Connecting LADM and IFC Standards – Pathways towards an Integrated Legal-Physical Model

Behnam ATAZADEH, Abbas RAJABIFARD and Mohsen KALANTARI, Australia

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SUMMARY

In 3D digital land and property registration systems, simultaneous representation of both legal spaces and physical elements can aid understanding of the spatial extent of property rights, restrictions and responsibilities (RRR). The integration of legal and physical objects can be done only at visualisation level without defining any semantic relationship between them, indicating the logical independency of legal spaces from physical elements. On the other side of the argument, this integration could be predicated on providing the possibility to define specific relationships between legal spaces and their physical counterparts when it is sometimes required to define these relationships. The latter approach could go beyond the visualisation level and facilitate querying physical objects associated with legal boundaries and other RRR information.

In this paper, we will investigate approaches to integrating legal information and physical information based on international standards. We consider Land Administration Domain Model (LADM) as the data model for modelling legal information while Industry Foundation Classes (IFC) standard provides physical data elements for managing lifecycle of buildings. Therefore, the scope of this study is limited to investigating integration of legal and physical objects located inside and around buildings using LADM and IFC standards. The study would lay the foundation for two pathways towards developing an integrated legal-physical international standard for 3D digital cadastre, namely extending IFC standard with legal information or further development of LADM standard with physical information. The former one suggests that how IFC standard can be specifically used and extended for land administration domain while the latter pathway recommends physical elements from IFC standard can be incorporated into the future version of LADM.

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1. INTRODUCTION

In urban areas, construction of multi-story buildings and complex infrastructures has dramatically affected land and property division practices. Traditionally, 2D-based partitioning methods were mainly used for the legal division of land and properties. However, these practices should also consider more communicable mechanisms to define legal partitions of 3D spaces located above and below the ground. The legal and physical dimensions of urban environments are intertwined to each other, which makes it very challenging to manage and represent 3D legal extent of property rights, restrictions, and responsibilities in urban spaces. Therefore, 3D digital management of land and property information is predicated on both legal and physical aspects. A cadastral data model plays a fundamental role in design and development of a land and property information system.

Current cadastral data models are very much focused on modelling legal information. In essence, legal information is adequate to subdivide and register ownership of land and properties. However, in the case of complex built structures, physical information plays a significant role in understanding and communicating legal information with inexpert stakeholders. For instance, if a legal boundary of an apartment unit is located inside a wall, a merely legal representation would not be adequate to orient the user. Representation of physical objects could help communicate and identify the spatial location of legal objects in the real-world. The integration of legal and physical objects can be done only at visualisation level without defining any semantic relationship between them, indicating the logical independency of legal spaces from physical elements. On the other side of the argument, this integration could be predicated on defining specific relationships, when it is required to define the relationship, between legal spaces and their physical counterparts. The latter approach could go beyond the visualisation level and facilitate querying physical objects associated with legal boundaries and other legal information. In this article, we will investigate approaches to integrating legal information and physical information based on international standards. We consider Land Administration Domain Model (LADM) as the data model for modelling legal information while Industry Foundation Classes (IFC) standards provides physical data elements for managing lifecycle of buildings. Therefore, the scope of this study is limited to investigating technical aspects of integrating legal and physical objects located inside and around buildings using LADM and IFC standards.

Currently, Land Administration Domain Model (LADM) provides an internationally accepted and standard-based approach to structuring legal relationships between interest holders and their land or property. LADM provides a formal data structure for managing legal information in current land administration systems. This standard could enable various jurisdictions to communicate legal information with each other in a common language. LADM is a conceptual model which may be implemented in various ways depending on the specific

needs of a particular jurisdiction. One approach to implement LADM concepts could be using the implementation schemas such as IFC standard. This is the first research question for this study: How can LADM-based legal concepts be logically mapped into the IFC standard? Addressing this question would provide an approach for incorporating legal information into the Building Information Modelling (BIM) environment, which would subsequently link legal information with lifecycle information about buildings in a collaborative 3D digital data space (see Section 3).

On the other hand, IFC standard is an international and open data model for exchanging physical information defined within 3D BIM models in the domains of Architecture, Engineering, and Construction (AEC). IFC standard is composed of several hundreds of entities that provide a rich view on physical aspects of buildings. In particular, its subschema "shared building elements" comprises the major physical components defining architectural and structural design of buildings. These physical concepts of the built environment are not currently considered in LADM standard. Therefore, another research question is: how can physical concepts be incorporated into the LADM standard? A response to this question would be considered as a first step towards extending LADM with physical information (see Section 4).

2. LITERATURE REVIEW

The integration of legal and physical concepts is quite a new research topic in 3D digital cadastre. Researchers investigated various approaches to combining legal objects with physical objects. As reviewed in (Kalogianni et al, 2017) and (Atazadeh et al, 2016), different integrations of physical models, such as CityGML, IndoorGML and IFC, and legal models, such as LADM and ePlan model, have been considered in these investigations (see Table 1). The investigation by Oldfield et al (2016, 2017) is the one relevant to the work presented in our paper. In their investigation, BIM data is considered as one major source of data for 3D digital cadastre in buildings. In particular, it was elucidated how IFC entities can be used to model some concepts from LADM. These concepts include:

1. Spatial unit: IfcSpace (indoor spaces) and IfcZone (zones) entities were considered for modelling spatial units.
2. Boundary face: IfcConnectedFaceSet (a set of arc-wise connected faces) entity was used for modelling the concept of boundary face.
3. Boundary face string: IfcPolyLoop (a loop with straight edges bounding a planar surface) was suggested for modelling boundary face strings in LADM.
4. Point: IfcCartesianPoint (a point in either 2D or 3D space) can be the candidate for representing the concept of points as defined in LADM.

The work by Oldfield et al (2017) has also recognized the use of property sets for managing legal information. However, they did not propose how various property sets based on LADM can be applied to different IFC entities. In addition, we believe the concept of spatial units is more comprehensive and includes other spatial elements (e.g. external spaces around buildings) and physical components. Other parts of LADM such as parties and administrative sources can be also mapped into IFC standard. Therefore, in next section, we will provide our approach for mapping LADM concepts into IFC standard.

Table 1. A summary of investigations that proposed integrated models of legal and physical objects

Integrated Model	Integration mechanism	Jurisdiction
CityGML and LADM	Incorporation of LADM-based legal concepts by developing an Application Domain Extension (ADE) for CityGML.	Jurisdiction Independent (Rönsdorff et al, 2014) Poland (Gózdz et al, 2014) China (Li et al, 2016)
Cadastral extensions of CityGML	The legal objects were defined as new entities within ADEs of CityGML.	The Netherlands (Dsilva 2009) Turkey (Çağdaş 2013)
CityGML and ePlan	Web ontology language (OWL) was used to semantically integrate physical components from CityGML with legal elements from ePlan model.	Singapore (Soon et al, 2014)
LandInfra	LADM and LandXML concepts were used for modelling legal objects while physical elements were considered based on IFC and CityGML standards	Jurisdiction Independent (Scarponcini et al, 2016)
IndoorGML and LADM	Two approaches are suggested: creating an extension module of IndoorGML based on LADM concepts, or connecting LADM and IndoorGML through external links	Jurisdiction Independent (Zlatanova, Li, et al, 2016, Zlatanova, Van Oosterom, et al 2016)
3D cadastral data model (3DCDM)	3DCDM is divided into two hierarchical structures, one for legal objects and another for physical objects.	Victoria, Australia (Aien 2013)
LADM-INTERLIS	INTERLIS language was adopted to integrate legal and physical objects by specifying constraints	Jurisdiction Independent (Kalogianni et al, 2017)
Cadastral Extension of IFC	Legal data elements was embedded into IFC standard with as minimum change as possible in the current data model of IFC.	Victoria, Australia (Atazadeh et al, 2017)
Cadastral extension of Unified Building Model (UBM)	Four types of legal boundaries were proposed in UBM, which is a physical model connecting IFC and CityGML. These boundaries include “Building Elements Surfaces”, “Digging Surfaces”, “Protecting Area Surfaces”, and “Real Estate Boundary Surfaces”	Sweden (El-Mekawy and Östman 2015)
UrbanIT project	The core of the urbanIT project was a proposed extension to the IFC standard for managing cadastral data both inside buildings as well as land parcels on the site of buildings.	New South Wales, Australia (Barton et al, 2010)

3. MAPPING LADM CONCEPTS INTO IFC

Our approach comprises two parts for modelling each LADM concept using IFC entities. First, we will identify suitable IFC entities for mapping each LADM concept itself. Second, we will propose the attributes of each LADM concept to be modelled as property sets applied to their counterpart IFC entities. The concept of property set definition is used to specialize and extend IFC entities without the need to define new subclasses. Property sets can be assigned to their corresponding IFC entities via “IfcRelDefinesByProperties” relationship.

Various types of properties can be defined such as properties with single values (IfcPropertySingleValue) and properties with enumerated values (IfcPropertyEnumerated-Value). The naming convention for a set or group of properties is "Pset_xxx", in which "xxx" is typically the name of concept to which the property set is applied.

3.1 Spatial units

The concept of spatial units (LA_SpatialUnit) includes a wide range of representation forms. It is an overarching concept defined for spatio-temporal subdivision of the whole space above and below the ground in terms of legally defined pieces of land, water, and air as well as real properties located below and above the ground. LADM standard allows multiple representations of spatial units, namely 0D, 1D, 2D, 3D and liminal. In this study, we consider 2D (land parcel) and 3D (legal spaces) representation forms. The suitable IFC entities for modelling these forms of spatial units are brought in Table 2.

Table 2. Suitable IFC entities for modelling spatial units

Form of spatial unit		**Suitable IFC entities**
Land parcel	Individual	IfcSite
	Multiple	IfcSpatialZone
Indoor legal space	Individual	IfcSpace
	Multiple	IfcZone, IfcSpatialZone
Outdoor legal space	Individual	IfcExternalSpatialElement
	Multiple	IfcSpatialZone

In LADM, spatial units are legal spaces having cognitive forms. However, if we consider physical objects as a constituting part of a spatial unit. In this case, subclasses of "IfcElement" entity, e.g. IfcBuildingElement (and its subclasses) and IfcDistributionElement (and its subclasses), can be used for modelling physical parts of a spatial unit. We can then use the "IfcSpatialZone" entity to model the spatial arrangement of multi-part spatial units comprising both legal spaces and physical objects.

Table 3. Attributes of spatial units proposed as a property set in IFC

Property Set Name	**Pset_LA_SpatialUnit**	
Attribute Name	**Property Type**	**Data Type**
area	IfcPropertySingleValue	IfcAreaMeasure
dimension	IfcPropertyEnumeratedValue	IfcLable
extAdressID	IfcPropertySingleValue	IfcIdentifier
lable	IfcPropertyEnumeratedValue	IfcLable
referencePoint	IfcPropertySingleValue	IfcCartesionPoint
suID	IfcPropertySingleValue	IfcIdentifier
surfaceRelation	IfcPropertyEnumeratedValue	IfcLable
volume	IfcPropertySingleValue	IfcSolidMeasure

Attributes of spatial units can be defined as a property set named "Pset_LA_SpatialUnit" in IFC schema (see Table 3 above). These attributes can be applied to the IFC entities mentioned in Table 2.

3.2 Boundaries

Boundaries in LADM are considered as merely topological concepts (boundary face and boundary face strings) specifying limits of spatial units. As stated in (Oldfield *et al*, 2017), LA_BoundaryFace and LA_BoundaryFaceString can be modelled by "IfcConnectedFaceSet" and "IfcPolyLoop" entities, respectively. In IFC standard, various geometric and topological representations are considered for modelling a variety of boundary lines and surfaces. In addition, semantic information about boundaries can be obtained in IFC standard. Similarly, we suggest "IfcRelSpaceBoundary" for modelling boundaries in 3D space since it includes the topological or geometric representation of the boundary through its "ConnectionGeometry" attribute which is associated to "IfcConnectionSurfaceGeometry". There are two options for defining the surface boundary, namely a surface (IfcSurface) or a face with an associated surface (IfcFaceSurface) via "IfcSurfaceOrFaceSurface" selection data type. In this study, we proposed that "IfcFaceSurface" should be choosen since it includes both topology and geometry of the surface boundary (see Figure 1).

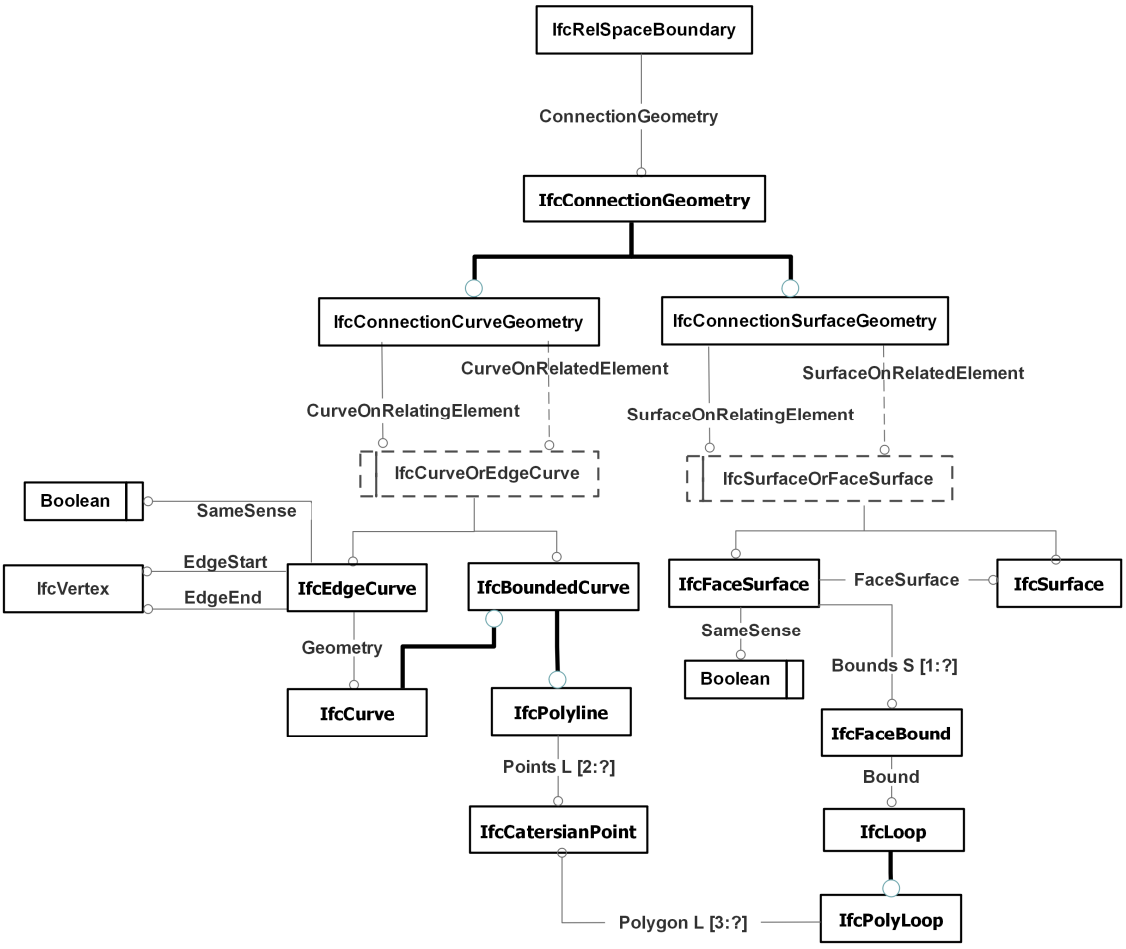

Figure 1. Modelling boundary face and boundary face string in IFC standard

For boundary lines, "IfcConnectionCurveGeometry" entity can be used to define the boundary. There are two choices for defining the line boundary, namely a bounded curve (IfcBoundedCurve) or an edge with an associated curve (IfcEdgeCurve) via "IfcCurveOrEdgeCurve" selection data type. In this study, we proposed that "IfcEdgeCurve" should be choosen since it includes both topology and geometry of the line boundary (see Figure 1 above).

3.3 Basic administrative units and RRR information

There is no equivalent IFC entity for modelling basic administrative units (LA_BAUnit) class. Since "LA_BAUnit" class typically refers to multiple spatial units, we define attributes of this class as a property set which can be applied to "IfcSpatialZone" and "IfcZone" entities (see Table 4). For modelling RRR information, LADM includes "LA_RRR" class and its subclasses "LA_Right", "LA_Restriction", and "LA_Responsibility". There are no equivalent IFC entities for these classes. One way of modelling RRR information in IFC standard can be also based on proposing the attributes of these classes as property sets assigned to spatial zones and zones. However, this would not keep the relationships between basic administrative units and RRR information.

Table 4. Property sets for basic administrative units and RRR information

	Attribute Name	**Property Type**	**Data Type**
Pset_LA_BAUnit	name	IfcPropertySingleValue	IfcLable
	type	IfcPropertyEnumeratedValue	IfcLable
	uID	IfcPropertySingleValue	IfcIdentifier
Pset_LA_RRR	description	IfcPropertySingleValue	IfcText
	rID	IfcPropertySingleValue	IfcIdentifier
	share	IfcPropertySingleValue	IfcReal
	shareCheck	IfcPropertySingleValue	IfcBoolean
	timeSpec	IfcPropertySingleValue	IfcText
Pset_LA_Right	type	IfcPropertyEnumeratedValue	IfcLable
Pset_LA_Restriction	partyRequired	IfcPropertySingleValue	IfcBoolean
	type	IfcPropertyEnumeratedValue	IfcLable
Pset_LA_Responsibility	type	IfcPropertyEnumeratedValue	IfcLable

3.4 Parties

"IfcActor" can be a suitable IFC entity for modelling parties defined in LADM. It references various IFC entities defined in "IfcActorResource" subschema in the resource layer. The important ones include (see Figure 2 below):

- IfcActorRole: In this entity, we can define the role of an actor. The "role" attribute of "LA_Party" can be modelled by this entity. In fact, enumeration values of the "LA_PartyRoleType" can be included in "IfcRoleEnum" enumeration. Alternatively, the "UserDefinedRole" attribute can include any value from "LA_PartyRoleType" code list.

- IfcOrganisation: This can be used for modeling organizations and non-natural persons as specific type of parties defined in LADM.
- IfcPerson: Natural persons defined in "LA_PartyType" can be modelled by "IfcPerson" entity.
- IfcPersonAndOrganisation: This entity can be used for modelling those parties acting on behalf of an organization. For instance, an owners corporation manager can act on behalf of owners corporation.

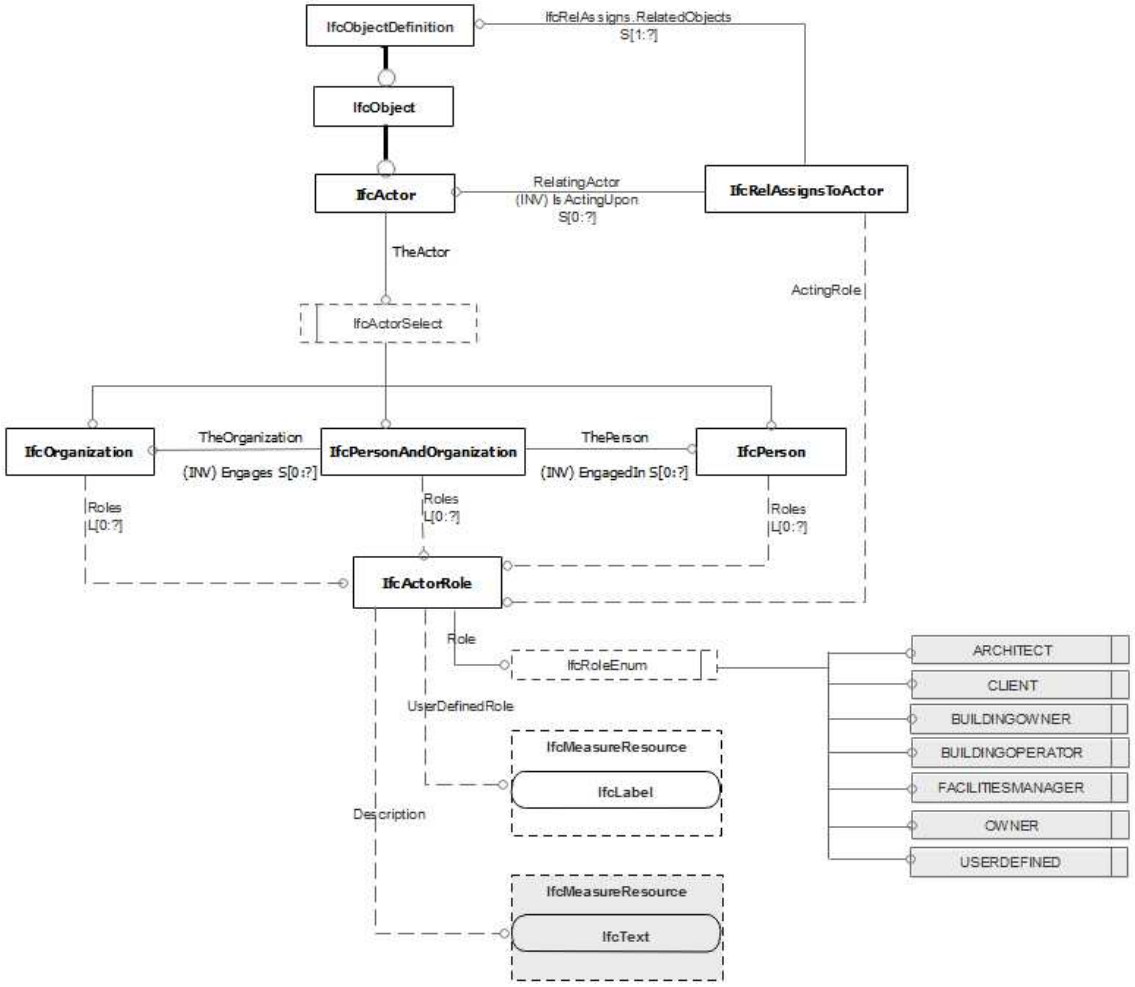

Figure 2. Assignment of actors in IFC standard

For modelling group parties, we can leverage "IfcGroup" entity. This can be achieved by using "IfcRelAssignsToGroup" objectified relationship between instances of "IfcActor" and "IfcGroup" entities. The assignment of parties to spatial units or administrative sources can be achieved through "IfcRelAssignsToActor" relationship between "IfcActor" and the relevant entity (all subclasses of IfcObjectDefinition). For instance, we can define the assignment between "IfcActor" and "IfcSpatialZone" entities to assign an owner to his legal interest.

Attributes of “LA_Party”, except “role” attribute defined via IfcRoleEnum, can be defined as a new property set assigned to “IfcActor” entity (see Table 5 below). For group parties, we can assign attributes of “LA_GroupParty” as a property set to “IfcGroup” entity.

Table 5. Property sets for party and group party

	Attribute Name	**Property Type**	**Data Type**
Pset_LA_Party	extPID	IfcPropertySingleValue	IfcIdentifier
	name	IfcPropertySingleValue	IfcLable
	pID	IfcPropertySingleValue	IfcIdentifier
	type	IfcPropertyEnumeratedValue	IfcLable
Pset_LA_GroupParty	groupID	IfcPropertySingleValue	IfcIdentifier
	type	IfcPropertyEnumeratedValue	IfcLable

3.5 Administrative sources

“LA_AdministrativeSource” class is used for managing information about documents in LADM. The relevant IFC entities for modelling this class are “IfcDocumentReference” and “IfcDocumentInformation” (see Figure 3). “IfcDocumentReference” entity provides a reference to the location of a document through its “Location” attribute. “IfcDocumentInformation” provides more metadata about documents exchanged during the building lifecycle. In addition to the location of the document, this entity provides other metadata elements such as purpose, scope, intended use, document owner, editor, and so on. The referenced documents are not part of an IFC file; however, “IfcDocumentInformation” and “IfcDocumentReference” provide a mechanism to externally access them from IFC files.

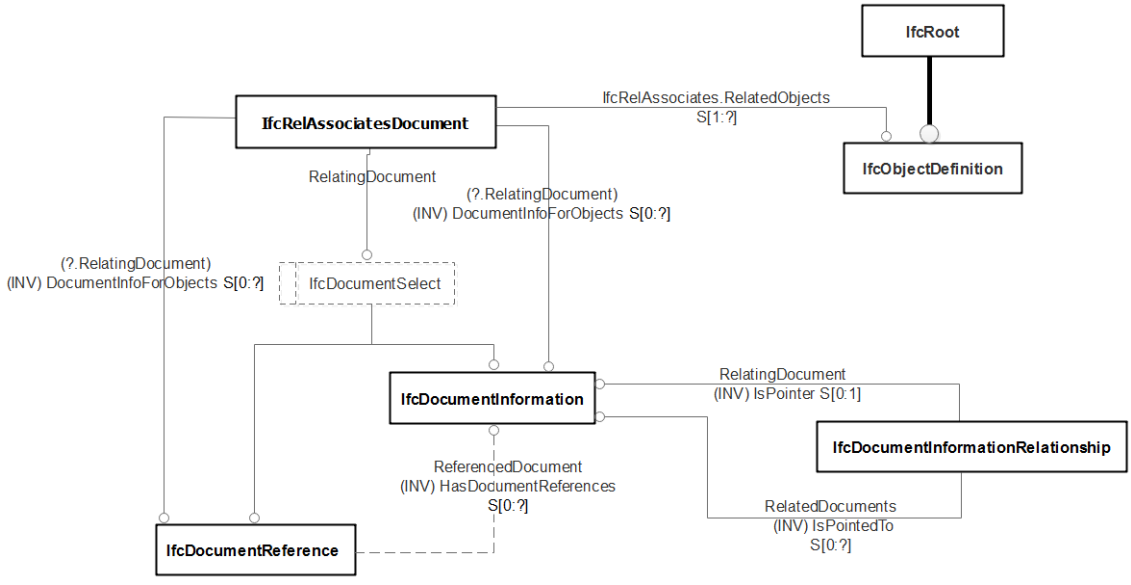

Figure 3. Referencing documents in IFC standard

Documents can be related to other IFC entities via “IfcRelAssociatesDocument” relationship entity.

For instance, this relationship can be used to associate a basic administrative unit (defined by IfcSpatialZone) to its administrative source (defined by IfcDocumentInformation). Another example could be associating a party (defined by IfcActor) to the relevant administrative source (defined by IfcDocumentReference). In addition, there is an objectified relationship “IfcDocumentInformationRelationship” entity that relates documents to each other. This relationship entity would be useful for defining those legal documents posing a restriction or condition on the other legal documents. For instance, we can define the relationship between mortgage and title documents using this entity.

4. EXTENDING LADM WITH IFC-BASED PHYSICAL OBJECTS

LADM standard currently includes mechanisms for referencing physical objects. However, the current mechanism does not consider specific relationships between legal objects and their physical counterparts. These relationships should not be considered as mandatory ones as they are not always required. Therefore, we only suggest that how we can consider physical objects in LADM standard and define their optional relationships with legal objects. Our proposal will be based on physical objects defined in IFC standard.

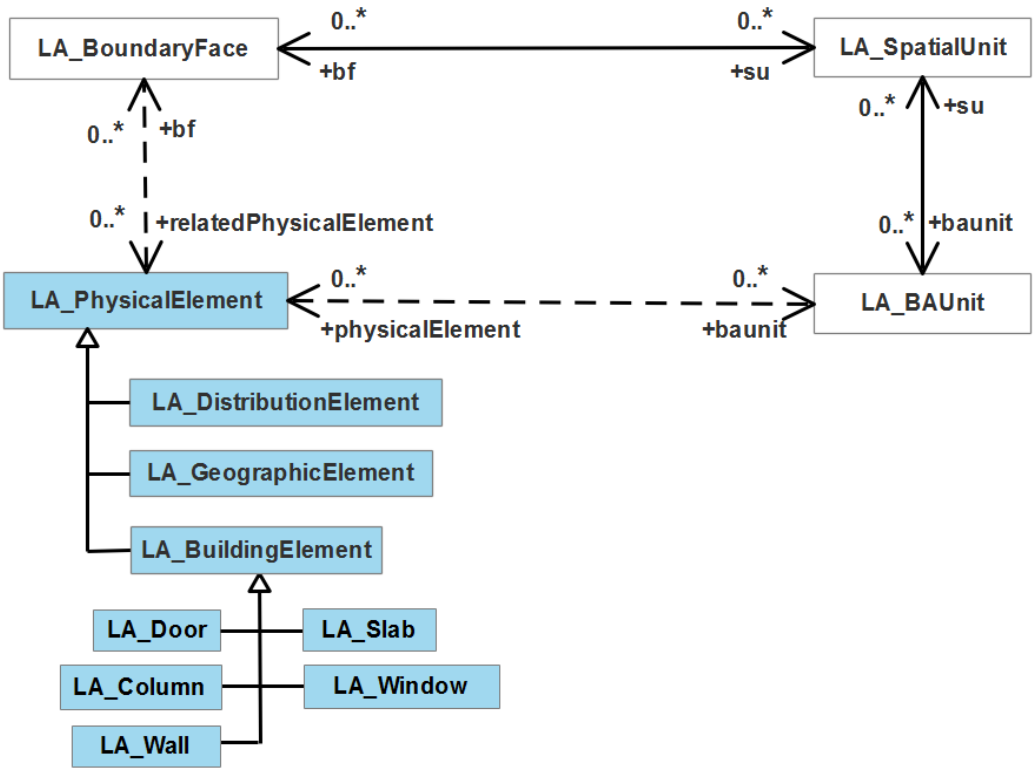

Figure 4. Proposed physical concepts for LADM

Figure 4 above shows that how physical elements can be feasibly defined in a future version of LADM. We consider physical elements in two aspects. First, these physical elements can act a reference for defining general boundaries which mainly refer to real-world and tangible objects. We defined this relationship between boundary face and physical elements. The second aspect is that physical elements can be considered as a constituent part of a legal arrangement or basic administrative unit in LADM's language. For example, a wall or ceiling between two private property units can be part of a common property unit. Therefore, we define the relationship between physical elements and basic administrative units.

5. DISCUSSION AND CONCLUSIONS

In this paper, we looked at two different approaches for integrating legal and physical dimensions of buildings based on existing international standards. This study was focused on integrating legal information and physical information at data model level since data models provide the structure for storing and managing data. For physical view of buildings, our choice was IFC standard in the BIM domain while LADM is considered as the appropriate data model for managing legal information. Existing research projects looked at various methods for developing an integrated legal-physical 3D data models; however, there is limited investigation on the interaction between IFC and LADM standards to construct an integrated model. Our suggested pathways for designing an integrated 3D cadastral data model were either encoding LADM concepts inside IFC standard using the extension mechanisms of IFC or expanding future versions of LADM standard by incorporating physical concepts from IFC standard. Here, we will discuss advantages and challenges of each pathway:

- Mapping LADM concepts into IFC: One important benefit of this approach is that it would provide the ability to link the legal information to other lifecycle information about buildings. IFC standard is the underlying basis for managing building lifecycle in an open and interoperable way. This approach would unlock the value of legal information beyond the property registration. For instance, legal rights, restrictions and responsibilities in property management, after its registration, can be easily determined if legal concepts of LADM are integrated with physical and lifecycle data elements. This would also help other land development stakeholders to better communicate and exchange information with land administration actors (such as land surveyors or land registries). Despite these benefits, there remain challenges in this pathway. One important challenge is establishing effective interactions between two standardization experts in LADM and IFC standards. Mapping LADM concepts into IFC standard requires a good understanding of standards by both expert groups.
- Extending LADM with IFC-based physical objects: This approach would motivate some jurisdictions, such as Victoria in Australia, to adopt LADM in implementing their 3D digital cadastral systems. This is because in these jurisdictions, building structures are used for boundary delineation and they are also considered as constituent parts of some legal arrangements. This would broaden the scope of LADM standard in covering various jurisdictional approaches for 3D property registration. However, incorporating physical elements into LADM standard requires a deep understanding of property subdivision practices in jurisdictions which rely on physical elements, in addition to surveying measurements, to define legal boundaries and legal arrangements.

In this study, we looked at the integration IFC and LADM concepts at the conceptual level of data modelling. Future investigations will be conducted more on applying this integration on real-world case studies, particularly in building developments with complex architectural design. This will help us refine the proposed approaches in line with real-world practices, which would subsequently result in a more feasible approach for integrating legal and physical dimensions of buildings in a 3D digital environment.

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BIOGRAPHICAL NOTES

Behnam Atazadeh is a post-doctoral research fellow in the Centre for Spatial Data Infrastructures and Land Administration, Department of Infrastructure Engineering, the University of Melbourne. He has extensive experience in using 3D building information models and other 3D digital technologies for cadastral surveying in urban areas.

Abbas Rajabifard is Professor at the University of Melbourne and head of the Department of Infrastructure Engineering and Director of both the Centre for SDIs and Land Administration and the recently established Centre for Disaster Management and Public Safety. He is immediate Past-President of Global SDI (GSDI) Association and is an Executive Board member of this Association. Abbas was Vice Chair, Spatially Enabled Government Working Group of the UN Global Geospatial Information Management for Asia and the Pacific. He has also consulted widely on land and spatial data policy and management and SDI.

Mohsen Kalantari is a Senior Lecturer in Geomatics Engineering and Associate Director at the Centre for SDIs and Land Administration (CSDILA) in the Department of Infrastructure Engineering at The University of Melbourne. He teaches Land Administration Systems (LAS) and Building Information Modelling and his area of research involves the use of 3D digital and spatial technologies in LAS and SDI. He has also worked as a technical manager at the Department of Sustainability and Environment (DSE), Victoria, Australia.

CONTACTS

Behnam Atazadeh
Department of Infrastructure Engineering, University of Melbourne
VIC 3010 AUSTRALIA
E-mail: behnam.atazadeh@unimelb.edu.au
Website: http://www.csdila.unimelb.edu.au/people/behnam-atazadeh.html

Abbas Rajabifard
Department of Infrastructure Engineering, University of Melbourne
VIC 3010 AUSTRALIA
E-mail: abbas.r@unimelb.edu.au
Website: www.ie.unimelb.edu.au/

Mohsen Kalantari
Department of Infrastructure Engineering, University of Melbourne
VIC 3010 AUSTRALIA
E-mail: mohsen.kalantari@unimelb.edu.au
Website: http://www.csdila.unimelb.edu.au/people/saeid-kalantari-soltanieh.html