space layer. Another application example is indoor tracking using presence sensors, such as RFID, as shown in Figure 12. Given an indoor space represented as a Topographic layer and RFID sensor coverage layer respectively, the movement of a mobile object can be deduced using a RFID tag by the sequence of RFID coverage cells and corresponding inter-layer space edges.

7.6.2. Inter-Layer Relations

To handle the interaction between several layers, it is necessary to represent the relationships between them. IndoorGML does this through the Inter-Layer connection which describes the spatial relationships (topology) between two layers. Unlike the topological relationships between cells of a same layer which are ruled by the Poincaré Duality (adjacency only), the inter-layer relations are ruled by the 9-intersection model (Egenhofer, 1989). IndoorGML 2.0 concentrates on six relationships: *contains*, *within*, *covers*, *coveredBy*, *overlaps* and *equals* between cells in the Primal space and nodes in Dual space.

As illustrated in Figure 13, there are three space layers. Each layer has its own Primal and Dual space representation. Following the same indoor tracking example, Figure 14 illustrates the inter-layer relations between the dual spaces of the layers in Figure 12. In a topographic layer, the nodes represent the possible states of a navigating object and correspond to cells with volumetric extent in primal space (e.g., rooms). The edges represent state transitions, i.e., the movement of an object from one space to another. They correspond to connectivity relations between the cells in primal space (e.g., adjacent rooms connected by a door). In the sensor space, the graph has a slightly different structure. The nodes represent again the cells (e.g., the entire coverage space of a Wi-Fi transmitter); the edges represent the transition from one space to another based on the neighbouring Wi-Fi coverage spaces. Since the layers cover the same real-world space, the separated dual graphs can be combined into a multi-layered graph.

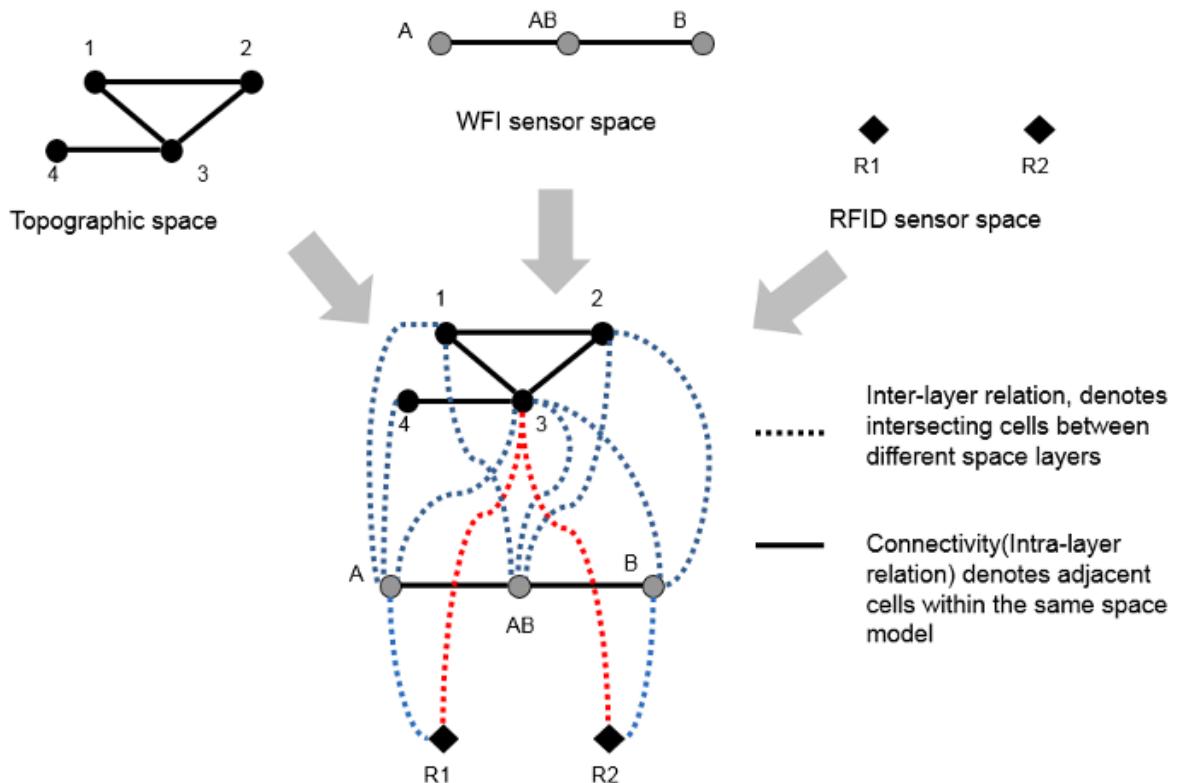


Figure 14 – Inter-Layer relations between three different layers of a same environment.

Figure 14 illustrates relationships in the Dual space between the three Primal spaces given in Figure 13: Topographic and two sensors' spaces WiFi and RFID. A novelty in the IndoorGML 2.0 model is the possibility of representing an inter-layer connection between two primal spaces. This is illustrated in Figure 15 where the inter-layer mechanism is used to represent a furnished room with a combination of two layers: One describing solely the cells of the room and openings (Figure 15(b)) and one describing the furniture CellSpaces (Figure 15(c)). The relationship between the two layers can be qualified as a containment (layer 1 contains layer 2, or layer 2 is within layer 1). This supports describing complex scenes while respecting the non-overlapping constraint of Poincaré duality.

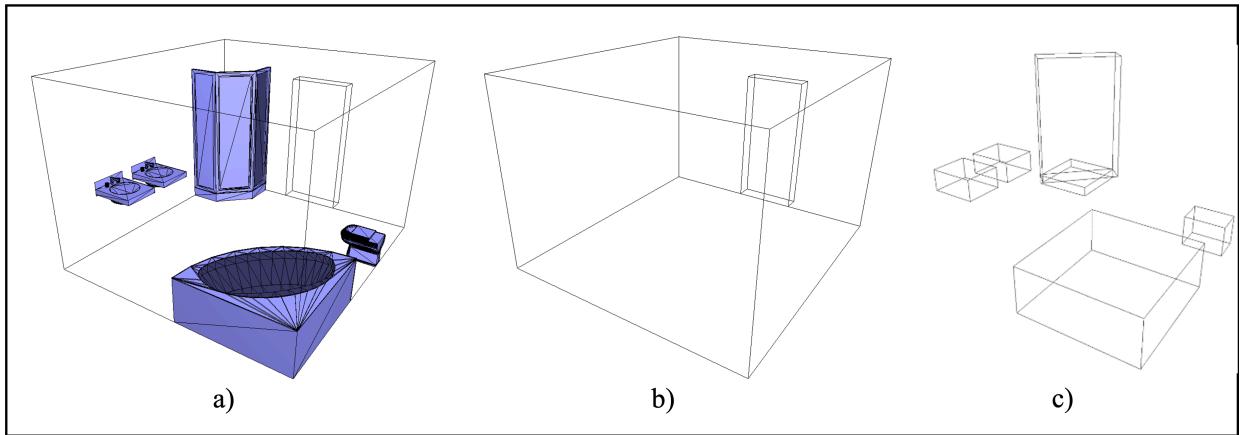


Figure 15 – Inter-layer connection between two primal spaces. (a) furnished room. (b) cells of the room and door only. (c) cells of furnishing elements only represented by minmax boxes.

8

DATA MODEL

This section presents the IndoorGML conceptual data model as UML class diagrams.

8.1. IndoorGML Core Module

The core module is composed of three main parts:

- The primal space which describes the cellular space (see Clause 7.2);
- The dual space which carries the network information (see Clause 7.3);
- The inter-layer connection which makes the link between thematic layers (see Clause 7.6.2).

In Figure 16, the UML diagram illustrates all the classes associated with those three parts. In the following, the classes are introduced and the data types that they invoke in their properties are detailed.

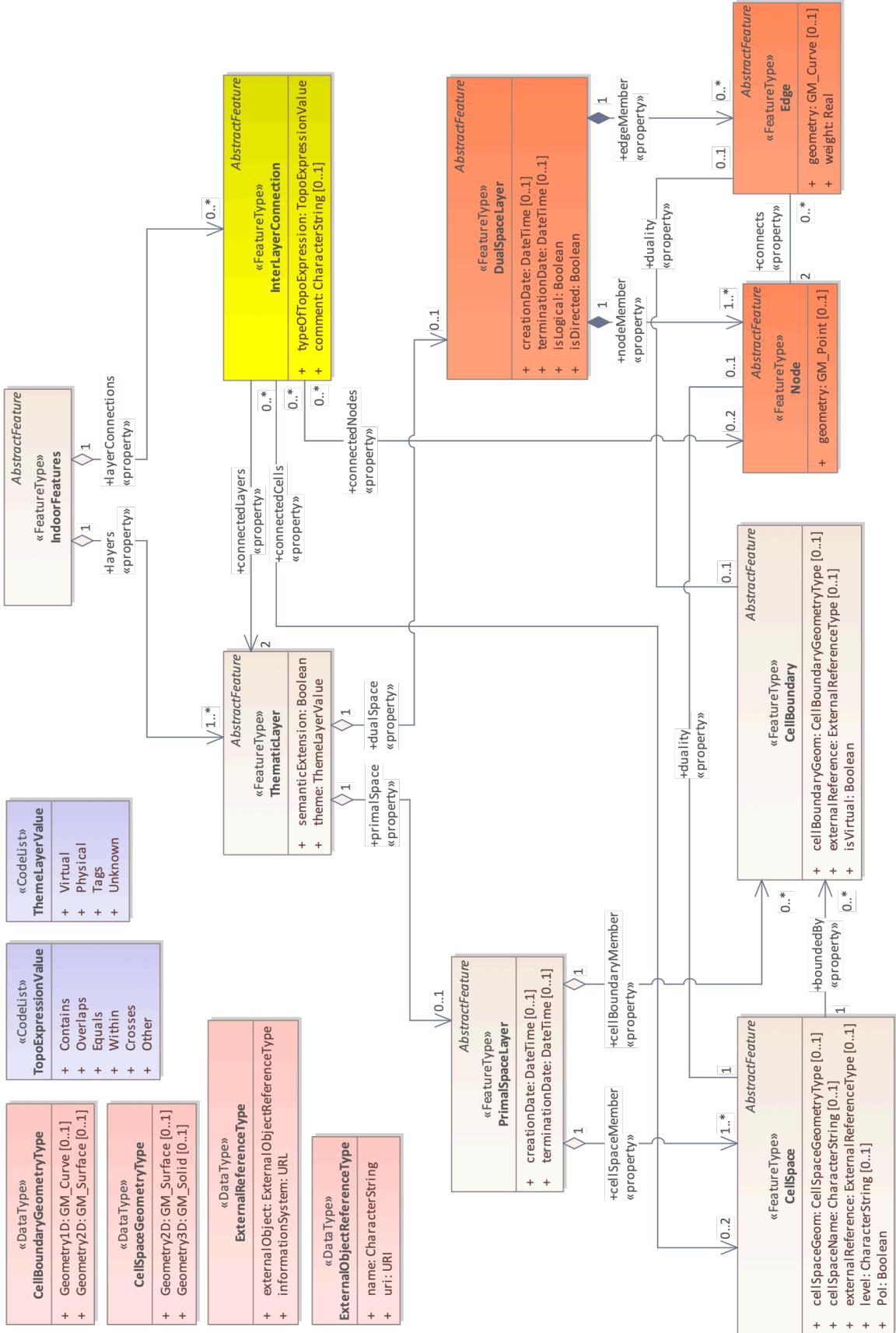


Figure 16 – UML diagram of the Core module.

8.1.1. CellSpace

CellSpace is a core module class for representing the indoor environment in terms of cellular space. CellSpace is a mandatory class to have a valid IndoorGML2.0 encoding. It contains the following properties (Figure 17):

- *cellSpaceGeom* (*CellSpaceGeometryType*)
 - *cellSpaceName* (*CharacterString*)
 - *externalReference* (*ExternalReferenceType*)
 - *level* (*CharacterString*)
 - *Pol* (*Boolean*)

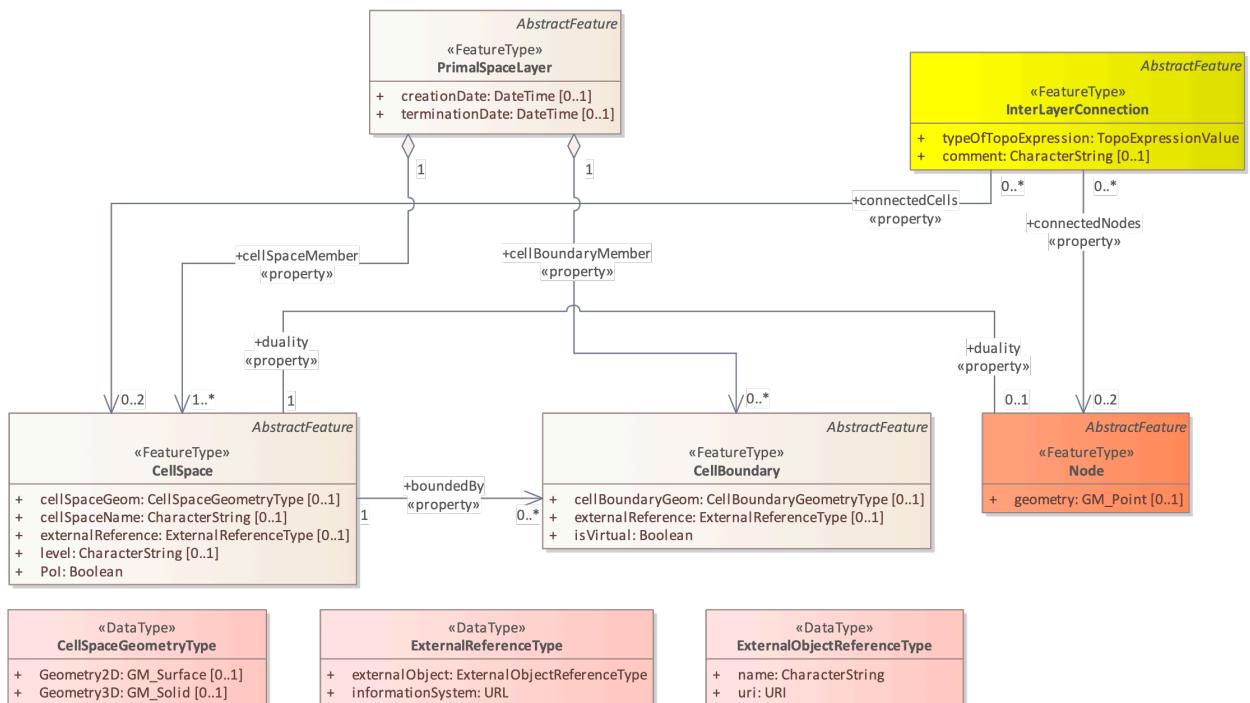


Figure 17 – CellSpace and its related classes: PrimalSpaceLayer, CellBoundary, Node and InterLayerConnection

The *cellSpaceGeom* property carries an instance of type *CellSpaceGeometryType* for the description of geometric representations of space. A *CellSpaceGeometryType* is a geometry class type with two possible properties: *Geometry3D* or *Geometry2D*. They provide the 3D and 2D description of a *CellSpace* instance. The *Geometry3D* property describes a representation of type solid, similar to the *GM_Solid* (ISO 19107) type. It is the default type for describing a 3D *CellSpace* as one single valid entity. The *Geometry2D* properties describes a representation of type surface, similar to the *GM_Surface* type. This property describes a *CellSpace* in 2D as one single surface (in the case of a 2D IndoorGML model). The geometry should be valid according to the ISO 19107 Standard terms. If a *CellSpace* cannot meet those requirements, e.g., be valid

2D or 3D geometry, the option to describe its geometry as a set of CellBoundary entities can be considered. The CellSpace can be defined without geometry as well.

The property *externalReference* is used for the reference of an object to its corresponding object in an external data set. A CellSpace also carries a *level* information, which can be left empty when it cannot be clearly identified. For example, this is the case for a CellSpace that aggregates several cells spanning across multiple stories. The value of *level* is given as a string rather than an integer because it is sometime given as plain text “M” for mezzanine floor and “RC” for ground floor. A newly introduced property in IndoorGML 2 is *cellSpaceName*. The purpose is to record the name given to a space according to any internal convention (e.g., MR.403 for meeting room 3 at level 4, or coverage of Wi-Fi 234). This is a common practice for large buildings and this property helps simplify space queries for applications. Another new property *Pol* is introduced to allow CellSpace elements to be flagged as Point of Interest for LBS applications. The property is a simple Boolean allowing the implementation of special considerations for flagged cells.

Note that apart from the *Pol* property, all applicable properties of a CellSpace can be null. For example, a network only IndoorGML model would not need a cellular space with explicit geometric description. However, CellSpace instances should always be described in an IndoorGML model (even without geometry property) as they may carry all the important information related to the primal space that other features from the dual space or other layers may need. For example, a node can be identified as a *Pol* or associated with a *cellSpaceName* thanks to the property of its primal space.

In terms of relationships, a CellSpace instance can describe relationship with multiple CellBoundary entities, which represent its surrounding boundaries partially or fully through the *boundedBy* association. For example, the choice can be made to store only boundaries which are important for the Dual Graph (e.g., boundaries that reflect adjacency between CellSpaces). In the case where a CellSpace does not carry the geometry of type Solid and uses a boundary-based representation instead, then all boundaries might be needed (to derive the geometry of the nodes or for visualization). Finally, with the *duality* association, a CellSpace can describe a reference to one Node instance corresponding to its representation in the dual space.

CellSpace instances are aggregated in a PrimalSpaceLayer according to a specific theme as explained in Clause 7.6. For the case of multiple PrimalSpaceLayers, the class InterLayerConnection establishes the link between the depended CellSpace instances.

8.1.2. CellBoundary

CellBoundary is a core module class that describes the boundary of each cell in a cellular space (Figure 18). Unlike CellSpace, CellBoundary is not a compulsory class. It is only required when Edge instances exist in the model. CellBoundary contains the following properties:

- *cellBoundaryGeom* (*CellBoundaryGeometryType*)
- *externalReference* (*ExternalReferenceType*)
- *isVirtual* (*Boolean*)

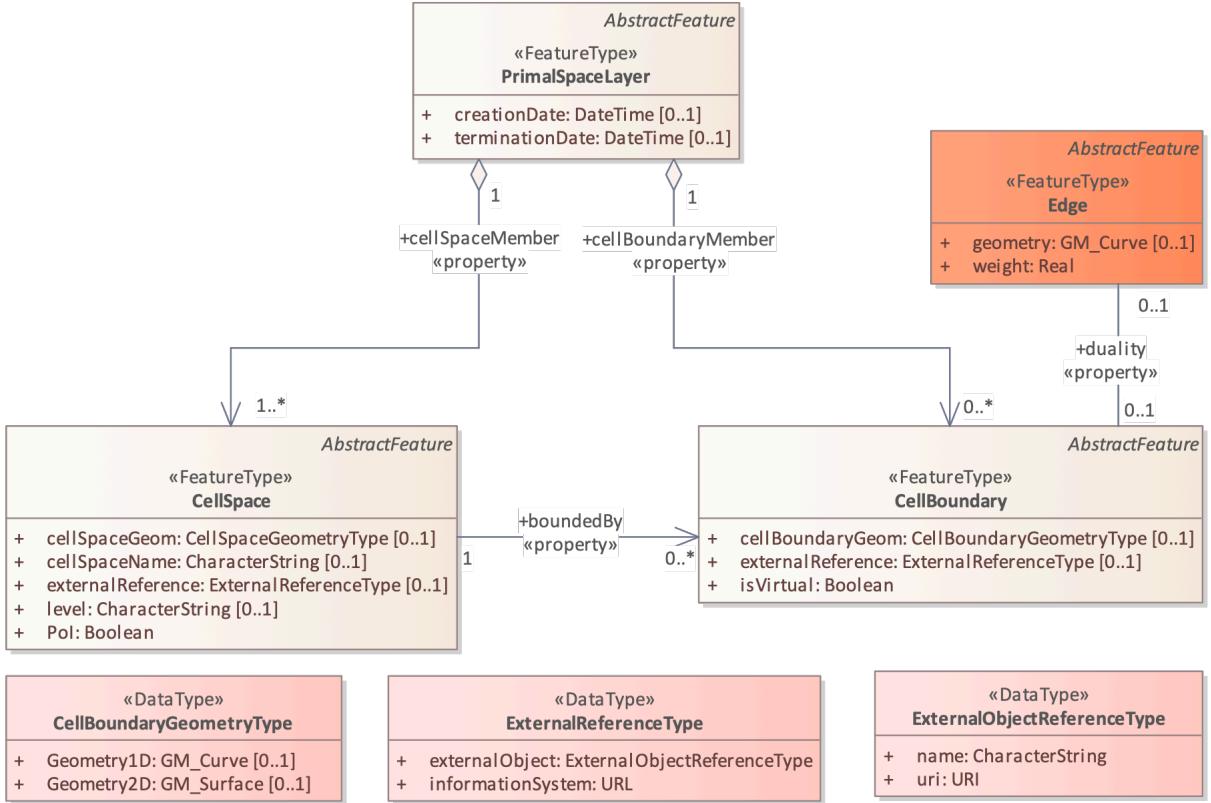


Figure 18 – CellBoundary and its related classes: PrimalSpaceLayer, CellSpace and Edge

The *cellBoundaryGeom* geometry property of the CellBoundary carries the geometry (of type *CellBoundaryGeometryType*) which is generally described by a surface in 3D or a curve in 2D. A *CellBoundaryGeometryType* is a geometry class type similar to the *CellSpaceGeometryType*, with two possible properties: *Geometry2D* and *Geometry1D*. The *Geometry2D* property is the same as that of *CellSpaceGeometryType*. Note, in this context, *cellBoundaryGeom* is embedded in 3D, i.e., has 3D coordinates and represents a part of the boundary of a CellSpace. The *Geometry1D* property describes a representation of type curve, *GM_Curve* type. Note, this property is intended for describing a CellBoundary in 2D as one single line/curve and has 2D coordinates. This is an adequate representations of *cellBoundaryGeom* based on 2D floor plans. The *cellBoundaryGeom* is not required. In this case, *cellBoundaryGeom* indicates only if a specific cell boundary is virtual.

The property *externalReference* is used for the reference of a geometric object to its corresponding object in an external data set and can be given by the url of the file containing the geometry. The *isVirtual* property is a Boolean value used to indicate whether a CellBoundary corresponds to a virtual surface (true) or a physical one (false), which should be the default value. Virtual boundaries are common in 3D indoor models, mainly when a space subdivision is applied.

Additionally, a CellBoundary can be linked to one Edge instance via the *duality* association, which corresponds to its dual representation. Unlike CellSpace, CellBoundary is not a mandatory instance in an IndoorGML data. In the case where there are CellSpace entities but no CellBoundary, the network may be derived from the cells using geometric operations.

In the case where there are CellBoundary entities provided without geometric properties in the model, only logical networks can be safely derived between two CellSpace entities sharing any of those CellBoundary. Therefore, providing geometric networks involves similar issues described previously. A final scenario may see an IndoorGML data with geometry information only with CellBoundary instances but not for CellSpace. That case is likely to happen if a solid geometry cannot be provided for a CellSpace, and a set of surface boundaries are provided with no guarantee of closure. In that case the generation of a Node for a CellSpace should be completed from CellBoundary instances, while guaranteeing its position inside the described space.

8.1.3. PrimalSpaceLayer

PrimalSpaceLayer is a core module class representing the primal cellular spaces of a given thematic layer (Figure 19). It aggregates CellSpace and CellBoundary (which are directly associated with their corresponding geometry properties) to represent spatial objects in primal space. The PrimalSpaceLayer class has the following properties:

- *creationDate (DateTime)*
- *terminationDate (DateTime)*

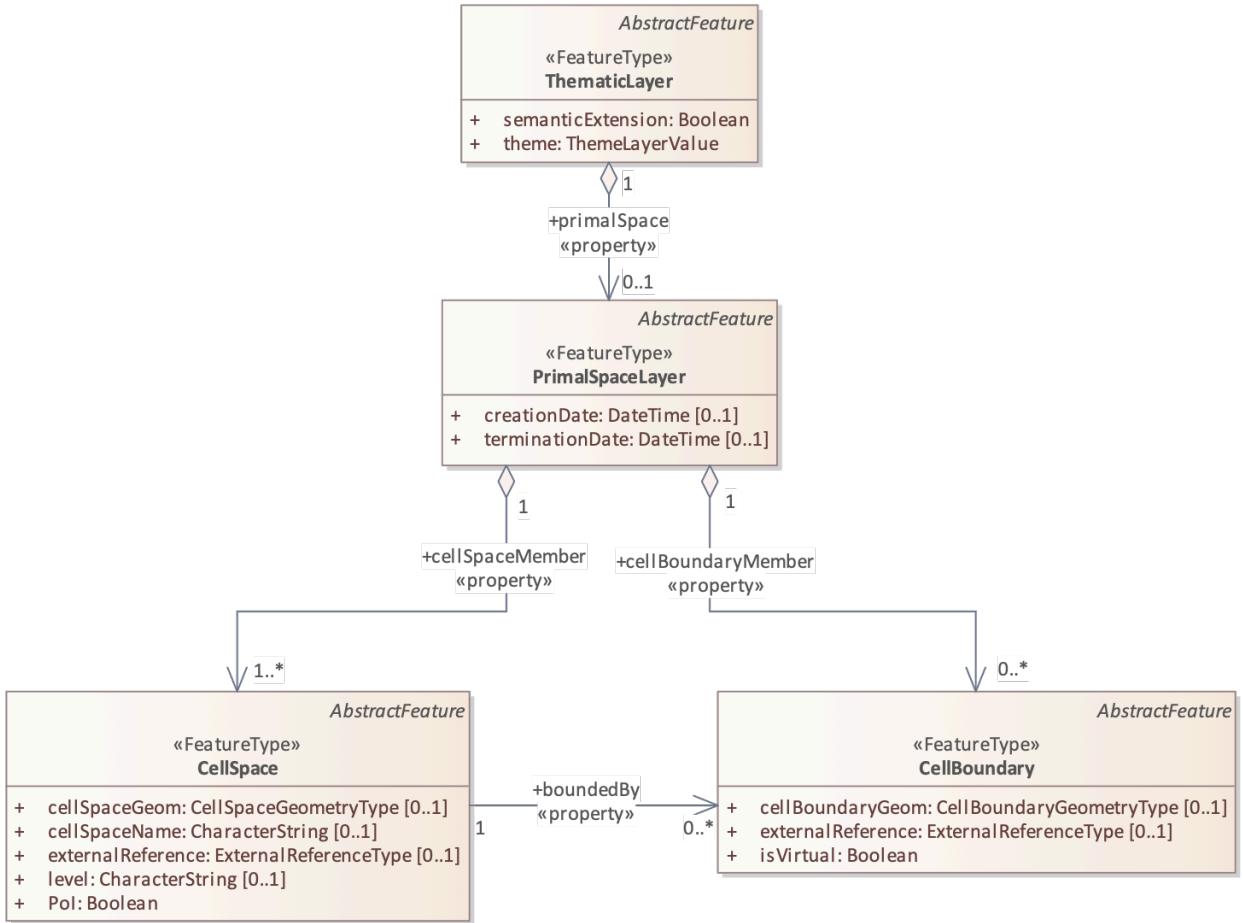


Figure 19 – PrimalSpaceLayer and its related classes: CellSpace, CellBoundary and Thematic Layer

Both *creationDate* and *terminationDate* properties can be used to describe the chronology of the layer. A PrimalSpaceLayer instance also provides references to its CellSpace and CellBoundary entities through the *cellSpaceMember* and *cellBoundaryMember* elements.

8.1.4. Node

Node is a core module class for representing a node in dual space (Figure 20). It has one property:

- *geometry (GM_Point)*

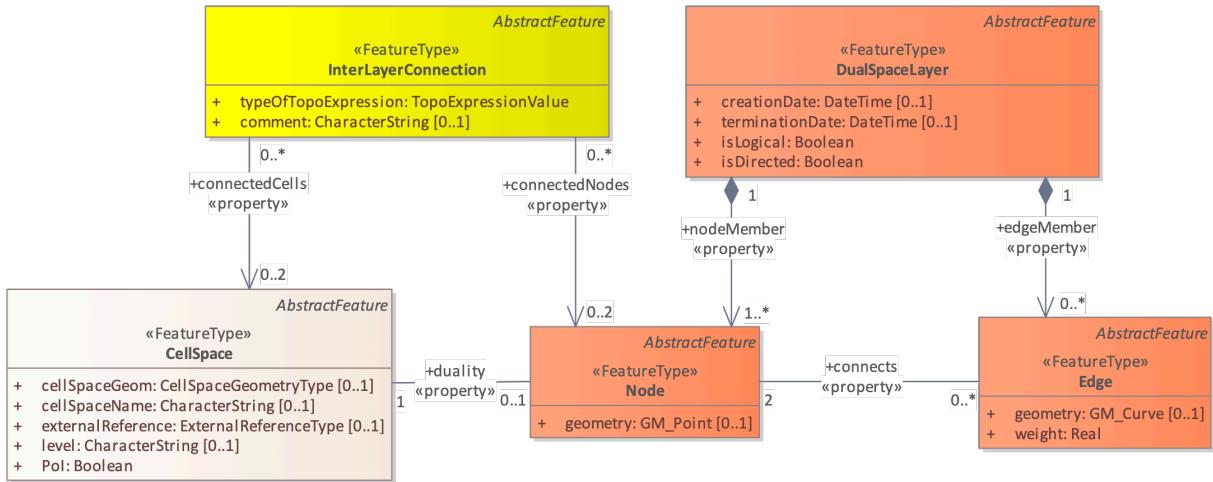


Figure 20 – Node and its related classes: CellSpace, Edge, DualSpaceLayer and InterLayerConnection

The value of *geometry* corresponds to a 2D or 3D Point in the IndoorGML model, but its cardinality can be 0 (no geometry provided) or 1. Because a Node is always the dual space abstraction of a primal space cell, a Node always has an association with its corresponding CellSpace (e.g., room, door, sensor coverage, etc.) through the *duality* association. This way, a Node can always access the information related to the cell it is representing (e.g., geometry, semantic, etc.). Note that the associated CellSpace may not carry any information as well, except the functional information for the specific cellular space. Additionally, a Node is also associated with at least one Edge instance that is linked to it via the *connects* association.

8.1.5. Edge

Edge is a core module class that represents the adjacency or connectivity relationships among Node elements representing space cells in primal space (Figure 21). The Edge class has the following properties:

- *geometry (GM_Curve)*
- *weight (Real)*

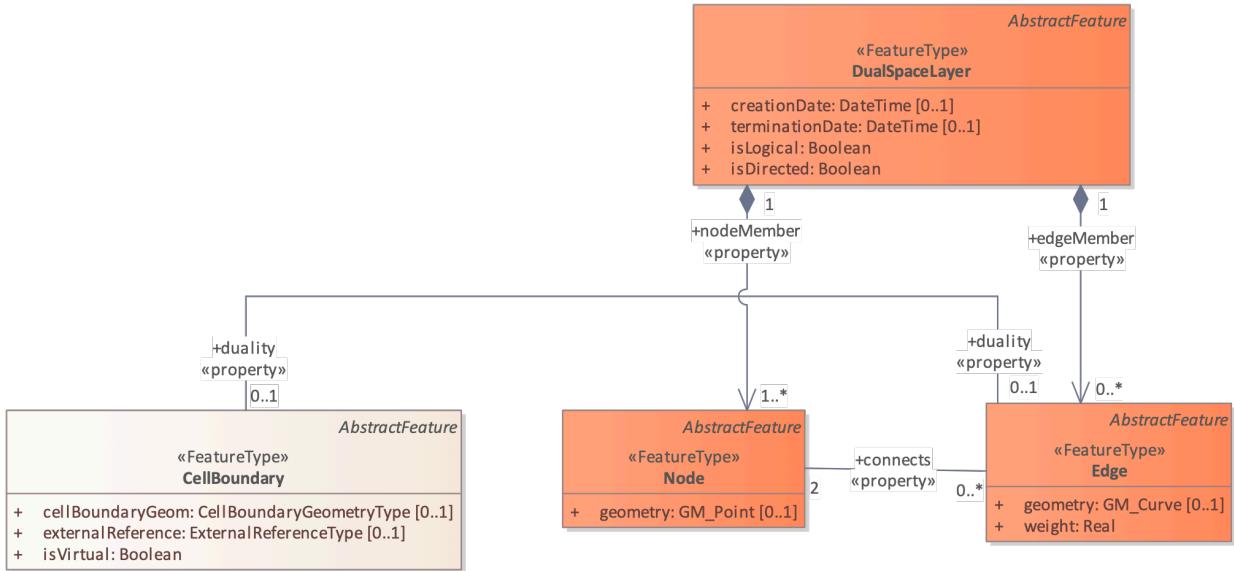


Figure 21 – Edge and its related classes: CellBoundary, Node and DualSpaceLayer

The property `geometry` provides the description of a 2D or 3D curve, but similar to `Node` entities its cardinality can be 0 or 1 as well. The property `weight` can be used for graph-based applications such as dealing with the impedance representing absolute barriers in transportation problems.

An `Edge` may be associated with a `CellBoundary` instance of the primary space via its `duality` association. This association can be skipped in situations where a `CellBoundary` is not necessary to represent the link between two `CellSpace` entities. For example, logical networks or visibility graphs where two `CellSpaces` connected by visibility may not share a `CellBoundary`. Finally, an `Edge` always connects two `Nodes`.

8.1.6. DualSpaceLayer

`DualSpaceLayer` is a feature class for representing the dual space features (e.g., room network) of a given thematic layer. The `DualSpaceLayer` class is composed of `Nodes` and `Edges` for representing the topology of objects from the primal space. It has the following properties:

- `creationDate` (`DateTime`)
- `terminationDate` (`DateTime`)
- `isLogical` (`Boolean`)
- `isDirected` (`Boolean`)

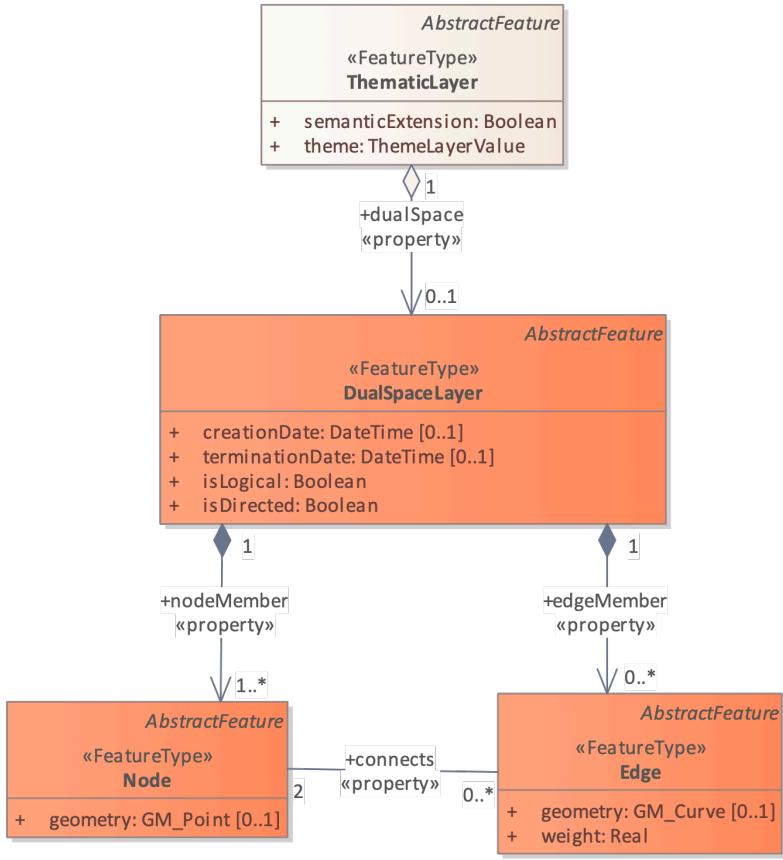


Figure 22 – DualSpaceLayer and its related classes: Node, Edge and Thematic Layer

While *creationDate* and *terminationDate* are similar to those of *PrimalSpaceLayer*, the *isLogical* property allows differentiating whether the provided network is a geometric or a logical network. This difference may matter for certain applications such as navigation, where a logical network would not be sufficient to evaluate travel distances between cells. Similarly, the *isDirected* property allows to specify if the graph associated with the *DualSpaceLayer* is directed or not. A directed graph implies that the node directions should be considered in the applications. Currently, the order of the nodes in the implementation formats determines their direction. Additionally, a *DualSpace* provides references to all its related *Node* and *Edge* entities through its *nodeMember* and *edgeMember* compositions.

8.1.7. InterLayerConnection

The *InterLayerConnection* class describes the connection between two layers in IndoorGML, either of type *PrimalSpaceLayer* or *DualSpaceLayer* (Figure 23). The *InterLayerConnection* class contains the following properties:

- *typeOfTopoExpression* (*TopoExpressionValue*)
- *comment* (*CharacterString*)

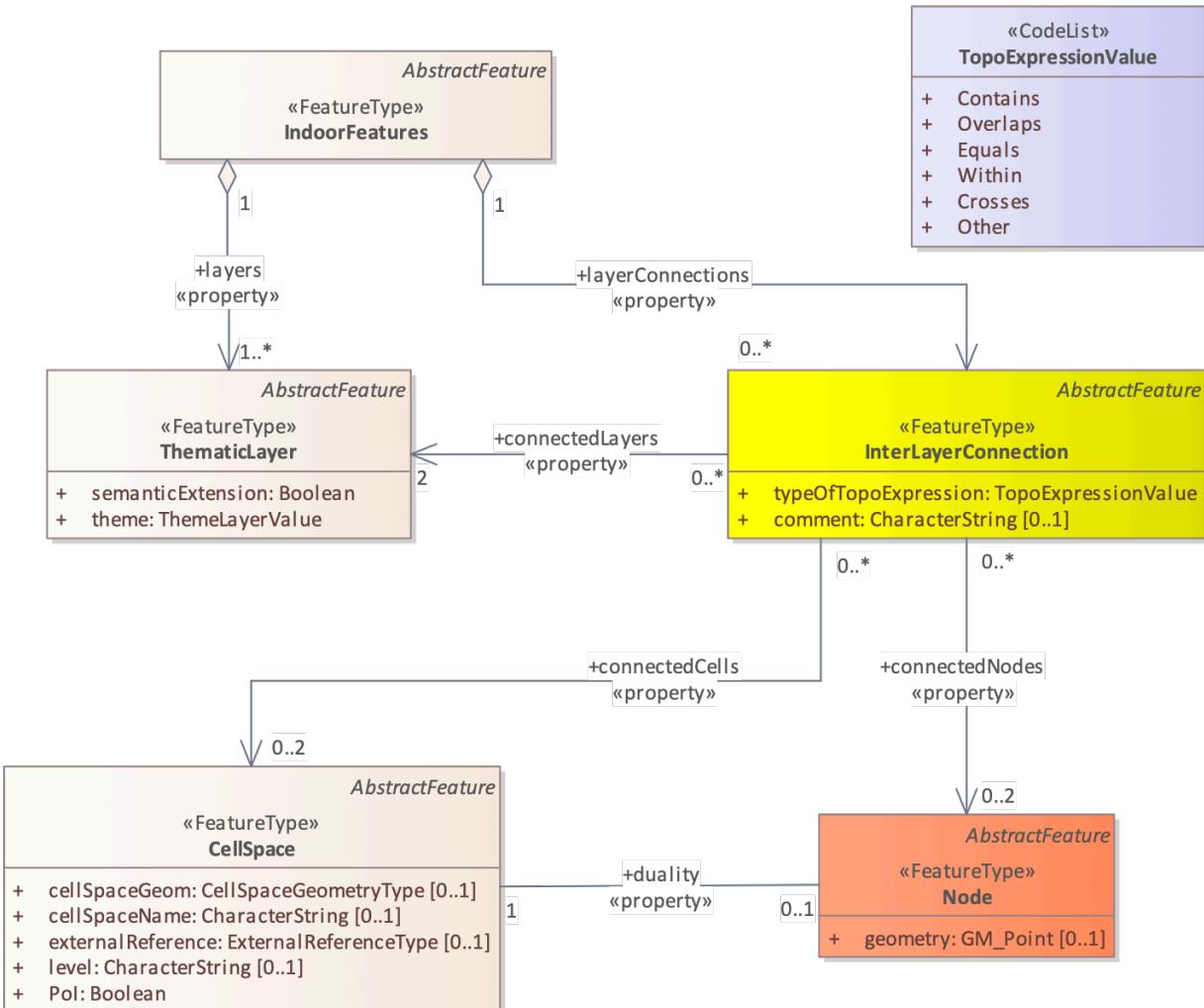


Figure 23 – InterLayerConnection and its related classes: CellSpace, Node, ThematicLayer and IndoorFeatures

The **typeOfTopoExpression** property represents the topological relationship between two layers. **typeOfTopoExpression** is a code list with the following values: *contains*, *within*, *crosses*, *overlaps* and *equals*. Those topological values are in the form of verbs for which the subject is the first instance of the **connectedLayers** property. In other words, for two layers successively described by the **connectedLayers** association, such as Layer 1 and Layer 2, one should read Layer 1 **typeOfTopoExpression** Layer 2 (e.g., Layer Room *contains* Layer Furniture).

An **InterLayerConnection** also describes the cells or nodes that are connected between two layers, using the **connectedCells** and/or **connectedNodes** associations. The former is used when the connection is between two primal spaces and the latter is used otherwise. Finally, the **comment** property can contain an additional description for the **InterLayerConnection**.

8.1.8. ThematicLayer

The ThematicLayer is a core module class introduced in IndoorGML2.0. ThematicLayer is an aggregation of PrimalSpaceLayer and DualSpaceLayer instances to allow definition of Thematic layers separately (Figure 24). Note, IndoorGML 1.1 enables the multi-layer mechanism only for the dual space (the networks).

The ThematicLayer class is composed of the following properties:

- *semanticExtension* (Boolean)
- *theme* (*ThemeLayerValue*)

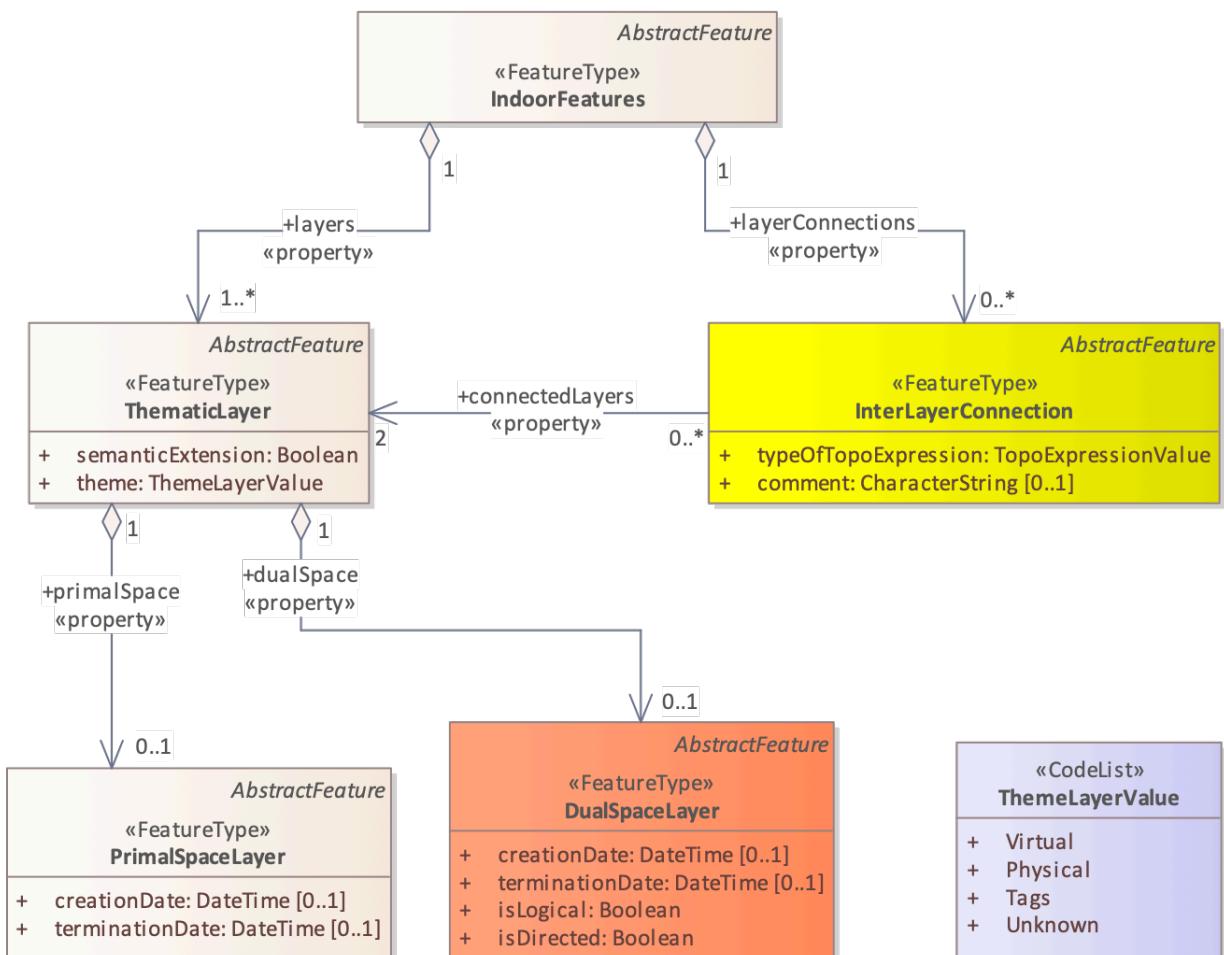


Figure 24 – ThematicLayer and its related classes: PrimalSpaceLayer, DualSpaceLayer, InterLayerConnection and IndoorFeatures

The *semanticExtension* property is a Boolean that indicates whether there is Extension module with additional semantic information associated to the PrimalSpaceLayer. The IndoorGML 2.0 Standard only specifies the Navigation extension module (see Clause 8.2). The use of a Boolean is considered enough to indicate the presence of the Navigation extension. However, this is

expected to evolve in the future (into a codeList). The *theme* property determines what type of representation of the model can be expected in the corresponding layer (e.g topographic). The *theme* property comes in the form of a code list which tells whether the layer is of type *Physical*, *Virtual*, *Tags* or *Unknown*.

A *Physical* layer is a layer that describes the indoor space on the basis of its physical constraints (e.g., the topographic cellular space in Figure 12) (Nagel et al., 2009). It is the most common type of layer for applications such as indoor navigation, where the physical elements highly constrain the use of the space. Similarly, a layer is qualified as *Virtual* when its description of the space relies exclusively on virtual, or a combination of physical and virtual extents. For example, the case for functional spaces that can represent spaces necessary for some indoor objects to operate or to be used properly (Diakité, 2018). This is also the case for sensor spaces such as the Wi-Fi spaces represented in Figure 12. Finally, the *Tags* type is useful for describing layers that use symbols or tags to represent the cellular space. The *Tags* type is a useful representation when the real geometry of the CellSpaces of a given layer are not relevant for a given application. Pol are often represented in a separate layer with their locations only (e.g., in Dual Space). Finally, any layer that does not fall in those previous categories will take the *Unknown* type.

8.2. Navigation Extension Module

The Navigation extension module provides semantic information for indoor space to support indoor navigation applications (Figure 25). The IndoorGML 2.0 semantics includes concepts related to navigability and connectivity between cells, obstacles and objects, as well as, routes for specific users. Further specialisation of cell is made available by introducing properties that can be used for additional navigation constraints such as temporal access related to as opening hours, or constraints resulting from properties of the navigation path.

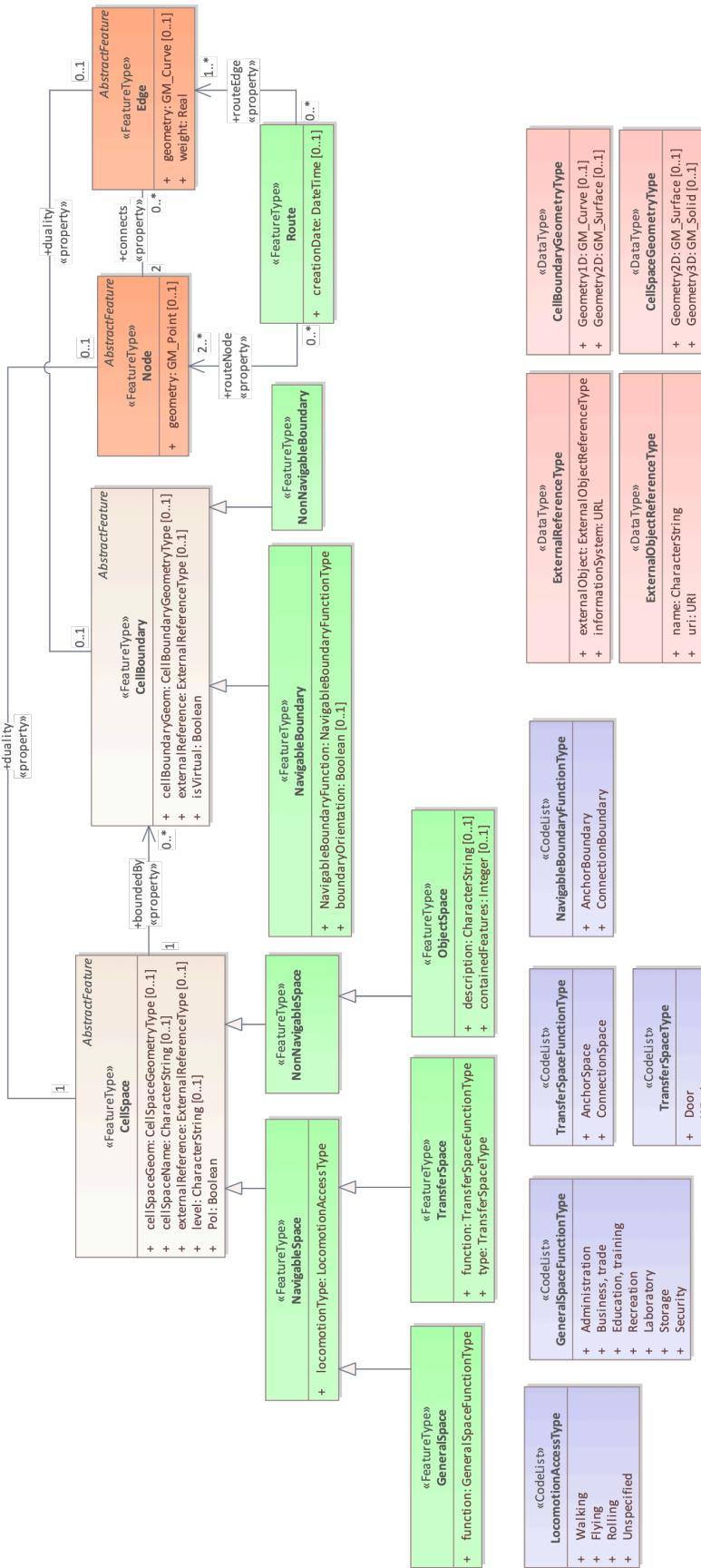


Figure 25 – UML diagram of the Navigation Extension Module (classes in green)

The space cells are classified into two major groups: *NavigableSpace* and *NonNavigableSpace*. *NavigableSpace* represents all indoor spaces (e.g., rooms, corridors, windows, stairs) that can be used by a navigation application. Spaces connecting others are also considered by this class (such as openings). *NonNavigableSpace* represents all indoor spaces that are not navigable, either because they are physically occupied by indoor features (such as furniture or walls) or because of other navigation constraints (e.g., accessibility). Both *NavigableSpace* and *NonNavigableSpace* are child's classes of *CellSpace*. Figure 26(a) illustrates such spaces on a 3D model.

NavigableBoundary and *NonNavigableBoundary* represents boundaries of *NavigableSpace* and *NonNavigableSpace* respectively. They are for describing the navigability of the spaces' sides. For example, for the door space in Figure 26(b), the sides that are meeting with the walls are of class *NonNavigableBoundary*, and the rest are *NavigableBoundary*. They are child's classes of the *CellBoundary* class. The association of *CellSpace* and *CellBoundary* classes with *Node* and *Edge* in IndoorGML core module ensures a link between the navigation module and the dual space.

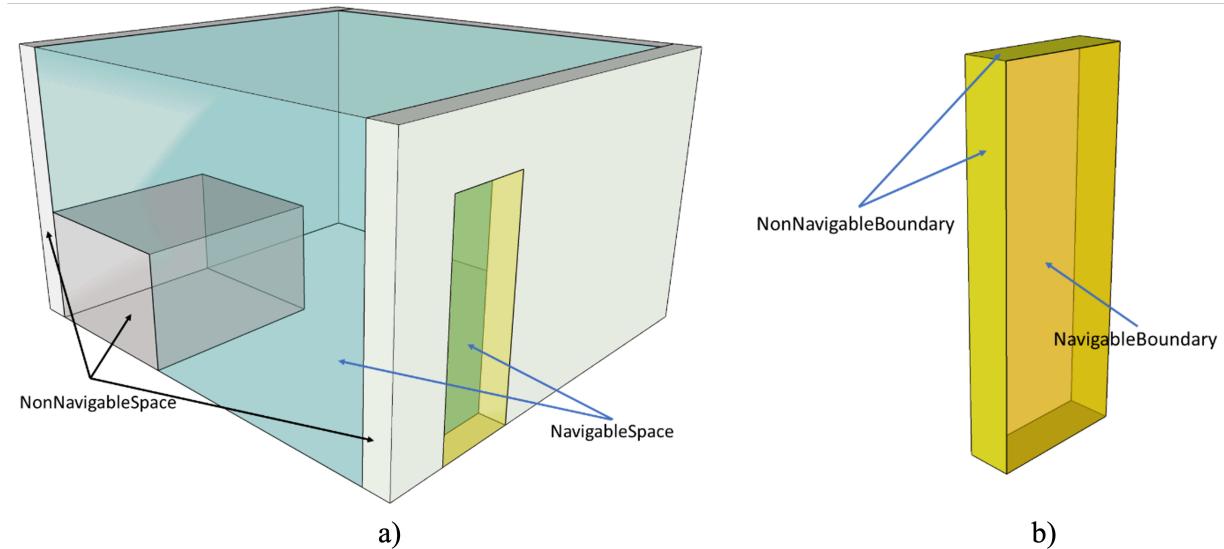


Figure 26 – Navigable and Non-navigable spaces (a) and boundaries (b) on a 3D model with walls and furniture (grey), indoor space (blue) and a door space (yellow).

8.2.1. NavigableSpace

The *NavigableSpace* class denotes a space in which users can move freely. It has two subclasses *GeneralSpace* and *TransferSpace* (Figure 27). The subclasses are classified depending on the purpose of the space. The compartmentalized spaces such as corridor, door, lobby, hallway, big room are represented as *NavigableSpace*. Note, door is represented as *NavigableSpace* as shown in Figure 26, especially in the 3D case. In 2D, doors are commonly represented as boundaries of rooms and must be considered *NavigableBoundaries* (see Clause 8.2.4)

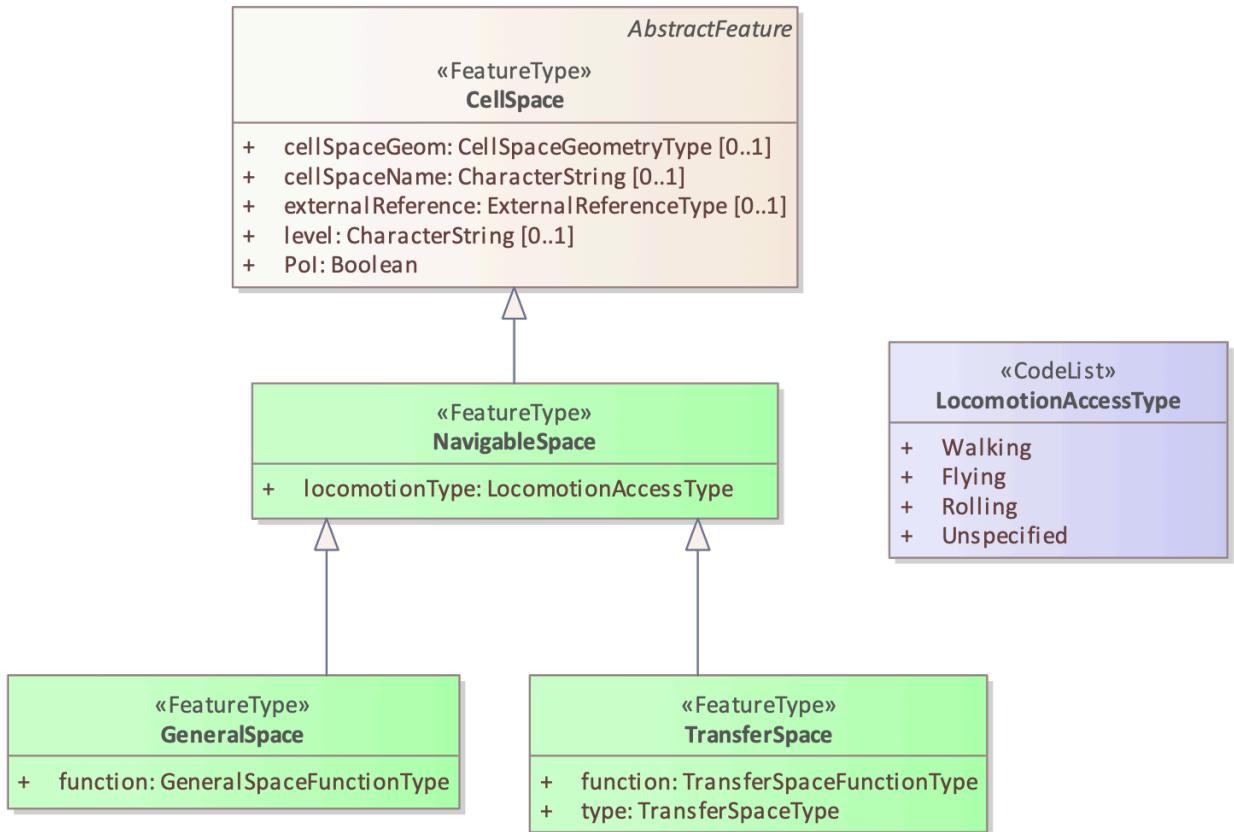


Figure 27 – NavigableSpace and its related class: CellSpace

NavigableSpace entities can carry information about the type of locomotion, which is the allowed transportation mode in indoor space. The *locomotionType* property has one of the following values: *Walking*, *Flying*, *Rolling* and *Unspecified*. A Navigable space may handle one or several of the locomotion types listed. Note, the class instances inherit the geometry of its parent CellSpace entity and can therefore be represented as GM_Solid on 3D data model or GM_Surface on 2D data model.

8.2.2. GeneralSpace

The GeneralSpace class is one of the two subclasses of NavigableSpace (Figure 28). GeneralSpace is identified as any navigable cells such as rooms, lobbies, kitchen, etc., which agents can use for a longer period of time and can serve as starting and target cell in navigation. It carries the property *function* which specifies details about the function of the cell. In IndoorGML, those functions are described in a code list derived from OmniClass Table 13 (OmniClass, 2021)

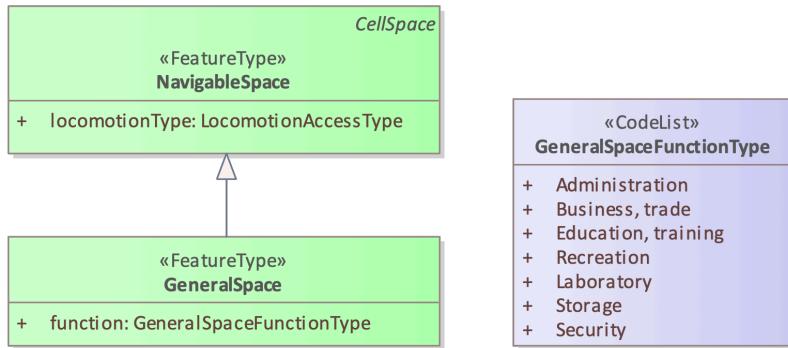


Figure 28 – GeneralSpace and its related class: NavigableSpace

8.2.3. TransferSpace

The class **TransferSpace** is specialization of **NavigableSpace**. It is used to model a space that provides passages between GeneralSpaces. Thereby, it typically describes openings (mainly doors but also windows) for horizontal transfer and entrances to staircase or lift cells for vertical transfers. Similarly to the **GeneralSpace** class, **TransferSpace** carries a **function** property that describes whether the space is an **AnchorSpace** (a space allowing to connect the indoor and the outdoor) or a **BoundarySpace** (a space connecting two indoor or two outdoor spaces). Another of its property is **type** which specified through a codeList the **TransferSpaceType** (Door or Window).

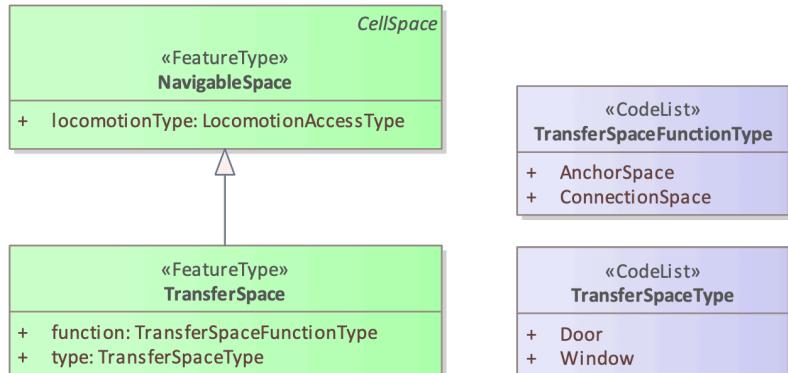


Figure 29 – TransferSpace and its related class: NavigableSpace

8.2.4. NavigableBoundary

The **NavigableBoundary** class is a specialization of a **CellBoundary** and provides further information related to **NavigableSpace** (Figure 30). As illustrated in Figure 26, it typically represents the space boundaries that correspond to entrances or exits through which agents navigate from one cell to another. The **NavigableBoundary** class is therefore mainly found between **GeneralSpace** and **TransferSpace** cells but can happen between two **GeneralSpace** cells as well such as in the case of a room subdivided to distinguish areas of different purposes.

A NavigableSpace is necessarily bound by at least one NavigableBoundary. In the specific case of a TransferSpace, it is expected to have at least two NavigableBoundary instances bound to it, as a TransferSpace serves for transition between connected spaces.

The class carries a *boundaryOrientation* property and a *navigableBoundaryFunction* property specifying if the boundary is an *AnchorBoundary* or a *ConnectionBoundary* (see Clause 8.2.3 for more details).

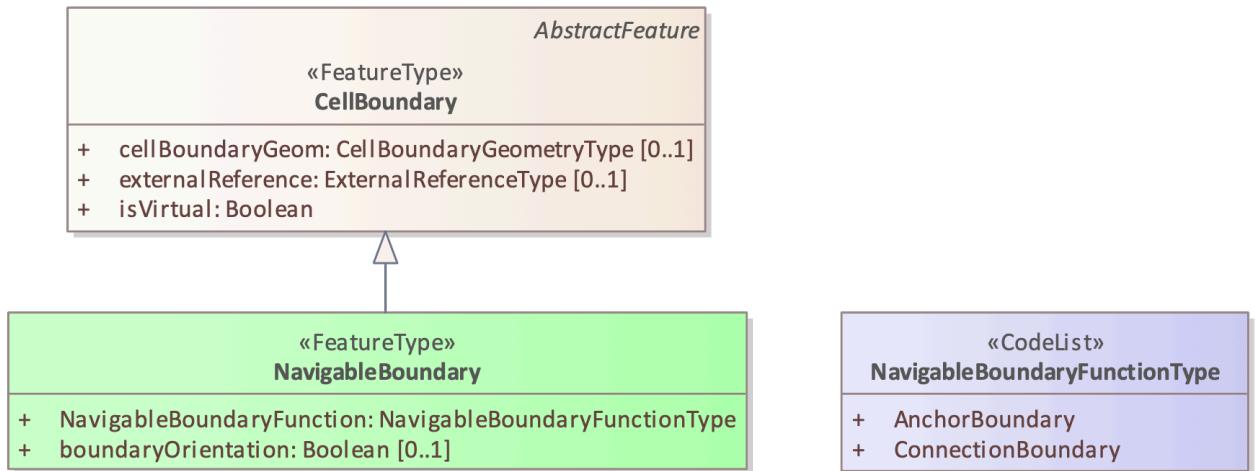


Figure 30 – NavigableBoundary and its related class: CellBoundary

8.2.5. NonNavigableSpace

The NonNavigableSpace class represents cells that are occupied by obstacles (Figure 31). It can correspond to the structural elements of a building (walls, slabs, etc.) or other indoor features populating the space (furniture, appliances etc.). NonNavigableSpace is a class without properties, but allows options to further classify non-navigable cells.

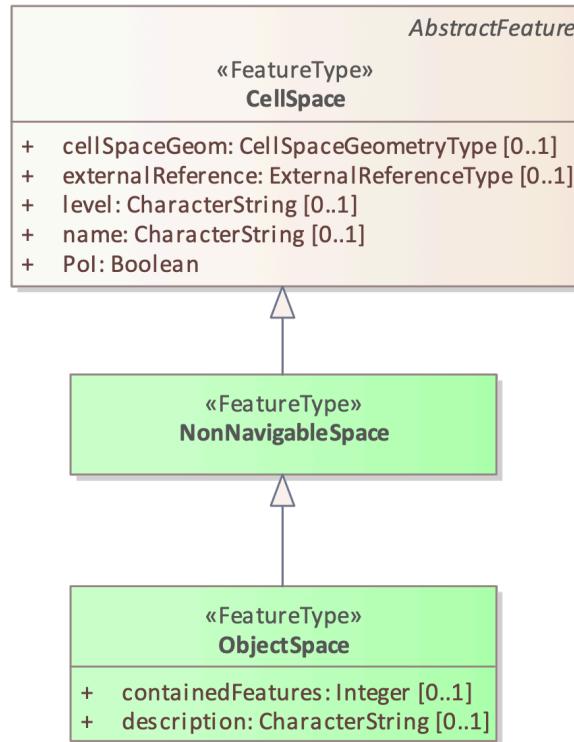


Figure 31 – NonNavigableSpace its related class: CellSpace

8.2.6. ObjectSpace

The ObjectSpace (Figure 32) class is meant to bring additional details to a NonNavigableSpace when it contains some objects that makes it non-navigable. The class has two properties: *containedFeatures* (Integer), and *description* (CharacterString).

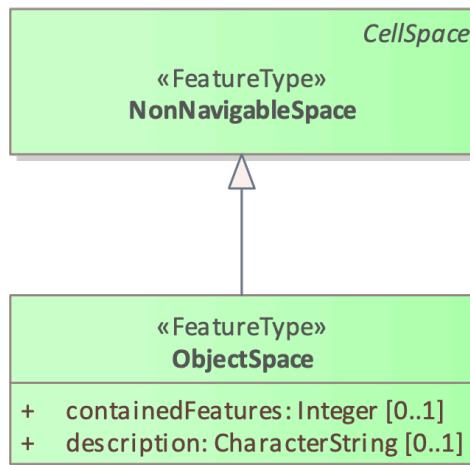


Figure 32 – ObjectSpace and its related class: NonNavigableSpace

The *containedFeatures* property is an integer that describes the number of objects encapsulated within the ObjectSpace and thus, by extension within the parent NonNavigableSpace. The

objects in question can be represented in a different layer of the model and the link to the corresponding ObjectSpace can be made through an InterLayerConnection instance with a *within* or *contains* relationship. The *description* property is meant to provide any relevant information regarding the objects contained within the space in plain text.

8.2.7. NonNavigableBoundary

NonNavigableBoundary entities represent the boundaries between two NonNavigableSpace cells or between a NavigableSpace and a NonNavigableSpace cells (Figure 33). As such, it is the type of boundary that can be found typically at the lateral sides of a TransferSpace (see Figure 26(b)), corresponding for example to the walls surrounding a door.

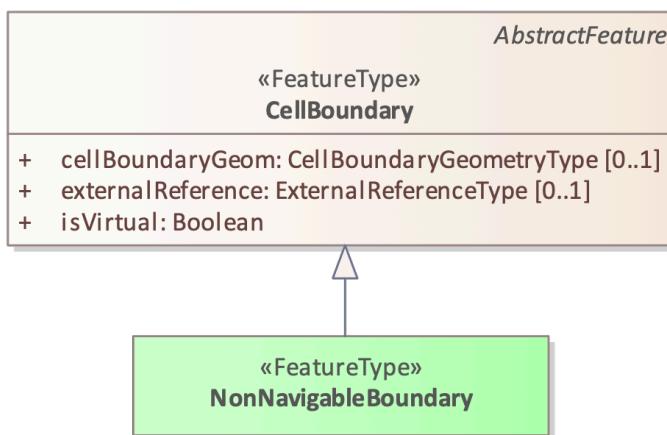


Figure 33 – NonNavigableBoundary and its related classes: CellBoundary

8.2.8. Route

The Route class is a specialization of a Dual space that represents a subset of Network (logical or physical), which includes a path to navigate through indoor space. It is usually defined as the result of a path finding query.

The Route class has one property: *creationDate*. Because dynamic indoor environments may imply change in space availability and accessibility, a suitable path at a given time may not be suitable at another time. For this reason, the *creationDate* property helps indicating at which time a given route was created. The *routeNode* and *routeEdge* properties are both ordered sequences of Node and Edge references to describe the different parts of the route path. Therefore, the first and last *routeNode* elements correspond respectively to the starting and destination points of the route.

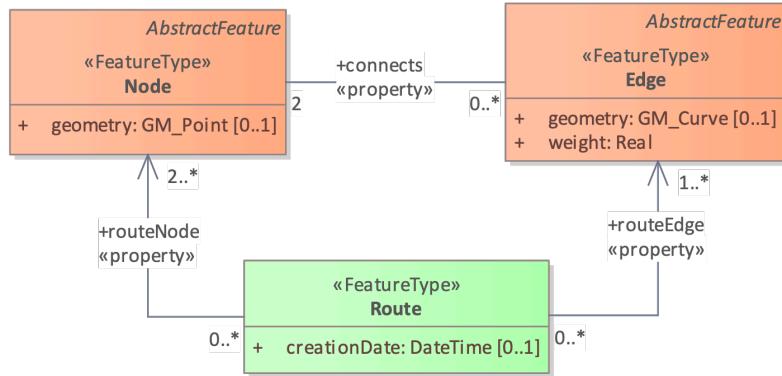


Figure 34 – Route and its related classes: Node and Edge

8.3. Requirements

In this subsection, the requirements for implementing IndoorGML Part 1 – Conceptual Model are defined. The implementation of IndoorGML Part I SHALL be in conformance with the requirements given in the list below.

REQUIREMENTS CLASS 1

IDENTIFIER	http://www.opengis.net/spec/indoorgml/2.0/req
TARGET TYPE	Implementation Specification
CONFORMANCE CLASS	Conformance class A.1: http://www.opengis.net/spec/indoorgml/2.0/conf
NORMATIVE STATEMENTS	<ul style="list-style-type: none"> Requirement 1: /req/umlclassdiagram Requirement 2: /req/thematiclayer Requirement 3: /req/cellspace Requirement 4: /req/cellboundary Requirement 5: /req/node Requirement 6: /req/edge Requirement 7: /req/interlayerconnection Requirement 8: /req/objectspace

REQUIREMENT 1: UML CLASS DIAGRAM

IDENTIFIER	/req/umlclassdiagram
------------	----------------------

REQUIREMENT 1: UML CLASS DIAGRAM

INCLUDED IN	Requirements class 1: http://www.opengis.net/spec/indoorgml/2.0/req
A	The Implementation Specification SHALL contain or represents the same concepts as defined in the UML class diagram – <ul style="list-style-type: none">• Contain elements which represent the same concept as that defined for the UML class,• Represent associations of the UML classes and their superclasses with the same source, target, direction, roles, and multiplicities, and• Contain the attributes of the classes and their superclasses with the same name, definition, type, code list, and multiplicity.
STATEMENT	

REQUIREMENT 2: THEMATIC LAYER

IDENTIFIER	/req/thematiclayer
INCLUDED IN	Requirements class 1: http://www.opengis.net/spec/indoorgml/2.0/req
A	Any feature of a thematic layer SHALL belong to the same theme.

REQUIREMENT 3: CELL SPACE

IDENTIFIER	/req/cellspace
INCLUDED IN	Requirements class 1: http://www.opengis.net/spec/indoorgml/2.0/req
A	Cell belonging to the same primal space layer SHALL not intersect.

REQUIREMENT 4: CELL BOUNDARY

IDENTIFIER	/req/cellboundary
INCLUDED IN	Requirements class 1: http://www.opengis.net/spec/indoorgml/2.0/req
A	Cell boundaries belonging to the same primal space layer SHALL not intersect.
B	The geometry of cell boundary SHALL not exceed the extent of the corresponding cell space.

REQUIREMENT 5: NODE

IDENTIFIER /req/node

INCLUDED IN

Requirements class 1: <http://www.opengis.net/spec/indoorgml/2.0/req>

A

When the isLogical property of a DualSpaceLayer is set to FALSE, the geometries of its Node instances SHALL be spatially located inside of their corresponding CellSpaces.

REQUIREMENT 6: EDGE

IDENTIFIER /req/edge

INCLUDED IN Requirements class 1: <http://www.opengis.net/spec/indoorgml/2.0/req>

A

No self-intersection is allowed when its geometry is given.

B

If dualspaceLayer.directed=true, then the order of nodes represents the direction.

REQUIREMENT 7: INTERLAYER CONNECTION

IDENTIFIER /req/interlayerconnection

INCLUDED IN Requirements class 1: <http://www.opengis.net/spec/indoorgml/2.0/req>

A

Two target cell spaces (or nodes) SHALL not belong to a same primal space layer (or dual space layer).

B

Connected nodes or connected cells SHALL be consistent with connected layers. This means that the target cell spaces (or nodes) SHALL belong to primal space layer (or dual space layer) of the connected layer.

C

The cardinalities of Node (connectedNodes property) and CellSpace (connectedCells property) SHALL either be 0 or 2 but can never be 1.

D

Two connectedNodes are not commutative. For example, "node A contains node B" does not mean "node B contains node A".

REQUIREMENT 8: OBJECTSPACE

IDENTIFIER /req/objectspace

INCLUDED IN

Requirements class 1: <http://www.opengis.net/spec/indoorgml/2.0/req>

REQUIREMENT 8: OBJECTSPACE

A

ObjectSpace instances also fall under the non-overlapping constraint of CellSpaces. As such, they SHOULD not overlap with any other CellSpace or its specialized classes. Therefore, ObjectSpace can either be carved out of the space containing them or they can be defined in different layers (to avoid complex Boolean operations for example).

9

DATA DICTIONARY AND REQUIREMENTS

DATA DICTIONARY AND REQUIREMENTS

In this section, the data dictionary of the feature types defined in IndoorGML 2.0 UML class diagram are defined. The aim is to clarify the concepts of each feature type and help the implementation of this standard. The data dictionary is defined based on ISO TC 211 Standards, particularly ISO 19109 for the rules for application schema, ISO 19107 for spatial schema, and ISO 19136 for GML. As IndoorGML 2.0 is a model based on these base standards, the data dictionary for the feature types defined by these standards is not included in this section. For example, the properties of GML AbstractFeature such as **gmlID**, and **name** are not described in the data dictionary. The data dictionary of the feature types defined in Clause 8 is provided in the following subsections.

9.1. Feature Types in Core Module

9.1.1. IndoorFeatures

Name	IndoorFeatures	
Definition	Set of all features and their relationships to describe a given indoor space.	
Super classes	GML AbstractFeature	
	Role name	Type and Cardinality
Composition	layers	ThematicLayer [1..*]
	layerConnections	InterLayerConnection [0..*]
Properties	Property name	Type and Cardinality
	none	
Constraints	Constraint ID	Constraint
	none	

9.1.2. ThematicLayer

Name	ThematicLayer	
Definition	Aggregation of features for a specific theme consisting of primal space layer and dual space layer.	
Super classes	GML AbstractFeature	
Association	Role name	Type and Cardinality
	connectedLayers	InterLayerConnection [1..1]
Properties	Property name	Type and Cardinality
	semanticExtension	Boolean [1..1]
Properties	theme	ThematicLayerValue[1..1]
	Constraint ID	Constraint
Constraints	Indoorgml2/constraints/thematiclayer	Any feature of a thematic layer SHALL belong to the same theme (Requirement ID: /req/thematiclayer)

9.1.3. PrimalSpaceLayer

Name	PrimalSpaceLayer	
Definition	Aggregation of cell spaces and cell boundaries describing the topography of a given theme in indoor space.	
Super classes	GML AbstractFeature	
Aggregation	Members	Class and Cardinality
	cellSpaceMember	CellSpace [1..*]
Properties	cellBoundaryMember	CellBoundary [0..*]
	Property name	Type and Cardinality

	creationDate	DateTime [0..1]
	terminationDate	DateTime [0..1]
Constraints	Constraint ID	Constraint
	none	

9.1.4. CellSpace

Name	CellSpace	
Definition	The basic unit of indoor space, such as room and corridor, the union of which makes the entire indoor space	
Super classes	GML AbstractFeature	
	Role name	Type and Cardinality
Association	boundedBy	CellBoundary [0..*]
	duality	Node [0..1]
	Property name	Type and Cardinality
	cellSpaceGeometry	CellSpaceGeometryType[0..1]
Properties	cellSpaceName	CharacterString [0..1]
	externalReference	ExternalReferenceType [0..1]
	level	CharacterString [0..1]
	Pol	Boolean [1..1]
Constraints	Constraint ID	Constraint
	Indoorgml2/constraints/ cellspace	Cell spaces belonging to the same primal space layer SHALL not overlap. (Requirement ID: /req/cellspace)

9.1.5. CellBoundary

Name	CellBoundary	
Definition	Explicit boundary of cell space, to which we may assign additional properties such as material, texture, etc.	
Super classes	GML AbstractFeature	
	Role name	Type and Cardinality
Association	bounds	CellSpace [1..2]
	duality	Edge [0..1]
	Property name	Type and Cardinality
Properties	cellBoundaryGeometry	CellBoundaryGeometryType [0..1]
	externalReference	ExternalReferenceType [0..1]
	isVirtual	Boolean
	Constraint ID	Constraint
Constraints	Indoorgml2/constraints/cellboundary-1	Cell boundaries belonging to the same primal space layer should not intersect. (Requirement ID: /req/cellboundary-A)
	Indoorgml2/constraints/cellboundary-2	The geometry of cell boundary SHALL not exceed the extent of the corresponding cell space. (Requirement ID: /req/cellboundary-B)

9.1.6. DualSpaceLayer

Name	Node	
Definition	Dual space layer corresponds to primal space layer and mainly describes adjacency or connectivity relationship between nodes, where node is an abstraction of cell space and edge is a relationship between two nodes. It is a graph composed of nodes and edges.	
Super classes	GML AbstractFeature	

	Role name	Aggregated Class and Cardinality
Aggregation	nodeMember	Node [1..*]
	edgeMember	Edge [0..*]
	Property name	Type and Cardinality
Property	creationDate	DateTime [0..1]
	terminationDate	DateTime [0..1]
	isLogical	GM_Curve [0..1]
Constraints	isDirected	Boolean [1..1]
	Constraint ID	Constraint
	none	

9.1.7. Node

Name	Node	
Definition	Space abstraction of cell space in dual space to a point or virtual point, which is defined as 0-dimensional topological primitive in ISO 19107.	
Super classes	GML AbstractFeature	
Association	Role name	Type and Cardinality
	connectedNodes	InterLayerConnection [0..*]
	duality	CellSpace [0..1]
	connects	Edge [0..*]
Properties	Property name	Type and Cardinality
	geometry	GM_Point [0..1]
Constraints	Constraint ID	Constraint

Indoorgml2/constraints/ node	When the isLogical property of a DualSpaceLayer is set to FALSE, the geometries of its Node instances SHALL be spatially located inside of their corresponding CellSpaces. (Requirement ID: /req/node)
------------------------------	--

9.1.8. Edge

Name	Edge	
Definition	Adjacency or connectivity relationship between nodes, which is defined as 1-dimensional topological primitive in ISO 19107.	
Super classes	GML AbstractFeature	
	Role name	Type and Cardinality
Association	connects	Node [2..2]
	duality	CellBoundary [0..1]
	Property name	Type and Cardinality
Properties	geometry	GM_Curve [0..1]
	weight	Real [1..1]
	Constraint ID	Constraint
Constraints	Indoorgml2/constraints/ edge-1	No self-intersection is allowed when its geometry is given. (Requirement ID: /req/edge-A)
	Indoorgml2/constraints/ edge-2	If dualspaceLayer.directed=true, then the order of nodes represents the direction. (Requirement ID: /req/edge-B)

9.1.9. InterLayerConnection

Name	InterLayerConnection	
Definition	Relationship between cell spaces and nodes in two different thematic layers	
Super classes	None	
	Role name	Type and Cardinality

	connectedLayers	ThematicLayer [2..2]
	connectedNodes	Node [0..2]
	connectedCells	CellSpace [0..2]
	Property name Type and Cardinality	
Properties	comment	CharacterString [1..1]
	typeOfTopoExpression	TopoExpressiveValue [1..1]
	Constraint ID	Constraint
Constraints	IndoorGML2/constraints/interlayerconnection-1	Two target cell spaces (or nodes) SHALL not belong to a same primal space layer (or dual space layer) (Requirement ID: /req/interlayerconnection-A)
	IndoorGML2/constraints/interlayerconnection-2	Connected nodes or connected cells SHALL be consistent with connected layers. This means that the target cell spaces (or nodes) SHALL belong to primal space layer (or dual space layer) of the connected layer. (Requirement ID: /req/interlayerconnection-B)
	IndoorGML2/constraints/interlayerconnection-3	The cardinalities of Node and CellSpace SHALL either be 0 or 2 but can never be 1. (Requirement ID: /req/interlayerconnection-C)
	IndoorGML2/constraints/interlayerconnection-4	Two connectedNodes are not commutative. For example, "node A contains node B" does not mean "node B contains node A". (Requirement ID: /req/interlayerconnection-D)

9.2. Feature Types in Navigation Module

9.2.1. NavigableSpace

Name	NavigableSpace	
Definition	A cell space in which users can move freely	
Super classes	CellSpace	
Properties	Property name	Type and Cardinality

	locomotionType	LocomotionAccessType [1..1]
Constraints	Constraint ID	Constraint
	none	

9.2.2. NonNavigableSpace

NAME NAVIGABLESPACE		
Definition	A cell space in which users cannot move	
Super classes	CellSpace	
Constraints	Constraint ID	Constraint
	none	

9.2.3. GeneralSpace

Name	GeneralSpace	
Definition	A type of NavigableSpace such as rooms, lobbies, kitchen, etc., where agents can stay or use for a longer period of time and can serve as starting and target cell in navigation.	
Super classes	NavigableSpace	
Properties	Property name	Type and Cardinality
	function	GeneralSpaceFunctionType [1..1]
Constraints	Constraint ID	Constraint
	none	

9.2.4. TransferSpace

NAME TRANSFERSPACE		
Definition	A type of NavigableSpace that provides passages between GeneralSpaces	
Super classes	NavigableSpace	
Properties	Property name	Type and Cardinality
	function	TransferSpaceFunctionType [1..1]
Constraints	Constraint ID	Constraint
	none	

9.2.5. ObjectSpace

NAME OBJECTSPACE		
Definition	A type of NonNavigableSpace containing objects that make it non-navigable	
Super classes	NonNavigableSpace	
Association	Role name	Associated Class
	none	none
Properties	Property name	Type and Cardinality
	containedFeature	Integer[0..1]
Constraints	description	CharacterString [0..1]
	Constraint ID	Constraint
Indoorgml2/constraints/objectspace	ObjectSpace instances also fall under the non-overlapping constraint of Cell Spaces. As such, they SHOULD not overlap with any other CellSpace or its specialized classes. Therefore, ObjectSpace can either be carved out of the space containing them or they can be defined in different layers (to avoid complex Boolean operations for example). (Requirement ID: /req/objectspace)	

9.2.6. NavigableBoundary

Name	NavigableBoundary	
Definition	A type of CellBoundary, which agents can pass through.	
Super classes	CellBoundary	
	Property name	Type and Cardinality
Properties	boundaryOrientation	Boolean [0..1]
	navigableBoundaryFunction	NavigableBoundaryFunctionType [1..1]
	Constraint ID	Constraint
Constraints	none	

9.2.7. NonNavigableBoundary

Name	NavigableBoundary	
Definition	A type of CellBoundary, which does not allow passage.	
Super classes	CellBoundary	
	Property name	Type and Cardinality
Properties	none	
	Constraint ID	Constraint
Constraints	none	

9.2.8. Route

Name	Route	
Definition	A path to navigate between two nodes	
Super classes	GML AbstractFeature	
	Role name	Associated Class and Cardinality
Association	routeNode	Node [2..*]
	routeEdge	Edge [1..*]
	Property name	Type and Cardinality
Properties	creationDate	DateTime [01..1]
	Constraint ID	Constraint
Constraints	none	



A

ANNEX A (NORMATIVE) ABSTRACT TEST SUITE

A

ANNEX A (NORMATIVE) ABSTRACT TEST SUITE

A.1. Introduction

This normative annex specifies the test suite, which will be used for the conformance test of OGC IndoorGML 2.0 Part I. As OGC IndoorGML 2.0 Part I is a conceptual model, this test suite is an abstract one and its executable test suite shall depend on the implementation of OGC IndoorGML 2.0 Part I, more precisely the encoding system of OGC IndoorGML 2.0 such as XML, JSON, or SQL.

A.2. General Tests

Since OGC IndoorGML 2.0 is based on ISO 19103:2015, ISO 19107:2019, ISO 19109:2015, and ISO 19111:2019, the abstract tests of these precedent standards shall be applied to OGC IndoorGML 2.0.

A.3. Conformance Class

CONFORMANCE CLASS A.1

IDENTIFIER <http://www.opengis.net/spec/indoorgml/2.0/conf>

REQUIREMENTS CLASS Requirements class 1: <http://www.opengis.net/spec/indoorgml/2.0/req>

TARGET TYPE Implementation Specification

CONFORMANCE TESTS
Abstract test A.1: /ats/umldatamadel
Abstract test A.2: /ats/thematiclayer
Abstract test A.3: /ats/cellspace

CONFORMANCE CLASS A.1

Abstract test A.4: /ats/cellboundary
Abstract test A.5: /ats/node
Abstract test A.6: /ats/edge
Abstract test A.7: /ats/interlayerconnection
Abstract test A.8: /ats/objectspace

A.3.1. UML Data Model

ABSTRACT TEST A.1

IDENTIFIER /ats/umldatamodel

REQUIREMENT Requirement 1: /req/umlclassdiagram

TEST PURPOSE UML class diagram defined in Clause 8 SHALL be correctly applied to any implementation of IndoorGML Part 2 – Conceptual Model

TEST METHOD Manual or automated inspection

A.3.2. Class ThematicLayer

ABSTRACT TEST A.2

IDENTIFIER /ats/thematiclayer

REQUIREMENT Requirement 2: /req/thematiclayer

TEST PURPOSE Any feature of a thematic layer SHALL belong to the same theme.

TEST METHOD Manual or automated inspection

A.3.3. Class CellSpace

ABSTRACT TEST A.3

IDENTIFIER /ats/cellspace

ABSTRACT TEST A.3

REQUIREMENT	Requirement 3: /req/cellspace
TEST PURPOSE	Cell belonging to the same primal space layer SHALL not intersect.
TEST METHOD	Automated inspection by geometric computation

A.3.4. Class CellBoundary

ABSTRACT TEST A.4

IDENTIFIER	/ats/cellboundary
REQUIREMENT	Requirement 4: /req/cellboundary
TEST PURPOSE	<ul style="list-style-type: none">Cell boundaries belonging to the same primal space layer SHALL not intersect.The geometry of cell boundary SHALL not exceed the extent of the corresponding cell space.
TEST METHOD	Automated inspection by geometric computation

A.3.5. Class Node

ABSTRACT TEST A.5

IDENTIFIER	/ats/node
REQUIREMENT	Requirement 5: /req/node
TEST PURPOSE	When the isLogical property of a DualSpaceLayer is set to TRUE, the geometries of its Node instances SHALL be spatially located inside of their corresponding CellSpaces.

A.3.6. Class Edge

ABSTRACT TEST A.6

IDENTIFIER /ats/edge

REQUIREMENT Requirement 6: /req/edge

TEST PURPOSE

- No self-intersection is allowed when its geometry is given.
- If dualspaceLayer.directed=true, then the order of nodes represents the direction.

TEST METHOD Automated inspection by geometric computation

A.3.7. Class InterLayerConnection

ABSTRACT TEST A.7

IDENTIFIER /ats/interlayerconnection

REQUIREMENT Requirement 7: /req/interlayerconnection

TEST PURPOSE

- Two target cell spaces (or nodes) SHALL not belong to a same primal space layer (or dual space layer).
- Connected nodes or connected cells SHALL be consistent with connected layers. This means that the target cell spaces (or nodes) SHALL belong to primal space layer (or dual space layer) of the connected layer.
- The cardinalities of Node and CellSpace SHALL either be 0 or 2 but can never be 1.
- Two connectedNodes are not commutative. For example, “node A contains node B” does not mean “node B contains node A”.

TEST METHOD Automated inspection by geometric computation

A.3.8. Class ObjectSpace

ABSTRACT TEST A.8

IDENTIFIER /ats/objectspace

REQUIREMENT Requirement 8: /req/objectspace

TEST PURPOSE ObjectSpace instances also fall under the non-overlapping constraint of CellSpaces. As such, they SHOULD not overlap with any other CellSpace or its specialized classes. Therefore, ObjectSpace

ABSTRACT TEST A.8

can either be carved out of the space containing them or they can be defined in different layers (to avoid complex Boolean operations for example).

TEST METHOD Automated inspection by geometric computation



BIBLIOGRAPHY



BIBLIOGRAPHY

- [1] Apple Inc.: OGC 20-094, *Indoor Mapping Data Format*. Open Geospatial Consortium (2021).
- [2] Policy SWG: OGC 08-131r3, *The Specification Model – Standard for Modular specifications*. Open Geospatial Consortium (2009).
- [3] Gerhard Gröger, Thomas H. Kolbe, Claus Nagel, Karl-Heinz Häfele: OGC 12-019, *OGC City Geography Markup Language (CityGML) Encoding Standard*. Open Geospatial Consortium (2012). <http://www.opengis.net/spec/citygml/2.0>.
- [4] David Burggraf: OGC 12-007r2, OGC KML 2.3. Open Geospatial Consortium (2015). <http://www.opengis.net/doc/IS/kml/2.3.0>.
- [5] Jiyeong Lee, Ki-Joune Li, Sisi Zlatanova, Thomas H. Kolbe, Claus Nagel, Thomas Becker, Hye-Young Kan: OGC 19-011r4, *OGC® IndoorGML 1.1*. Open Geospatial Consortium (2020). <http://www.opengis.net/doc/IS/indoorgml/1.1.0>.
- [6] ISO: ISO 16739-1, *Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries – Part 1: Data schema*. International Organization for Standardization, Geneva <https://www.iso.org/standard/84123.html>.
- [7] ISO: ISO 19152, *Geographic information – Land Administration Domain Model (LADM)*. International Organization for Standardization, Geneva <https://www.iso.org/standard/51206.html>.
- [8] Yan, J., Diakité, A. A., Zlatanova, S.: A generic space definition framework to support seamless indoor/outdoor navigation systems. *Transactions in GIS*, 23, 6, 1273-1295 (2019)
- [9] Zlatanova, S., Yan, J., Wang, Y., Diakité, A., Isikdag, U., Sithole, G., Barton, J.: Spaces in Spatial Science and Urban Applications—State of the Art Review. *ISPRS International Journal of Geoinformation*, 9, 1, 58 (2020)
- [10] Alattas, A., Zlatanova, S., Van Oosterom, P., Chatzinikolaou, E., Lemmen, C., Li, K. J.: Supporting Indoor Navigation Using Access Rights to Spaces Based on Combined Use of IndoorGML and LADM Models. *ISPRS International Journal of Geoinformation*. 6, 12, 384 (2017)
- [11] Becker, T., Nagel, C., and Kolbe, T. H.: A Multilayered Space-Event Model for Navigation in Indoor Spaces. *Proc. 3rd International Workshop on 3D Geoinformation*. 61-77 (2009)
- [12] Diakité, A. A., Zlatanova, S.: Spatial subdivision of complex indoor environments for 3D indoor navigation. *International Journal of Geographical Information Science*. 32, 2, 213-235 (2018)

- [13] Egenhofer M.J.: A formal definition of binary topological relationships. In: Litwin W., Schek HJ. (eds) Foundations of Data Organization and Algorithms, FODO 1989, Lecture Notes in Computer Science. 367, 457–472 (1989)
- [14] Gröger, G., B. George: Geometry and Topology. In: Kresse, W., Danko, D. (eds) Springer Handbook of Geographic Information. 303-321 (2012)
- [15] Morris, S.: Topology Without Tears, <http://www.topologywithouttears.net/topbook2023.pdf>
- [16] Munkres, J. R.: Elements Of Algebraic Topology (1st ed.). CRC Press. <https://doi.org/10.1201/9780429493911> (1984)
- [17] Lee, J.: A spatial access-oriented implementation of a 3D GIS topological data model for urban entities. GeoInformatica, 8, 237-264 (2004)
- [18] Princeton University.: WordNet, <https://wordnet.princeton.edu/>