

MSc thesis in Geomatics for the Built Environment

# BIM Legal

Proposal for defining legal spaces for apartment rights in the Dutch cadastre using the IFC data model

Roeland Willem Erik Meulmeester  
2019



BIM LEGAL: PROPOSAL FOR DEFINING LEGAL SPACES FOR  
APARTMENT RIGHTS IN THE DUTCH CADASTRE USING THE IFC  
DATA MODEL

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# ABSTRACT

In this thesis, a proof of concept is developed that describes a complete data processing chain for registering new apartment rights in 3D. This chain starts by defining and adding legal space to Industry Foundation Classes (IFC) Building Information Model (BIM) models. Once the IFC BIMs are enriched with legal space, the 3D parcels are automatically extracted. The legal space is checked and validated, and stored in a Land Administration Domain Model (LADM) compliant database. Finally, the legal space is visualised on a desktop and browser-based client.

Currently, there is no functional 3D Cadastral system functional in the Netherlands. A pilot study has been conducted to register 3D rights on the railway station in the city of Delft. This complex area contained many stacked objects such as a tunnel, offices, shops, etc. [Stoter et al., 2017]. However, the 3D drawings of the area were stored in a PDF document, which only serves as a visualisation tool in a separate document in the Public Registers. As a result, it is not possible to check for overlap with other 3D Cadastral objects.

This research focuses on registering apartment rights for a 3D cadastre by using IFC BIM models as source data. Apartment rights are one of the most common rights found in apartment complexes. The IFC file format is chosen because it is the most widely used open data format for the exchange of BIM. In the Netherlands, submitting a IFC BIM file is mandatory for obtaining a construction permit for buildings with a value of 10 million euro or higher.

IFC BIM files contain a lot of information, including 3D geometries of the indoor spaces, constructions and building infrastructure. However, there is no explicit information defining the individual apartments (property units). Therefore, the IFC is enriched with legal space in order to enable fully automatic extraction of the 3D spaces that belong to one apartment.

This enrichment is based on analysing the current way of registering apartment rights using annotated 2D floorplans as part of a notarial deed [Kadaster, 2014, 2019c], analysing the Dutch legal system related to apartment rights, and based on this knowledge make a proposal for enriched IFC IFC files. To reach practical suggestions for the IFC enrichment, that can be used in the Architecture, Engineering and Construction (AEC) industry, stakeholders such as notaries, the Dutch cadastre, BIM experts and other parties are involved. Also, current guidelines and practices in the Netherlands on IFC usage have been taken carefully into consideration, such as specification documents of the National Government and the National BIM Platform.

The conclusions of this research are that it is possible to enrich IFC BIM model with legal space in such a way that it fits current IFC BIM practices and legal system as much as possible. This is demonstrated with two use cases that describe the registration process of a (fictional) new apartment building, and sub splitting apartment rights of a (fictional) existing building. It is also concluded that there is still many future work to be done, such as improving the definition of legal space in IFC, further researching cadastral administration systems, and the changes to the current in the legal system that are required to facilitate 3D registration of property units.



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# ACRONYMS

GIS	Geographic Information System	5
GUI	Graphical User Interface	55
2D	Two Dimensional	1
3D	Three Dimensional	1
AEC	Architecture, Engineering and Construction	1
B3DM	Batched 3D Model Tile	12
BCF	BIM Collaboration Format	17
BIM	Building Information Model	1
B-rep	Boundary representation	21
CRS	Coordinate Reference System	12
CSG	Constructive Solid Geometry	21
DSRM	Design Science Research Methodology	11
GIS	Geographic Information System	5
GUI	Graphical User Interface	55
HVAC	Heating, Ventilation, and Airconditioning	18
IA	Internal Arrangements	26
IDM	Information Delivery Manual	5
IFC	Industry Foundation Classes	1
IFD	International Framework for Dictionaries	17
ISO	International Organization for Standardization	1
KNB	Koninklijke Notariële Beroepsorganisatie (Royal Dutch Association of Civil-law Notaries)	26
KML	Keyhole Markup Language	12
LADM	Land Administration Domain Model	7
NCG	Nederlands Centrum voor Geodesie en Geo-informatica (Netherlands Center for Geodesy and Geo-Informatics)	61
MIA	Modelreglement (Model Internal Arrangements)	26
MVD	Model View Definition	17
NAP	Nieuw Amsterdams Peil (Amsterdam Ordnance Datum)	21
RRR	Rights, Restrictions and Responsibilities	4
RVB	Rijksvastgoedbedrijf (Central Government Real Estate Agency)	9
STEP	Standard for the Exchange of Product model data	21
UML	Unified Modelling Language	8
WFS	Web Feature Service	12



# 1

## INTRODUCTION

Urbanisation is a growing phenomenon and it is estimated that by 2050 two-thirds of the population will be living in cities [United Nations, 2018]. Consequently, this puts high pressure on land use. Multipurpose buildings, with several uses such as residential, retail and transportation on the same building footprint will be more often the rule than the exception. Current Land Administration systems are still mainly registering property rights on a Two Dimensional (2D) drawing, and this is also the case for the Dutch cadastre. To get more insight of property rights in a Three Dimensional (3D) setting to prevent misunderstandings and mistakes concerning these rights, a 3D cadastral system is necessary [Stoter, 2004]. Such a cadastral system is not functional yet in the Netherlands, but a pilot study has been conducted to register 3D rights for the railway station in the city of Delft [Stoter et al., 2017].

The main source for 3D building information of new buildings is a Building Information Model (BIM). BIMs are digital 3D models of buildings that can be used for planning, design, construction, maintenance, etc. The most widely used data model for BIMs in the Architecture, Engineering and Construction (AEC) sector is the Industry Foundation Classes (IFC) file format [Abanda et al., 2015]. This is an International Organization for Standardization (ISO) standardized [ISO, 2018b] data format developed and maintained by the buildingSMART consortium [buildingSMART, 2018] as an open and neutral data format for BIM models. Some of the main benefits are that open data formats enable different software vendors to have better cooperation and increase efficiency by eliminating interoperability problems when files are exchanged.

IFC can be a good source for cadastral registration since the data format can contain a lot of relevant information, such as geometry, and semantics (meaning) added to this geometry [Oldfield et al., 2017]. However, a concept for registering rights using the IFC format as a source for legal space is still missing. Having the IFC data model enriched with legal space would pose many advantages, especially for all activities in which land administration is involved, such as 3D ownership right registration. To be able to provide a full representation of the ownership situation of an apartment building in the current cadastral system, a large amount of 2D floorplans and cross-section diagrams are needed [Jazayeri et al., 2014]. To get an overview in 3D of ‘who owns what’ is labour intensive and cumbersome. This problem of clear representation and the dichotomy between the 2D drawing and real world is shown in Figure 1.1, which is also the pilot study of the first 3D registration of the Netherlands.

### 1.1 PROOF OF CONCEPT

This thesis presents how the IFC data model can be used as a source for 3D cadastral registration of apartment rights by developing a proof of concept which denominates all necessary steps to register apartment rights using an IFC BIM as a source for the legal space. Therefore, the first step is to enrich the IFC data model with legal space. It is very important to have an awareness of the fact that the IFC data model enriched with legal space has to be used in practice by many parties. To facilitate this multi-user aspect, this research will not refrain from mere technical specifica-

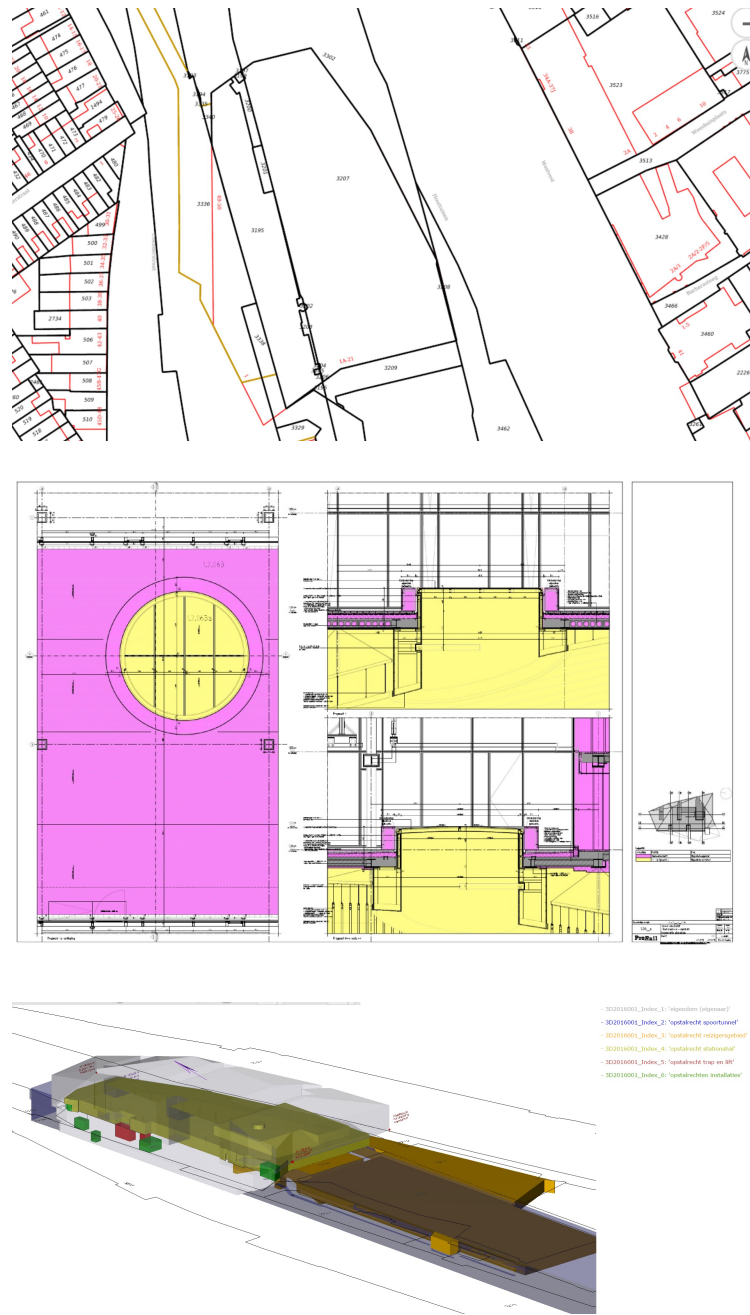


Figure 1.1: 3D Registration of Railway Station in Delft. The top image shows the 2D cadastral parcel map. In the middle the 2D views and cross sections, at the bottom the 3D representation of the complex. Figure adapted from Stoter et al. [2017]

tions for additions or usage of the IFC data model. To reach practical suggestions that can be used in the AEC Industry, stakeholders such as notaries, the Dutch cadastre, construction companies, and other parties have to be considered during the development of the new concept legal space in the IFC data model. By addressing the multi-actor component in the developed proof of concept, this research is a mixture of both the Geomatics Engineering and Policy Analysis fields. Furthermore, this research will be conducted in cooperation with the Dutch Kadaster (Land Registry and Mapping Agency).

The proof of concept is divided in six elements which together form a workflow to reach the objective of this thesis which is using a legal space enriched IFC BIM to register apartment rights in 3D:

1. BIM legal creation: the IFC data model will be enriched with legal information.
2. Extraction of 3D legal space: from existing IFC BIMs the required data for registration of apartment rights is obtained.
3. Validation: the BIMs enriched with legal space are examined in terms of correctness and completeness.
4. Storage in cadastral database: the extracted legal space information of the IFC BIMs is stored in a database maintained by the national cadastral agency.
5. 3D web visualisation for dissemination: the extracted legal space of IFC BIMs visualised in a web browser for dissemination purposes.
6. Splitting: sub splitting and merging existing 3D parcels in a building.

## 1.2 THESIS OUTLINE

Chapter 2 starts with a literature review of related work to this research. In Chapter 3 the methodology applied to this thesis is described. Chapter 4 contains background information about the the IFC data format. In Chapter 5 the legal context of apartment rights is described, and requirements for 3D registration of apartment rights are formed. In Chapter 6 a solution is proposed which adds legal space for apartment rights to the IFC data format. The proposed solution is further illustrated in Chapter 7 by applying it on two use cases; registering apartment rights of a new building and sub splitting apartment rights of an existing building. Chapter 8 concludes this research by answering the research questions and suggesting future research directions.

## 1.3 OBJECTIVES AND RESEARCH QUESTIONS

The main objective of this thesis is to develop a proof of concept on how to use the IFC data model for cadastral registration in the Netherlands. When an IFC BIM is created, what aspects should be added in order to use the IFC file for cadastral registration? To reach this objective the main research question is formed as:

*How can the IFC data model possibly be extended to automatically extract legal spaces for apartment rights for registration in the Dutch cadastre?*

Apartment rights are chosen specifically because it is the most common right found in complex 3D building structures. Other rights, such as superficies, easement, usufruct, and long leasehold lie outside the direct scope of this research. However, the results of this thesis could offer a framework for the registration process of these

rights in complex building structures with layered property rights, possibly also in an international context.

Defining the legal space in the IFC model is an important element for the proof of concept that is developed. Besides a literature study, it is researched by consulting experts in the field such as legal experts, academia, and employees of the Dutch cadastre. Together with their knowledge and expectations, the current practices and technical analysis of the IFC data model, a solution is proposed to enrich the IFC data model with legal space.

An important objective to consider is the sub splitting of apartment rights since this is a common practice in the Netherlands [CBS, 2016]. Once an apartment in an IFC BIM is defined according to the proposed solution, it should be relatively simple, or at least possible, to split apartment rights that are registered with this method. Therefore, the first sub-question is formed:

*1. What model additions or guidelines can be part of future registration in order to add legal spaces to the IFC data model?*

Apartment rights apply to a physical object with a certain geometry. This geometry is of great importance for cadastral use. To give suggestions on how to use the IFC model for cadastral registration the (geometric) content of the data should be intrinsically known. Therefore the second sub-question is formed as:

*2. How can the new concept IFC legal space reuse geometric data from the existing concepts in IFC related to the physical objects?*

This sub-question is formed to investigate how the semantics of apartment rights can be connected to physical elements of the building (geometry) and stored in a well documented and defined manner. The legal spaces should be designed in such a way that inspection and checks can be performed on them. When a building is designed according to the suggested guidelines for defining legal spaces, these legal spaces must at least be checked for consistency, completeness, correct naming, overlap, total building coverage by legal space. By having set this goal, the guidelines make it possible for legal space enriched IFC BIMs to be checked by an automated process. This leads to the third sub-question:

*3. How can the IFC files enriched with legal spaces be checked for consistency and correctness?*

The research questions are answered by developing the proof of concept that enriches the IFC file format with legal space, extracts the legal space, checks the legal space, registers the legal space, visualises the legal space, enables merging and splitting of legal space.

## 1.4 SCOPE

Related work [Atazadeh et al., 2018] has focused on adding several elements to the IFC data model. These added elements do not only contain the legal spaces in the IFC, but also the Rights, Restrictions and Responsibilities (RRR)s and much more information, such as leases, mortgages, easements, etc. But still missing are other concepts such as party (persons), surveys etc. Therefore it is still not a complete model. Also, a collection of IFC files is not an optimal cadastral database for registration due to the large file sizes and amounts of information not relevant for land administration. Even though the IFC data model could be suitable to carry all this information, for feasibility reasons it is chosen to only make guidelines involving apartment rights in the Dutch legal system.

As mentioned before, besides the proposal for IFC additions, a proof of concept is developed. This proof of concept shows that the enriched IFC file can be used in practice to register apartment rights. But this workflow is partially developed with the help of theoretical elements. That means not all system aspects will be literally produced or are present in the real world, they are either assumed or described. This is necessary because, at the time of writing, there is no infrastructure present in the Netherlands for land administration to register rights in 3D. But to show this could be possible, the developed proof of concept describes that it is possible to enrich an IFC BIM with legal space and use it to register apartment rights in the Netherlands in 3D with minimal change to current practices, such as legislation and systems.

## 1.5 VISUALISATION

Communicating results of this research require the visualisation of legal spaces, preferably in a web browser. Visualising data, especially 3D cadastral data in a web browser, is a non-trivial task which has been a topic of research for some time [Shojaei et al., 2018; Cemellini, 2018; Vandysheva et al., 2012]. This research will focus on the usage of the IFC data model for cadastral purposes, and one of the many applications of 'legal space enriched BIMs', is visualising them. Therefore, existing tools are used for visualisation. During the research, Geographic Information System (GIS) software is used for visualisation due to time limitations. However, the legal space formed in IFC BIMs will also be visualised in Cesium JS [Cesium, 2019] because this platform is used in a 3D cadastre viewer prototype developed by [Cemellini, 2018]. The web browser based Cesium JS visualisation adds relevance to this research in that it shows the usability of legal space enriched IFC BIMs fit in existing research for 3D cadastre visualisation.

## 1.6 RESULTS

A complete proof of concept is developed in this thesis. The legal space is added to the IFC data model by designing a user defined property set with cadastral information. The 'Cadastral Information user defined property' set contains the required information to register the spatial representation of apartment rights in 3D. Apartment rights are established in the Netherlands with a notarial deed, which contains a 2D drawing of the areas and floor plans that are registered. The requirements for the 2D drawing are projected on a 3D representation, which resulted in the contents of the cadastral information user defined property set. This proposed solution fits within the current standards of the buildingSMART consortium and can be communicated to users with an Information Delivery Manual (IDM). A proposal for the Dutch IDM is developed to show how the proposed solution of defining legal space can be put in practice by BIM creators.

The proof of concept further described the steps that can be taken to use the legal space from the IFC BIM in a notarial deed as a 3D representation, and that it can be published to the Cadastre and become part of the Public Registers and the Cadastral database. This process is illustrated through two use cases. One describes the workflow to register a new building, while the other case study describes a scenario in which apartment rights are split with this concept of 3D legal space registration.





# 2

## RELATED WORK

This chapter is divided into four sections to show the scope of this research in the academic world and to place it into the context of the professional debate surrounding the usage of BIM in society. First, in [Section 2.1](#) research related to 3D cadastral systems is described. Then in [Section 2.2](#) the work in relation to BIM as input for a 3D cadastre is reviewed. [Section 2.3](#) describes work in which BIM is related to the Land Administration Domain Model (LADM). Besides academic publications, publicly available documents containing the current practices and usage guidelines of BIMs in the Netherlands by both the Dutch national government and private companies are researched in [Section 2.4](#).

### 2.1 3D CADASTRES

3D Cadastres are a topic of research and practice in some countries for many years. The 3D cadastre topic includes a wide variety of subdomains such as data acquisition, data modelling, system architecture and visualisation.

3D property information and management are important in densely populated urban areas to secure and describe ownership and other rights of stratified properties, creating a framework for more effective management and use of space in three dimensions [[Paasch et al., 2016](#)]. This results in time savings, cost reduction, increased transparency in transactions and improved land use. An example of this is the validation of overlapping 3D parcels to ensure rights are secured and disputes are minimized [[Shojaei et al., 2018](#)].

[Stoter et al. \[2013\]](#) described the current status of 3D cadastres in the Netherlands, including a use case of the railway station in the city of Delft. This was the first 3D registered building complex of the Netherlands ([Figure 1.1](#)) and lead to many findings. One of which is that registration in three dimensions at initial stages of the design would have saved large amounts of time and effort compared to 3D registration performed after the building complex is constructed. This shows the relevance of this research where the source of 3D registration is sought in the data that is produced already (in the IFC file) during the design phase of a construction project. This leads to a demand for research on how to define legal spaces at the beginning of the design phase.

Other countries, such as Spain and Turkey currently already support the registration of 3D legal spaces. In Spain, apartment units in a complex can be registered in 3D, and the floor, ceiling, and walls act as boundaries for the private areas. Common property is also registered, but only the geometry<sup>1</sup>. Turkey also registers legal spaces for building units in 3D. Similar to Spain, the boundaries of the apartment units are walls and ceilings. Contrary to Spain, the shared spaces inside the building are not registered but considered to be held in common property for those who benefit from the common property<sup>2</sup>.

<sup>1</sup> [http://www.gdmc.nl/3DCadastres/participants/3D\\_Cadastres\\_Spain2018.pdf](http://www.gdmc.nl/3DCadastres/participants/3D_Cadastres_Spain2018.pdf)

<sup>2</sup> [http://www.gdmc.nl/3DCadastres/participants/3D\\_Cadastres\\_Turkey2018.pdf](http://www.gdmc.nl/3DCadastres/participants/3D_Cadastres_Turkey2018.pdf)

## 2.2 BIM AS INPUT FOR A 3D CADASTRE

Until now, research regarding the use of BIMs in 3D cadastres briefly mention that BIMs can be used as input for a 3D cadastre. However, they do not research specific data models nor give any suggestions on practical usage of BIM models as input [Gulliver et al., 2017; Aien et al., 2013; Ho and Rajabifard, 2016].

The most recent and relevant research on the use of BIM in the context of 3D cadastres is that of Oldfield et al. [2017]. The authors go into detail on the IFC data model components and give suggestions on usage as input for a 3D cadastre. The research concludes that the use of the *IfcSpace* in combination with the *IfcZone* element could be fit for cadastral registration. Chapter 4 contains more details about these elements. This thesis aims to go further in this research direction and produces practical suggestions on how to add cadastral information to the elements as mentioned earlier. Included in this research, topics such as the naming of legal spaces and boundary modelling are discussed.

Research on boundary modelling, especially apartment walls, within the IFC data model has been carried out by [Atazadeh et al., 2017]. The paper suggests four methods on boundary modelling in relation to the legal space in the BIM. These methods are modelling the interior structural boundary, exterior structural boundary, median structural boundary, projected boundary, and fixed boundary. This thesis researches which of their methods could also be applied for apartment right registration in the Dutch legal system.

## 2.3 LAND ADMINISTRATION DOMAIN MODEL (LADM)

Atazadeh et al. [2016, 2018] discusses utilizing the IFC in relation to the LADM. The LADM is a conceptual information model for land administration. One of its main goals is to provide an extensible basis for the development and refinement of efficient and effective land administration systems [Lemmen et al., 2015]. The model covers all basic information related to components of land administration and is an ISO standard [TC/211, 2012]. Among others, the model components concern the party related data (the people involved), data on RRRs and the basic administrative units the RRRs apply to. In the context of this research, connecting apartment rights to 3D parcels is of most importance. See Figure 2.1 for a Unified Modelling Language (UML) diagram of the classes in the LADM.

When adding cadastral elements to the IFC model it is important to take the LADM into consideration since it is a widely known international standard, which is currently under revision. It is especially important in case the results of this thesis are scaled from a Dutch to a more international framework of adding legal spaces to the IFC model. In this research, the mapping of the extracted geometry of legal spaces to the LADM is of interest for visualization purposes, to communicate the produced results. LADM at its current edition has support for 3D geometry, the *LA\_SpatialUnit*, *LA\_BAUnit*, *LA\_BoundaryFace* and *LA\_BoundaryFaceString* classes can be used for this to have an internationally recognised concept for a volumetric space.

Oldfield et al. [2017] mapped the *IfcSpace* to the LADM at a conceptual level and this approach forms the main basis of the LADM mapping of the developed proof of concept in the context of this research. Also [Cemellini, 2018] use a LADM database model to store volumetric data together with cadastral information for 3D visualisation of cadastral information. The mapping of the new concept legal space to the LADM is further described in Section 6.2.





# 3 | METHOD

This research is conducted according to the Design Science Research Methodology (DSRM) approach [Geerts, 2011]. This methodology enables the research questions to be answered in a well structured and substantiated manner. One of the many advantages of this approach are the feedback loops embedded in the methodology. This thesis has as the main goal to create guidelines to add legal spaces to the IFC data model. These guidelines have to be designed. But an important aspect of designing these guidelines is new knowledge gained by the author during the research process as well as input and involvement of experts in the field (see Table 3.1 for involved experts). These experts are involved by interviewing them about specific aspects that are part of the developed proof of concept. The feedback moments in the DSRM approach are fit to develop guidelines in cooperation with these experts.

Figure 3.1 shows the DSRM approach according to Geerts [2011]. The diagram is divided into four blocks. The first block describes the steps in the methodology. Block 2 describes the activity in detail. Block 3 shows the knowledge base, this describes “the raw materials from and through which design science research is accomplished” [Geerts, 2011]. Additional to this methodology framework is block 4; the experts that will be involved. This has as a benefit that it shows clearly which expert is involved at specific steps and tasks in this thesis. Table 3.1 shows in more detail which experts will be interviewed and the tasks they are involved in.

The research activities are set up as follows: First, the definition of legal spaces in relation to the Dutch law concerning apartment rights are researched. Then the IFC data format will be examined on possibilities to add the legal spaces in such a way that it fits the Dutch law as best as possible. Also, the relation between physical elements and legal boundaries is researched. Literature research together with the involvement of experts will help to answer these questions.

Another aspect in which experts will be involved is the initial identification of the legal space. Does every room get a parcel number? Or does only an entire apartment get a parcel number, and rooms a room number? How do these numbers have to be assigned? This type of questions will be answered by researching the current for guidelines for cadastral apartment registration, the documents from the Kadaster [2014, 2017] will be the starting point for the development of the apartment identification in combination with the industry guidelines described in Section 2.4. The future splitting of apartments should also be supported based on the presence of namespace given to rooms and apartments. To show this is possible, one of the case studies in Chapter 7 will describe a workflow in which an apartment right in a building is split into two apartment rights.

Name	Institution/Company	Activity of Involvement
P.J.M. Oosterom	TU Delft (University)	Define Legal Space Evaluate Proposed Solution Primary Supervisor
H.D. Ploeger	TU Delft	Define Legal Space Evaluate Proposed Solution Secondary Supervisor
E. Hagemans	Kadaster (Dutch Cadastre)	Define Legal Space Evaluate Proof of Concept Contactperson Kadaster
G. Dabroek	Kadaster	Define Legal Space Evaluate Proof of Concept Contactperson Kadaster
A. Alattas	TU Delft	Enrich BIMs with legal space
L. Boellaard	Westland Partners (Legal Firm)	Evaluate Proof of Concept

Table 3.1: Overview of expert involvement of research activities

### 3.1 TOOLS

The building, editing and viewing of IFC BIMs is done with Autodesk Revit [Autodesk, 2019]. This software can add information to existing buildings or create new buildings enriched with legal space and export them to the IFC data format. Solibri Model Viewer [Solibri, 2019] is used for viewing IFC files. Extracting and converting legal space from the enriched IFC files is done with FME [Safe Software, 2019]. This software is also used to store the legal space in a database PostgreSQL [PostgreSQL, 2019] database with a PostGIS [PostGIS, 2019] extension. FME is also used for data manipulation, such as changing Coordinate Reference System (CRS), attribute information and changing data formats. Checking the legal space enriched IFC files is conducted with Solibri Model Checker [Solibri, 2019]. This software can apply custom made rulesets to IFC files, in this research it is used to check for correct cadastral information is present in the IFC according to the proposed solution of a cadastral information user defined property set.

The viewer that is primarily used to show and communicate legal spaces is QGIS [QGIS, 2019]. This GIS software is chosen for its ease of use, integration with PostGIS and Web Feature Service (WFS) capabilities. As stated in the introduction, the 3D Cadastral Viewer Prototype of [Cemellini, 2018] is taken into consideration during the development of this proof of concept. The Prototype cadastral viewer is based on the Cesium JS platform [Cesium, 2019], but the exchange format are Keyhole Markup Language (KML) files. In this research IFC files enriched with legal space are converted to a Batched 3D Model Tile (B3DM) format to visualise them in Cesium JS to show the potential of using IFC BIM for cadastral registration. More information about the visualisation aspects of this research can be read in Section 6.5. An overview of all software used can be found in Table 3.2 and screenshots of the most used software can be seen in Figure 3.2.

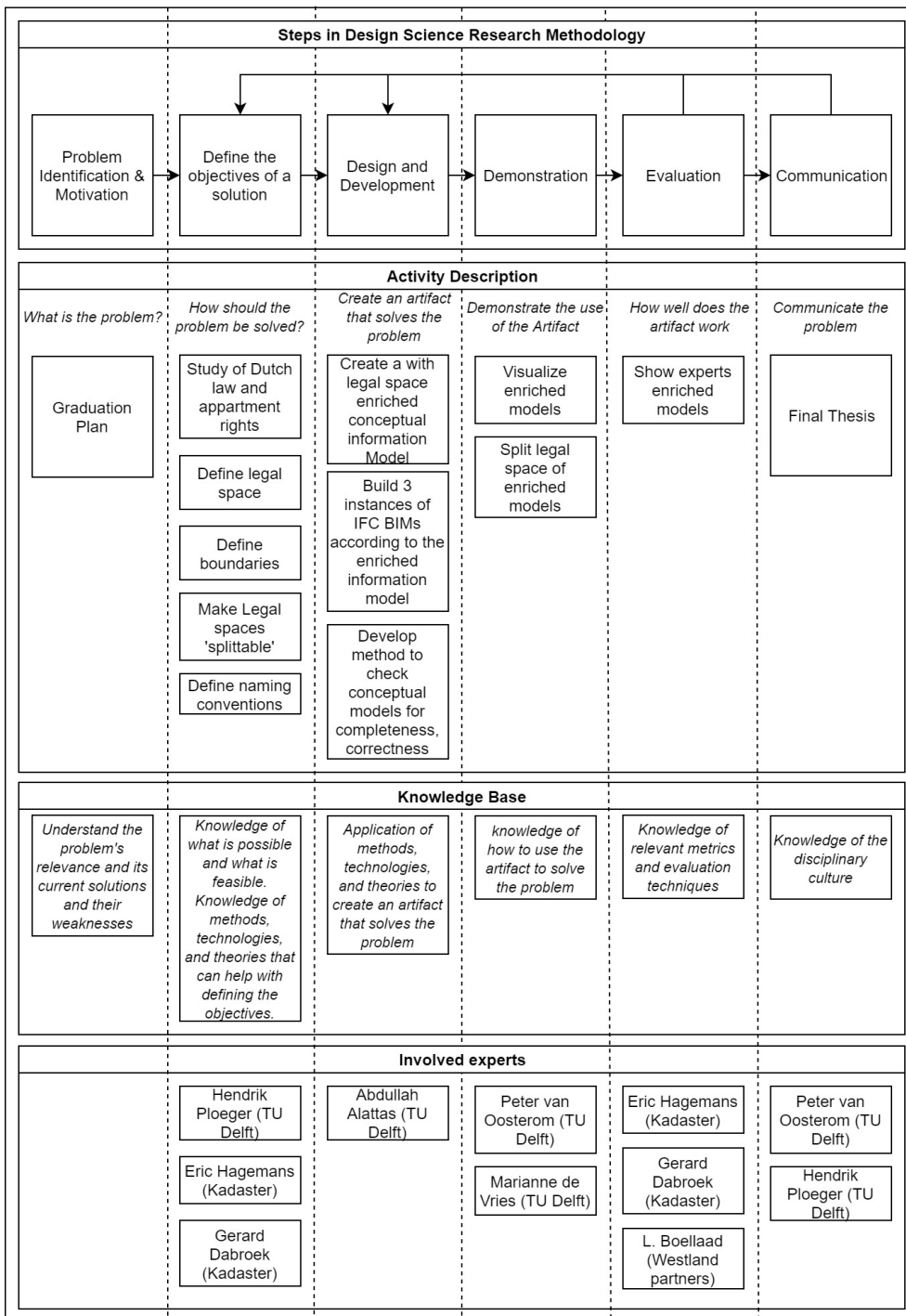


Figure 3.1: Flowchart of Design Science Research Methodology [Geerts, 2011] applied to add legal space to the IFC data model.

Software	Version	Task
AutoDesk Revit [Autodesk, 2019]	19.0.1.1	Manipulate IFC files
Solibri Model Viewer [Solibri, 2019]	9.8.30	View IFC files
Solibri Model Checker [Solibri, 2019]	9.9.5.113	Check IFC files for corectness
FME [Safe Software, 2019]	2017.1.2.1	Extract geometry from IFC files Store legal space in database
pgAdmin [pgAdmin, 2019]	4.4	Convert data format for viewing in Cesium JS View database content
PostgreSQL [PostgreSQL, 2019]	9.6	Database
PostGIS [PostGIS, 2019]	2.4.1	Spatial extension for PostgreSQL
QGIS [QGIS, 2019]	3.6	Visualise and change legal space information
Cesium JS [Cesium, 2019]	1.5.4	Visualise legal space online

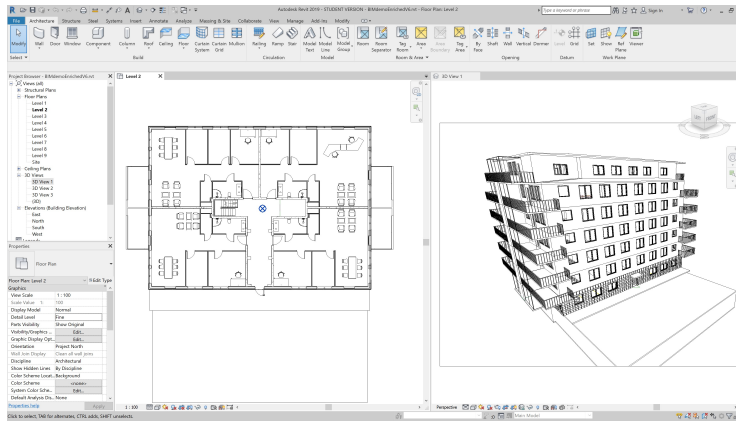
Table 3.2: Description of software used in this research together with the tasks

### 3.2 DATASETS

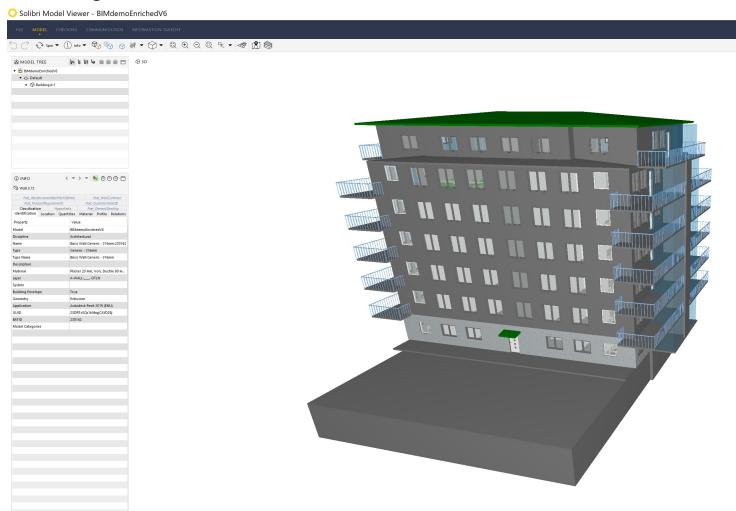
The proposed solution is designed for IFC files that are compliant with existing rules and guidelines in the Netherlands; the RVB BIM Norm V1.1 [Rijksvastgoedbedrijf, 2013] and the BIM Basic IDM [BIM Locket, 2018]. However, these type of IFC files are not freely available. Therefore, three IFC datasets are used to develop the proof of concept. It should be noted that the absence of compliant IFC files does not interfere with the development of the proof of concept. Three IFC datasets are used in this research:

- Apartment Building [BIMobject Model Repository, 2016]: this dataset is used to show the proof of concept works for a 'common' apartment building. See Figure 3.3a
- Office Building [The University of Auckland, 2016]: this dataset is used to show that all types of buildings benefit from the proposed solution of enriching IFC BIMs with legal space. See Figure 3.3b.
- TU Delft Faculty of Architecture [Alattas et al., 2017]: this dataset is used to present the progress of the research throughout the development because this building is familiar for the author and involved mentors. See Figure 3.3c.

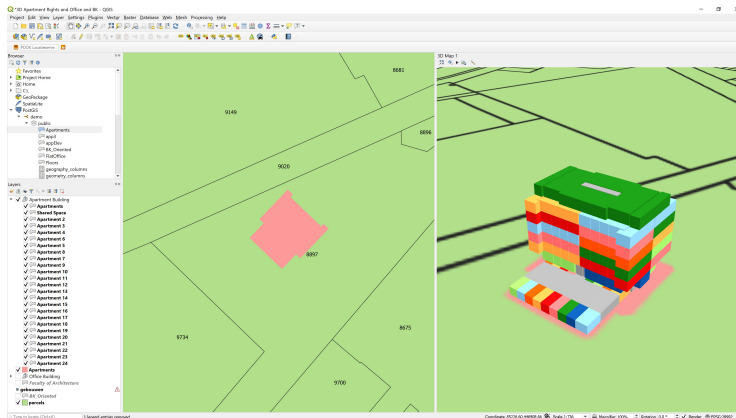




(a) Autodesk Revit [Autodesk, 2019] used for producing and manipulating IFC files.

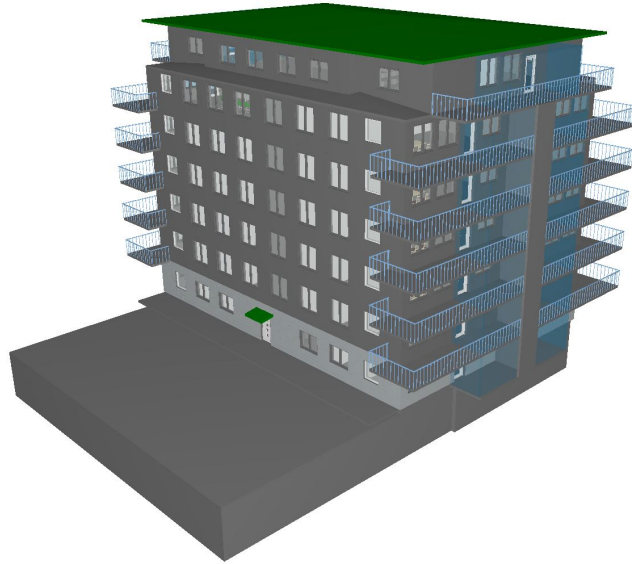


(b) Solibri Model Viewer [Solibri, 2019] used for visualisation of IFC files.

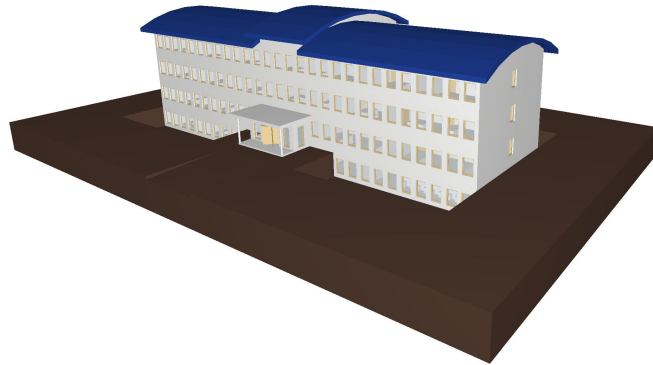


(c) QGIS [QGIS, 2019] used for visualisation of concept legal space together with other datasets such as the Dutch cadastral parcel map.

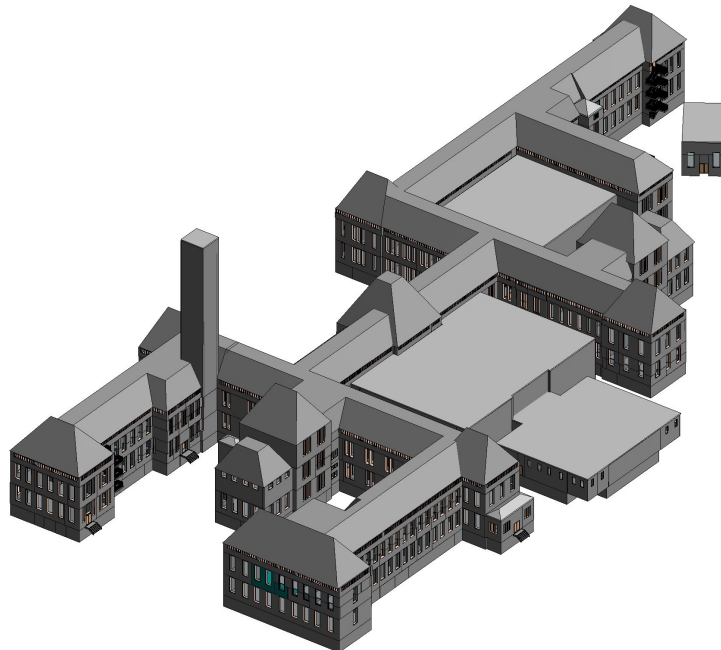
Figure 3.2: Screenshots of most used software during the research.



(a) IFC BIM of 'common' apartment building



(b) IFC BIM of 'common' office building



(c) IFC BIM of TU Delft Faculty of Architecture building

Figure 3.3: Three IFC BIMs used to develop the proof of concept

# 4 | IFC

This chapter describes the IFC data format. Section 4.1 starts with a brief general background of the IFC data format, followed by a technical description of the contents of the data format. Section 4.2 continues with current usage of the IFC in the AEC industry in the Netherlands.

## 4.1 INDUSTRY FOUNDATION CLASSES

The buildingSMART consortium created the IFC as an open data model for the exchange of BIM models. BIM is used in different stages such as design, construction, procurement and maintenance operations [buildingSMART, 2019b]. An open data format supported by different software vendors enables cooperation and increases efficiency by eliminating interoperability problems when files are exchanged. IFC is internationally standardised as ISO 16739 [ISO, 2018b] and the geometry definitions are standardised in ISO 10303 [ISO, 2014]. Besides the standardization of the file format IFC, buildingSMART manages other methodology standards involving the exchange of BIM related aspects. These standards are the Information Delivery Manual (IDM), Model View Definition (MVD), International Framework for Dictionaries (IFD) and BIM Collaboration Format (BCF). See Figure 4.1 for an overview and a short explanation of these standards.

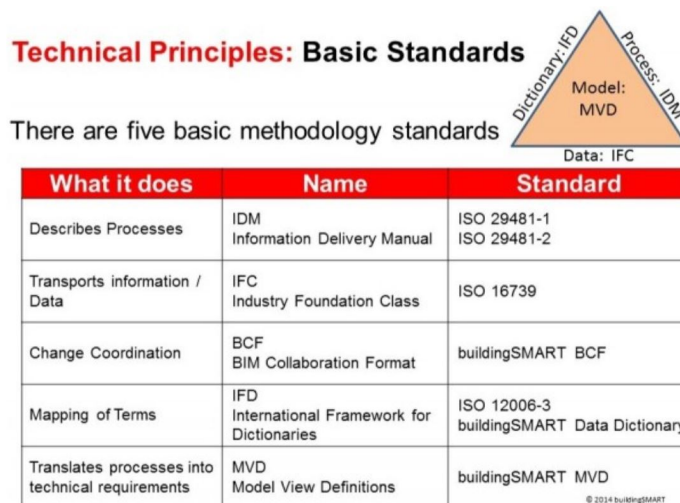


Figure 4.1: buildingSMART Standards, image taken from <https://www.buildingsmart.org/about/what-is-openbim/ifc-introduction/>

This research is focused primarily on the usage of IFC, but to visualise an IFC file a MVD has to be present. When data is exchanged between BIM tools, not all data has to be exchanged every time the two tools interoperate. The IFC describes a schema with all information that can be exchanged, the MVD acts as a subset of this schema in order not to have unnecessary data exchanged.

The complete IFC schema is developed as a set of individual topic schemas. Each topic schema typically represents a consistent overall idea (e.g. structural analysis, cost, materials, etc.), see Figure 4.2 for a fragment of the architecture diagram of

the IFC. On completion, all of the topic schemas are brought together into the single schema which is the authorized working version. It contains hundreds of entities (classes), data types and property sets (the IFC components) [Wix et al., 2008; buildingSMART, 2010]. This IFC system architecture can be seen in Appendix E.

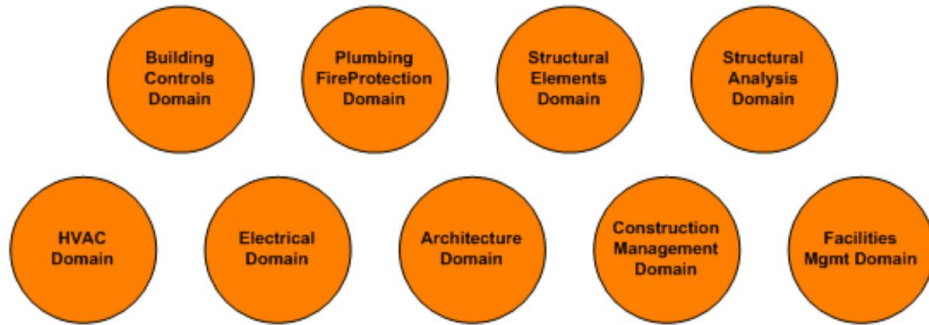


Figure 4.2: Fragment of IFC architecture diagram displaying the various topics, image taken from [buildingSMART, 2010] and edited by the author.

The IFC is a comprehensive data format with 776 entities in schema version 4 (IFC4). This research is focused on schema version IFC2x3 because this release is still the most commonly used version [Grani, 2016]. This scope is also supported by the contents of the current IFC usage documents as can be read in Section 4.2, and the datasets used in this research are also schema version IFC2x3.

The IDM is the third buildingSMART standard relevant for this research. A short recap: the IFC is the open data standard for the BIM, and the MVD is the standard that defines exchange requirements. The IDM is the method that defines such exchange requirements. An exchange requirement might be simple as in the case of an order that results from a purchasing process enabling a supplier to provide the required components. Alternatively, it might be complex as in the case of an architect providing a basic building model to an Heating, Ventilation, and Airconditioning (HVAC) consultant to enable thermal analysis calculations to be undertaken [See et al., 2012]. Figure 4.3 shows a conceptual model of the IFC data coordination process with the use of an IDM and MVD.

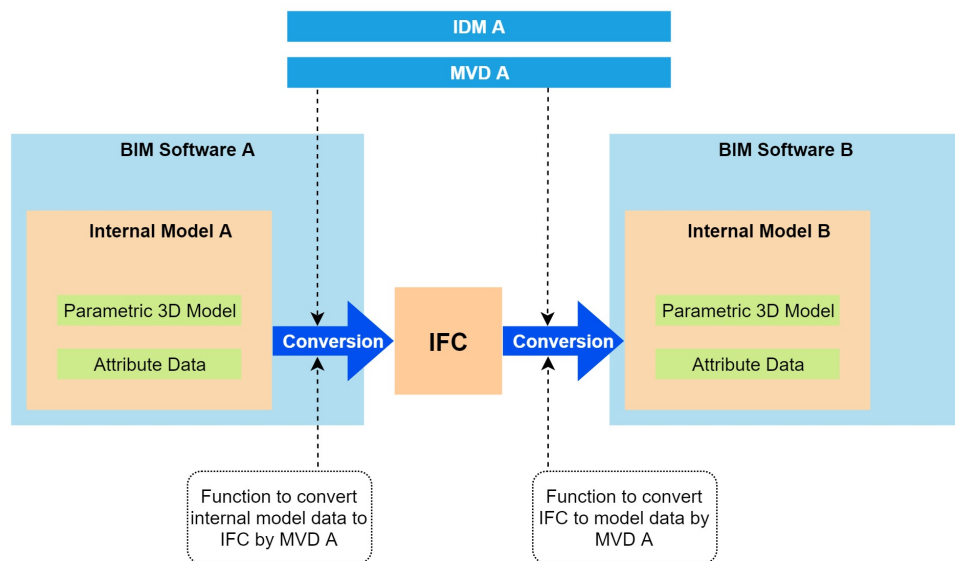


Figure 4.3: IFC Data coordination process with an IDM and MVD, image recreated and edited from <https://en.building-smart.or.jp/ifc/mvd/>

#### 4.1.1 Model contents and structure

The IFC is a complex model that can consist of many elements. These elements are independently modelled and defined by a hierarchy of transformations. This statement is depicted by giving an example of modelling a door in an IFC BIM (the element *IfcDoor*) and this process is guided by the hierarchy model of the IFC in Figure 4.4. A fragment of the UML diagram of the IFC data model can be seen in Figure 4.5.

1. The top of the model tree starts with the root (*IfcRoot*) class. This is an abstract supertype to *IfcPropertyDefinition*, *IfcObjectDefinition* and *IfcRelationship*. It allows every entity (such as the *IfcDoor*) to be provided with a unique identification (*GUID*), to have defined relations and attribute information.
2. The next item in the model hierarchy is the *IfcObject*, which is: "any object, or any aid to define, organize and annotate an object, that relates to a geometric or spatial context. Subtypes of *IfcProduct* usually hold a shape representation and a local placement within the project structure" - [buildingSMART, 2018].
  - a) 'Shape representation' is the kind of geometric representation for the product. These types are further explained in Section 4.1.3
  - b) 'Local placement' is information about where in the model instance the object is placed. This can be absolute (i.e. defined with respect to the whole project's coordinate system) or relative (i.e. defined with respect to another product). This concept is visualised with an *IfcSpace* element in Figure 6.17.
3. Descending from *IfcProduct* through the model hierarchy, the *IfcElement* is present. This element is an aggregation of all possible AEC elements, i.e. for construction (*IfcBuildingElement*) or furnishing (*IfcFurnishingElement*).
4. The *IfcDoor* is then a subclass of the *IfcBuildingElement*

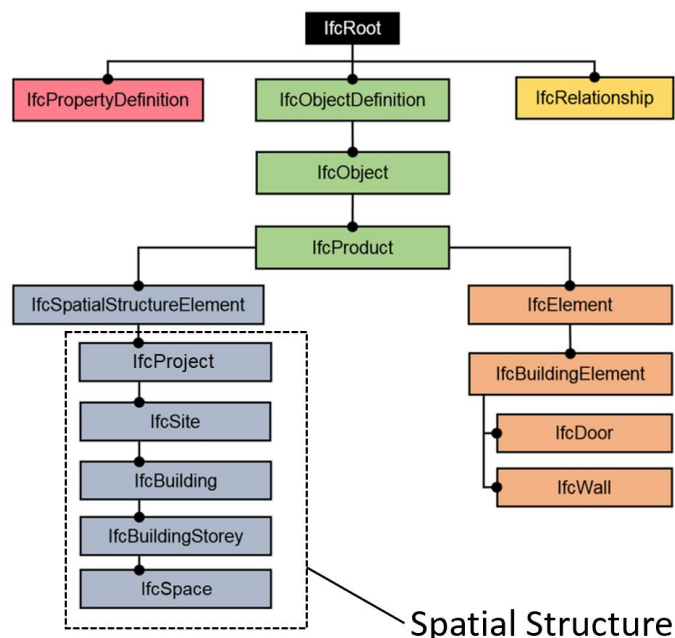


Figure 4.4: Hierarchy model of IFC. Image taken from [Vonthron et al., 2018] and edited by the author.

It should be noted that the previous enumeration is one of the modelling of an element in IFC, it is different from the spatial structure of the IFC. The spatial structure

is a more logical containment of elements in a model instance and acts as a project structure hierarchy. A spatial project structure element (*IfcSpatialStructureElement*) might define as many levels of decomposition as necessary for the building project. Elements within the spatial project structure are *IfcProject*, which decomposes in one or more *IfcSites*, which on their term contain one or more *IfcBuildings*. Each *IfcBuilding* has one or more *IfcBuildingStoreys* which can contain zero or more *IfcSpaces*. See Appendix F for an overview of this hierarchy together with the definitions by buildingSMART.

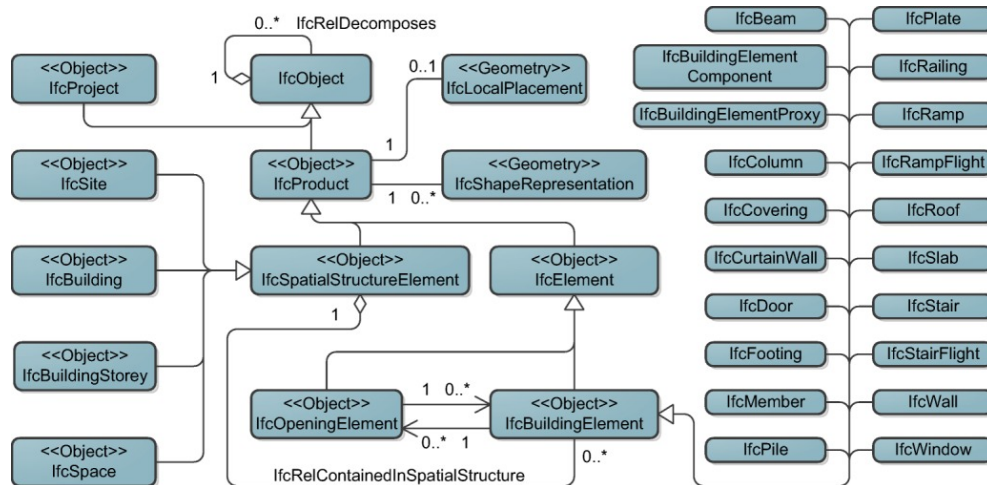


Figure 4.5: UML diagram of some classes in the IFC data model. Image taken from [Donkers et al., 2016]

#### 4.1.2 Semantics

An important aspect of the IFC in this research is the storage of semantics; the information added to elements in an IFC model instance. In the 'door' example of the previous subsection, this could be information on whether the door is fireproof or not. This information is added by using a property set. A property set is a list of attributes that can be added to an element to enrich it with more information. When this list has predefined instructions made by the IFC, it has the naming convention *Pset\_Xxx* applied to it. For the door, the possible property sets are *Pset\_DoorCommon*, *Pset\_DoorWindowGlazingType* and *Pset\_DoorWindowShadingType*. A part of the *Pset\_DoorCommon* can be seen in Figure 4.6 as an example to show how an *IfcDoor* can be enriched with fireproofing information through the use of a common property set as part of the IFC standard. Users can add this property set to the door, but this is not mandatory. Through the use of an IDM (see Section 4.1) the use of property sets can be demanded.

##### Property Definitions:

Name	Property Type	Data Type	Definition
Reference	IfcPropertySingleValue	IfcIdentifier	Reference ID for this specified type in this project (e.g. type 'A-1')
FireRating	IfcPropertySingleValue	IfcLabel	Fire rating for this object. It is given according to the national fire safety classification.
AcousticRating	IfcPropertySingleValue	IfcLabel	Acoustic rating for this object. It is given according to the national building code. It indicates the sound transmission resistance of this object by an index rating (instead of providing full sound absorption values).

Figure 4.6: Part of common property set for an *IfcDoor*, taken from [http://www.buildingsmart-tech.org/ifc/IFC2x3/TC1/html/psd/IfcSharedBldgElements/Pset\\_DoorCommon.xml](http://www.buildingsmart-tech.org/ifc/IFC2x3/TC1/html/psd/IfcSharedBldgElements/Pset_DoorCommon.xml)

### 4.1.3 Geometry and data format encoding

Geometry of IFC is ISO 16739 [ISO, 2018b] standardised and physical elements can be modelled in four ways: Primitive instancing, Constructive Solid Geometry (CSG) and Boolean Operations, Sweep volumes and Boundary representation (B-rep). Primitive instancing represents an object based on a set number of predefined parameters. IFC defines forms of 2D profiles together with volumetric objects (spheres, cones, pyramids). CSG objects are represented as a tree of Boolean set operations (union, intersection, and difference) of volumetric objects. Sweep volumes are solids defined by a 2D profile along which the surface is extruded. A B-rep is an object represented by its bounding surfaces (triangulated meshes, polygonal meshes, topological arrangements or free-form surfaces) [Arroyo Ogori et al., 2018].

Besides local geometry of elements, IFC also has possibilities for geo-referencing. The *IfcSite* class allows for storage of the coordinates of a IFC file (*RefLatitude*, *RefLongitude*) in the WGS84 (EPSG:4326) CRS. The *RefElevation* attribute can be used for the local height. In the Netherlands the local projection is EPSG:28992. When coordinates in this CRS are the source data of surveys, they will have to be reprojected to WGS 84 to put them in the IFC. The height datum can be stored in the *RefElevation* attribute of the *IfcSite* class, the local height datum in the Netherlands is the Nieuw Amsterdams Peil (Amsterdam Ordnance Datum) (NAP) and can be put directly in the IFC. More information about georeferencing IFC files in the proof of concept can be read in Section 6.3.1.

The ISO 10303 standard [ISO, 2014] prescribes the encoding of IFC files, which is in Standard for the Exchange of Product model data (STEP) format, modelled in the EXPRESS language and have a .ifc extension. EXPRESS is a language designed specifically to represent aspects of product data through schemas and constraints; it is not a programming language, although it was influenced by several programming languages. ISO 10303-11 states, "A schema written in EXPRESS describes a set of conditions which establishes a domain. Instances can be evaluated to determine if they are in the domain." [ISO, 2014]. A set of constraints expressible in EXPRESS allows comparisons incorporating many of the mathematical and logical operations included in programming languages and also supports the use of procedures and programmed functions as part of the constraint expression and hence in the evaluation process [Sustainability of Digital Formats, 2017]. See Figure 4.7 for an example of a part of an .ifc file in STEP encoding.



Figure 4.7: STEP Encoding of .ifc file, a # starts every line followed by the entity definition. The = names the entity. The parameters (between brackets) are (among others) empty (\$), a number, a list, a string, or the ID of other entities [Arroyo Ogori et al., 2018]. Image taken from [https://blog.areo.io/content/images/2016/01/IFC\\_file\\_contents-1.png](https://blog.areo.io/content/images/2016/01/IFC_file_contents-1.png)

## 4.2 CURRENT USAGE

This section describes how the IFC is currently used in practice in the Netherlands. Table 4.1 shows an overview of the documents in which current practices are described, they stem from a variety of authors, such as the Dutch national government, private companies and the Dutch BIM Gateway (BIM Locket).

Institution	Document
National BIM Gateway (BIM Locket)	Information Delivery Manual [BIM Locket, 2018]
	Information Delivery Manual Support Document [BIM Locket, 2016b]
	National BIM Protocol [Bouw Informatie Raad, BIM Locket, 2016]
Private Companies	Dura Vermeer: Dura Vermeer kiest voor open standaarden [Dura Vermeer, 2015]
	Root BV: IFC usage and export articles [Terpstra, 2017; Groenewoud, 2018; Terpstra, 2018]
Governmental Agencies	Central Government Real Estate Agency: BIM Norm V1.1 [Rijksvastgoedbedrijf, 2013]
	Kadaster: BIM verzamelen, verbinden en visualiseren voor vergunningverlening [Greefhorst et al., 2018]

Table 4.1: IFC usage documents sorted by institution to show societal context.

The BIM Gateway is a Dutch standardisation platform for BIM and aims to promote the use of Open BIM standards because *“they are key to a country-wide, full implementation of BIM in the Dutch Construction industry”* - [BIM Locket, 2016a]. With over 370 (notable) members of the construction industry and involvement of other standardisation organisations, it is a key actor in IFC usage in the Netherlands. The BIM gateway has developed the “BIM Basic IDM” [BIM Locket, 2018, 2016b] as a way to achieve the exchange of structured and unambiguous information in the whole life cycle of the built environment. The document prescribes the correct use of IFC, such as using the correct entities, naming conventions and modelling rules. The most important rules of the BIM Basic IDM are summarized in Table 4.2, the authentic document can be found in Appendix G. The BIM Gateway is also involved in the National BIM Protocol, a standardised agreement between parties for contracts on the delivery of BIMs, part of this protocol is the agreement on a specified IDM. An example of the use of the BIM Basic IDM is the use of the spatial structure of IFC as described in Section 4.1.1.

Rule	Relevance
3.4: Correct use of entities	For identifying legal space, it is important to have correct a consistent use of entities in the BIM
3.5: Structure and naming	Legal space has to be defined, this is only possible when there is an existing standardised structure of the BIM
3.8: Duplicates and intersections	Legal space cannot overlap or be duplicate
4.2: Is external	Helps identifying potential legal space to be inside or outside the bulding

Table 4.2: Most relevant rules of the BIM Basic IDM [BIM Locket, 2018] in the context of adding legal space to the IFC

The RVB published the “RVB BIM Norm” [Rijksvastgoedbedrijf, 2013], which is similar to the BIM Basic IDM, but far more extensive and detailed. Construction companies that build for the RVB have to deliver their BIMs according to the specifications set in this document. The contents of these two documents coincide in terms of IFC usage with the BIM Basic IDM. Private companies describe in publicly available documents how they operate according to the rules set by the RVB and the BIM Gateway [Dura Vermeer, 2015; Terpstra, 2017; Groenewoud, 2018; Terpstra, 2018].

The Dutch cadastre published about the use of IFC BIM for building permit checking and approval [Greefhorst et al., 2018]. The aim of the research was to see how IFC data can be used in the reviewing process of permits in relation to the “bouwbesluit” (Dutch Building Decree), and the potential sharing of geometry. One



of the conclusions is that the formerly described BIM Basic IDM should be officially standardised for creating an IFC BIM. However, Greefhorst et al. [2018], together with Arroyo Ohori et al. [2018] and Diakit  and Zlatanova [2016] ascertain that many IFCs in practice are not created in the same way, nor do they conform to any guidelines. Especially geo-referencing is an aspect prone to be left out, or filled in incorrect.

It can be concluded that in the Netherlands clear and well-documented guidelines are present for the usage of IFC. These guidelines are important since they are promoted or required by either standardisation organisations or the Dutch national government and help the building industry in exchanging information. Therefore it is decided that the designed solution of enriching IFC with legal spaces should fit the current guidelines.



# 5 | LEGAL CONTEXT

This chapter describes the legal context of apartment rights in the Netherlands as the scope of this research is the relation between IFC BIM and the registration of apartment rights. Research is conducted on what apartment rights are and how they are established to form requirements for a 3D representation derived from an IFC BIM to register apartment rights. Throughout this chapter, requirements are formed by researching various parts of Dutch law.

Section 5.1 is a summary of Dutch law, specifically the parts where apartment rights are described. In Section 5.2 geometry representation requirements are formed based on the current Dutch law. Section 5.3 continues with the cadastral requirements for the 2D drawing used in the current process of registration. This chapter ends with some practical requirements for the geometry representation of apartment rights. In Appendix D all requirements for a 3D registration of apartment rights are summed up to create an overview of requirements.

## 5.1 APARTMENT RIGHTS IN THE DUTCH CIVIL CODE

The legal base of apartment rights in the Netherlands is described in the Dutch Civil Code, Book 5, Real Property Rights, Title 5.9 Apartment Rights, Section 5.9.1 General Provisions. The parts that are relevant for the registration of the apartment rights using a 3D cadastral map which will be derived from an IFC BIM are discussed and explained. The authentic (Dutch) text of the articles can be found in Appendix C.

Article 5:106 Paragraph 4 (Section C.1.1) describes what an apartment right precisely is. Summarized it states that an apartment right is a share in an asset that gives the exclusive right to use certain parts of the building as a separate private unit. Especially the (in English translated) sentence "...the exclusive right to use certain parts of the building, which parts are to be used, according to their functional arrangement, as a separate private unit..." is important, because it states that, what can be seen as a separate private unit, is derived from its functional arrangement. This could be for example a room which is enclosed by walls; by the functional, arrangement it is clear the room can be seen as a private unit. However, the private unit does not necessarily have to be a residential apartment (condominium) in a building complex, it could also be an office, entire house, a section of water (in a marina) or a piece of land without a building [Bartels and Velten, 2017]. An apartment right itself can be sub split in two or more apartment rights.

Before requirements can be formed about the registration in 3D, the current requirements of registering apartment rights in 2D are reviewed. An apartment right is established with a notarial deed. This is a formal requirement, embedded in the law in Article 5:109 (Section C.1.3). To split a building up in apartments, this notarial deed is called a 'splitsingsakte' (splitting deed). A notarial deed to establish apartment rights (after this just called the notarial deed) consists of a written part in which, among other things, a written description of the parts of a building on which the apartment right is formed. This written part can refer to a drawing that is attached to the deed. The drawing is a crucial part to visualize the ownership situation of a building when apartment rights are registered, an example of this drawing can be seen in Figure 5.1. The drawing has certain requirements which can be found

in Article 3:16, paragraph 2, of the Dutch Civil Code and the [Uitvoeringsregeling Kadasterwet 1994 \[2017\]](#). One of these requirements is that the drawing is to be delivered in a 2D format. By reviewing the requirements for this 2D drawing, together with other parts of the Dutch Civil Code concerning apartment rights, general requirements for a 3D representation are formed. This 3D representation will later in this research be derived from an IFC BIM after it has been enriched with legal space.

## 5.2 DRAWING REQUIREMENTS

In Article 5:106 Paragraph 4 ([Section C.1.1](#)), the first requirement for cadastral registration of apartment rights in 3D can be found. It states that it should be clear that according to the functional arrangement, a space can be considered to be an area meant for private usage. Therefore the first requirement is stated as:

*It should be clear a part of the building is meant for private usage.* (1)

The next article relevant for registration in 3D is Article 5:108, Paragraph 1 ([Section C.1.2](#)). It states that owners have the duty to preserve the construction and functional arrangement of the building. This implies that, even though an owner has exclusive access rights to a certain part of the building, the owner may not alter the space in such a way it affects the structural integrity of the building. This is relevant for the requirements of the drawing concerning the modelling of the boundaries between apartments, i.e. the walls. If in the 3D representation the walls are drawn, they should not necessarily belong to one specific apartment owner. But this would only be the case when there is a physical boundary present. Apartment rights can also be established on parcels of land and water, which are not necessarily split up by physical boundaries.

However, the boundaries between apartments should be 'indicated' according to Article 5:109 Paragraph 2 ([Section C.1.3](#)). Therefore, the conclusion is drawn that, even though the boundaries have to be indicated, their main purpose is to show which areas are meant for private usage, and do not describe the nature of the boundary. This can also be seen in [Figure 5.1](#), where the boundaries between apartment units are drawn as thick lines. [Figure 5.1](#) is a valid 2D drawing which is attached to a notarial deed to register apartment rights. Besides Article 5:109 Paragraph 2 and the current requirements of drawing a boundary in a 2D drawing with a thick line, the conclusion that the main purpose of the boundaries is to show the difference in access rights to the private areas and shared spaces, the nature of the boundaries itself are arranged in the Internal Arrangements (IA) that are part of the notarial deed.

The IA are a part of the notarial deed containing several RRRs of the apartment owners. They are a mandatory part of establishing apartment rights (Article 5:111, [Section C.1.4](#)) and contain regulations about "the use, management and maintenance of the individual parts which are intended to be used exclusively by the apartment owners as their own separate private units" - Article 5:111 ([Section C.1.5](#)). In practice, the Modelreglement (Model Internal Arrangements) (MIA) [[Koninklijke Notariële Beroepsorganisatie, 2017](#)] are mostly used and adapted for local circumstances [[Bartels and Velten, 2017](#)]. The MIA is drafted by the Koninklijke Notariële Beroepsorganisatie (Royal Dutch Association of Civil-law Notaries) (KNB)<sup>1</sup> and serves as a 'model' for these regulations, suitable for most cases of establishing apartment rights. Sometimes, only the parts where the deed deviates from the MIA are written down in the deed, referring to the MIA for the regulations.

<sup>1</sup> The main task of the KNB is to ensure the observance of good standards of professional practice by notaries and junior notaries in the Netherlands and to promote their professionalism. Furthermore the KNB is engaged in several (policy) issues. [[Koninklijke Notariële Beroepsorganisatie, 2019](#)]

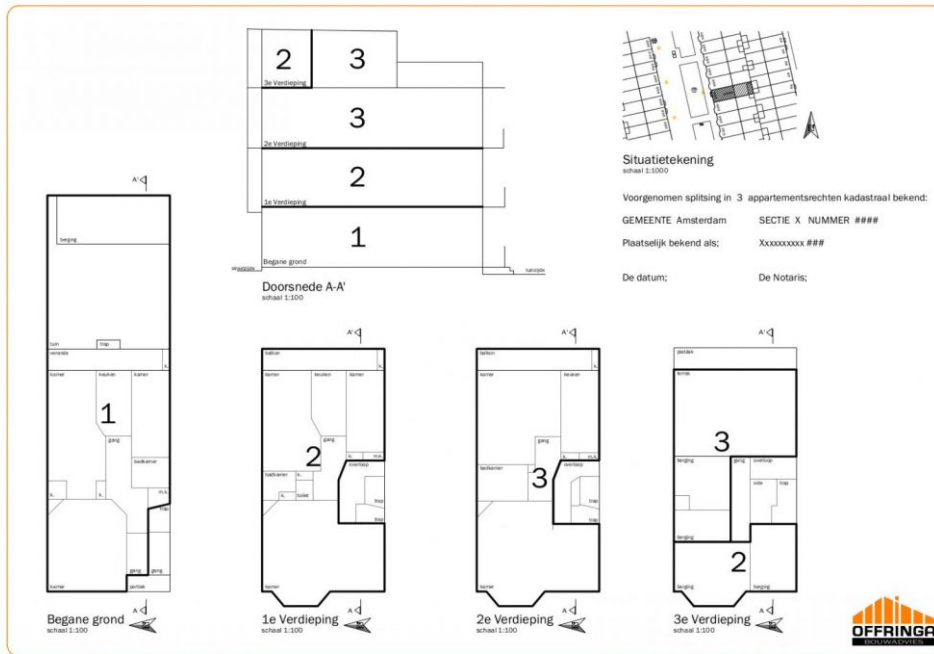


Figure 5.1: Example of 2D drawing in notarial deed, retrieved from <https://offringa-bm.nl/splitsingstekening/>. It can be seen that boundaries are drawn as thick lines, and have the purpose of showing the different private areas, rather than demarcating the ownership situation of the bounding element (the wall) itself.

Therefore, the IA do not only form an important aspect of the registration of apartment rights, they also have an impact on the way the 3D drawing is used to represent apartment rights in a BIM. The 2D drawing is not the only source for the ownership situation, and therefore the 3D drawing should not be either. Instead, the 3D drawing should fulfill the same purpose as the 2D drawing, which is visualising the areas that are meant for private usage. Therefore, the second requirement can be formed:

*Distinction between private and shared parts of the building has to be visible.* (2)

Article 5.111 (Section C.1.4) is further examined for requirements for a 3D representation and is due to its importance put in its entirety the text down below. It is a translation of the Dutch Civil Code taken from Goossens [2014].

*The notarial deed by which the apartment rights are established must contain:*

- (a) *a description of the place where the building and related land is located;*
- (b) *a precise description of the parts of the building and related land that are to be used as separate private units, which may occur by referring to the drawing meant in Article 5:109, paragraph 2, and an allocation of these parts to the individual apartment rights (making it clear that a specific apartment right encloses the exclusive right to use that part as private unit);*
- (c) *the cadastral number and description of the different apartment rights, with an indication of the apartment owner of each individual apartment right;*
- (d) *the internal arrangements applying to the apartment owners, that have to entail the provisions of a precisely defined standard regulation which is registered in the public registers at the place where the notarial deed itself must be registered.*

Item (a) demands a textual description in the notarial deed about the location of the building. This can also be visualised in 3D by having the cadastral parcel number present. This forms the third requirement:

*The cadastral parcel number on which the apartment is registered is present in the 3D representation* (3)

It should be noted this requirement is a simplification of the reality for establishing apartment rights. An apartment right can only be registered when a 'Complex identifier' or complex number (Complexaanduiding) is present. This complex number shows the relation between the cadastral parcel and the apartment rights established on this parcel. The complex identifier is usually made up of the cadastral parcel number followed by the capital 'A' [Kadaster, 2019b]. In practice an apartment complex can be built on multiple cadastral land parcels. This is a simplified explanation of the creation of a complex number by the cadastre, but it is sufficient in the context of this thesis. The goal is to have the ability to register the complex number.

The requirement described in item (b) demands that the spaces in the drawing can be identified according to the apartment right to which they belong to as described in the notarial deed. For the 3D representation this requirement is formed as:

*The spaces which enclose the exclusive right to use as private unit should be identifiable as such and relatable to the contents of the notarial deed* (4)

The requirement of item (c) can only be partially used, the names of the apartment owners are left out. The registration of apartment owners' names in a BIM, although technically possible, lies outside of the scope of this research (see Section 1.4). An IFC BIM will be enriched with legal space making it possible to register apartment rights, the IFC BIM itself will not be the system in which all cadastral information concerning apartment rights is stored, as suggested by Atazadeh et al. [2016]. Therefore, only the apartment numbers will be a requirement for registration in 3D. These numbers are the apartment index numbers, which indicate the individual apartment units in a building (i.e. apartment 1, apartment 2 etc.), this forms the fifth requirement for a 3D drawing.

*The cadastral apartment index number should be present in all spaces which belong to an individual apartment* (5)

Item (d) of Article 5.111 is a source for Requirement 2 and does not lead to the next requirement, but emphasizes again the importance of the IA as described previously in this section. The written description of the apartment in the notarial deed, together with the IA and the drawing all have equal importance in the determination of the ownership situation of an apartment. This has been displayed in several instances of case law regarding disputes of ownership situations. Especially a particular case of apartment complex 'The Prinsenwerf' in Amsterdam<sup>2</sup>. In this court case, the dispute focused on the fact that the written description of the deed differs from the ownership situation drawn on the drawing. Even though the drawing displays certain areas as private, the supreme court stated it is shared space due to the intentions underlying to the splitting of the building in multiple apartment rights. For the court to determine what these intentions were, many documents have been reviewed. Among which, the architectural designs. This adds to the relevance of this research: the architect could already have designated parts of the BIM as shared spaces, therefore ruling out indistinctness of the usage of spaces. This leads to

<sup>2</sup> HR 1 november 2013, NJ 2013/522 (VvE De Prinsenwerf Amsterdam)

the sixth requirement for a 3D representation and shows the role of the drawing in relation to the notarial deed and written contents.

*The 3D representation should visualise the private and shared spaces as described  
in the notarial deed* (6)

Two other cases are also the basis for requirements for a 3D representation. In The Hague a case came to court<sup>3</sup> which clarifies more about the term private space. In this case, it was under dispute if an apartment owner should pay for the maintenance of the construction parts of his balcony, which was demanded by the owner association<sup>4</sup>. The drawing in the splitting deed showed the balcony is marked as a private area, belonging to the apartment right of the aforementioned owner. The judge ruled that, even though the balcony is meant for private usage and the owner has exclusive access to it, the maintenance has to be paid for by the owners association because the construction of the balcony belongs to the entire building. It is stated that a private area can contain shared elements (in this case load-bearing construction elements and such).

This case is described to show that the terms private space and shared space are not 'black and white' terms in case of ownership, especially when visualising it on a drawing in a notarial deed. Therefore, the seventh requirement can be formed to state that a 3D representation does not change the legal status or meaning of the private spaces as meant in Article 5.111 (Section C.1.1).

*A private area in the 2D drawing has the same meaning and legal values  
as in the 3D representation* (7)

To illustrate what happens if in the drawing an area is not clearly demarcated as a private area, a case from The Hague is described<sup>5</sup>. The owner's association took a case to court because the drawing did not clearly demarcate an area as private space (a parking space), but an apartment owner rented this parking space out to a third party. Neither the drawing displayed this space to be private nor was it described in the notarial deed. The judge looked at Article 5.108 Section 1 (Section C.1.2) and determined that a precise description of the areas meant to be used as separate private area had to be present; therefore the situation as described in the notarial deed had to be maintained. Therefore, it was concluded that if a space is not described or drawn for private usage (private space), it can be considered to be shared space. This is a requirement that is also applicable to the 3D representation:

*If a space in the 3D representation is not marked as private, it becomes  
shared space by default* (8)

To conclude this section on the intents of the notarial deed in relation to the visualisation of apartment rights; the most important purpose of the drawing is to visualise the private and shared spaces. Hence this should also be a requirement for 3D visualisation of apartment rights in a BIM. In the next section, more requirements are formed for the 3D representation based on the requirements the Dutch cadastre currently enforces on the 2D drawing in a notarial deed.

<sup>3</sup> Rb. 's-Gravenhage, ECLI:NL:RBSGR:2010:BO2741

<sup>4</sup> All apartment owners are obliged to be members of the official Owners' Association. The objective of this special association is to take care of the joint interests of the owners. Therefore the Owners' Association is obliged to maintain a reserve fund to cover costs other than the usual annual costs, such as the costs of (major) maintenance. [Asselberg & Klinkhamer Advocaten, 2019]

<sup>5</sup> Rb. 's-Gravenhage 28 augustus 2002, NJkort 2002/65

### 5.3 CADASTRAL REQUIREMENTS

Besides the requirements for the drawing in the notarial deed that are described in the Dutch Civil Code book, additional requirements for the drawing are present on the website of the Kadaster [2014]. These requirements are embedded in the *Uitvoeringsregeling Kadasterwet 1994* [2017] and this section forms requirements based on the current laws for 2D drawings. The original requirement is first stated, followed by the implications or requirements for a 3D representation. The original text of the article can be found in [Appendix C Section C.2](#).

Article 6.1.b: *"The drawing contains floor plans of the ground floor and floors on which the spaces are located. If necessary, also cross sections and views of the building and also the ground belonging to the building complex";*. The 3D drawing will fulfill this requirement by visualising the entire building. This way, cross sections, floorplans and views can all be derived and visualised because of the nature of the 3D representation of the building. However, IFC BIMs do not usually contain the surrounding land in the model. Therefore, only the visualisation of the entire building in which the apartment right is established will be required for the 3D representation:

*The 3D representation visualises the entire building in which the apartments are located*  
(9)

Article 6.1.c: *"The drawing shows the differences of distinguishable floor plans of the building and the ground that are meant to be used as a separate complete unit. And the exclusive access and usage of the areas in the apartment right will be incorporated as well as the location of these areas in relation to the other areas of the building or ground;"*

This article states that the difference between individual apartments has to be visible, which is fulfilled by [Requirement 2](#) and [Requirement 4](#). It also states the complete building has to be visible in the drawing, which is set in [Requirement 9](#). However, to explicitly state that all private and shared areas of a building are visualised and also identifiable as such, the 10th requirement is formed:

*The location of the private and shared spaces in relation to the rest  
of the building should be visible*  
(10)

Article 6.1.d: *"In the drawing an index number as characteristic is visible for every separate area with arabic numbers;"*

This is fulfilled by [Requirement 5](#) by demanding an apartment index number has to be present in all spaces that belong to an individual apartment unit. This number should be in arabic numbers and can be realised by technical means in an IFC BIM, which can be found in [Chapter 4](#).

Article 6.1.e: *"In case a separate unit as such is built up from spaces that are not neighbouring each other or in the same horizontal plane, every space should have the same index number as identification of the unit identifier;"*

This leads to a new requirement which makes sure all spaces are visualized that are part of an apartment right, even if they are not connected to each other. Examples in practice could be parking spaces or storage areas in the basement of an apartment building. It also makes sure every space on which a specific apartment right is established is present in the drawing and has the same identifier (cadastral apartment index number). Therefore requirement 11 is formed as:



*The 3D representation should visualise all spaces belonging to a specific apartment right with the same cadastral apartment index number, even if they are not connected.* (11)

Article 6.1.f: *"The cadastral apartment index number, as meant in item 6.1.d and 6.1.e form a continuous ascending series of natural numbers,;"*

This does not lead primarily to an extra requirement as has been stated in [Requirement 5](#). It is rather the way this information is filled in by the user, instead of having the ability or space to fill in this information in the first place.

Article 6.1.h: *"The cadastral apartment index number is placed as much within the confines of the areas meant for private usage;"*

This is also fulfilled by [Requirement 5](#). The 3D representation will contain the index number, the way it is visualized is later determined in [Section 6.5](#)

Article 6.1.i: *"The scale of the drawing does not exceed 1:100 and is not smaller than 1:200;"*

Article 6.1.j: *"Every drawing that makes up the drawing contains the scale that is used"*

These laws are not directly applicable to a 3D representation, because these requirements are based on the usage of paper drawings. However, it will be translated into requirements about the accuracy and precision of the 3D representation that is derived from an [IFC BIM](#), this is discussed in chapter [Chapter 6](#) together with other technical requirements.

Article 6.1.k: *"The direction of the north should be present on all drawing that make up the drawing"*

This leads to a new requirement about the orientation of the 3D representation, which should be to the north, or the direction of the true north has to be known.

*The 3D representation needs to be oriented in relation to the true north* (12)

## 5.4 PRACTICAL CADASTRAL REQUIREMENTS

A 'Questions and Answers' document together with a 'Checklist for splitting apartments' document can be found on the website of the Kadaster [[Kadaster, 2014, 2019c](#)]. These documents are also used to form requirements for the 3D representation, besides the requirements that are embedded by law as described in the previous sections.

The 'Checklist' requires the true cadastral boundary of a parcel should coincide with the drawing. It also requires the presence of a 'situation plan' (situatieschets) on which the cadastral parcel on which the apartment right is established is visible (see the top right of [Figure 5.1](#)). Both of these points can be fulfilled by demanding the 3D representation is geo-referenced. That means the drawing contains information that makes it possible to link coordinates of the 3D representation to real-world coordinates. In a digital environment, the 3D representation can then be placed on top of a digital map of cadastral parcels. Because the building is also oriented correctly in relation to the north ([Requirement 12](#)), the 3D representation would be

placed correctly with other digital geographic information that are georeferenced correctly. Therefore the thirteenth requirement is formed:

*The 3D representation has to be geo-referenced* (13)

The 'Questions and Answers' document [Kadaster, 2019c] contains a question whether a house number (the numbers in the postal address) may be displayed on the drawing. The answer is that it is allowed as long as it does not interfere with the readability and usability of the drawing. Adding a house number to apartments would add more insight in the consultability of the 3D representation, and is therefore the fourteenth, but non-mandatory requirement:

*The spaces which enclose the exclusive right to use as private unit may contain the address' house number belonging to those spaces as long as this does not interfere with the usability of the 3D representation* (14)

In this chapter fourteen requirements are formed for a 3D representation that is part of a notarial deed to establish apartment rights. A listing of all the requirements can be found in [Appendix D](#) to give a quick overview. Based on these requirements, a solution is proposed in [Chapter 6](#) that translates the requirements to an IFC file.

# 6

## PROOF OF CONCEPT DEVELOPMENT

This chapter describes the development of the proof of concept in six steps, as described in [Chapter 1](#). In [Section 6.1](#) a solution is proposed to add legal space to the IFC data model. In [Section 6.2](#) the process to described to extract this legal space from an IFC BIM, which is later stored in a database that will be discussed in [Section 6.3](#). [Section 6.4](#) continues with the development of checks for the legal space. [Section 6.5](#) describes the visualisation of the legal space. This chapter ends with a brief discussion about changing the legal space, such as sub splitting an apartment in [Section 6.6](#).

### 6.1 BIM LEGAL CREATION

The first step in this proof of concept is the development of a model to enrich an IFC BIM with legal information according to the requirements formed in [Chapter 5](#). These requirements are formed in compliance with the current laws applicable to the process of registration of apartment rights (See [Appendix D](#) for a complete list of these requirements) and current guidelines for standardised BIM use in the Netherlands (see [Section 4.2](#)). [Section 6.1.3](#) describes what the formed requirements look like when they are applied to an IFC file.

#### 6.1.1 Cadastral Information in the IFC

The term ‘cadastral information’ in the context of this research is all information deemed necessary to retrieve a 3D geo-referenced representation from an IFC BIM which fulfils the legal requirements formed in [Chapter 5](#). This cadastral information is the cadastral parcel number, the cadastral index number, the space type and the house number (optional). An overview of the cadastral information and the requirements it is based on can be seen in [Table 6.1](#).

Cadastral Information added to <i>IfcSpace</i>	Fulfilled Requirement
Is the area in a building private or shared space	1, 10, 11
The cadastral parcel number to which the apartment right of the space is established	2
The cadastral apartment number of the private area	3, 4, 5, 6
The house number of the private are	14 (Optional)

**Table 6.1:** Cadastral Information derived from requirements formed in [Chapter 5](#) which have to be added to *IfcSpace* elements

Per apartment unit in an IFC, this information has to be present in order be able to identify a separate apartment unit on which apartment rights can be established in an IFC BIM. The design choice is made to add the cadastral information to an *IfcSpace* element because of four main reasons:

1. The *IfcSpace* element is part of the spatial structure<sup>1</sup> and logical hierarchy of a building project in IFC.
2. The information of volumes should be stored in *IfcSpace* elements according to the RVB Bim Norm V1.1 [[Rijksvastgoedbedrijf, 2013](#)].

<sup>1</sup> See [Section 4.1.1](#) for more information on the spatial structure of IFC

3. Academia [Oldfield et al., 2017; Atazadeh et al., 2018] suggest the *IfcSpace* element is suitable for registration of private property.
4. The buildingSMART *IfcSpace* official definition [buildingSMART, 2018] states the element represents an area or volume bounded by actual or theoretical boundaries, which fits in the dutch legal defintion of an area on which an apartment right van be established (Section 5.2).

An *IfcSpace* visually represents empty spaces (Figure 6.1) and the entity can carry several attributes, such as Name, ObjectType, Description, and LongName in order to enrich the space with semantics. See Figure 6.2 for the technical *IfcSpace* attributes as defined by the buildingSMART Consortium. However, these attributes are not suitable for the required cadastral information as defined in Table 6.1. The use of these *IfcSpace* attributes for storage of cadastral information would be in conflict with existing guidelines of IFC usage in the Netherlands. The Rijksvastgoedbedrijf [2013] on page 16 describes the usage of the *IfcSpace* element. The ObjectType and LongName attribute already have to be filled in according to a fixed choice list. Therefore, it is not an option to store cadastral information directly in the *IfcSpace* entity. A part of the RVB BIM Norm can be seen in Figure 6.3 regarding the guidelines for the usage of the *IfcSpace* element in the IFC. Appendix G gives a visual representation of how space usage in a IFC should look like according to the BIM Basic IDM (Groepering van Ruimten)[BIM Loket, 2016b].

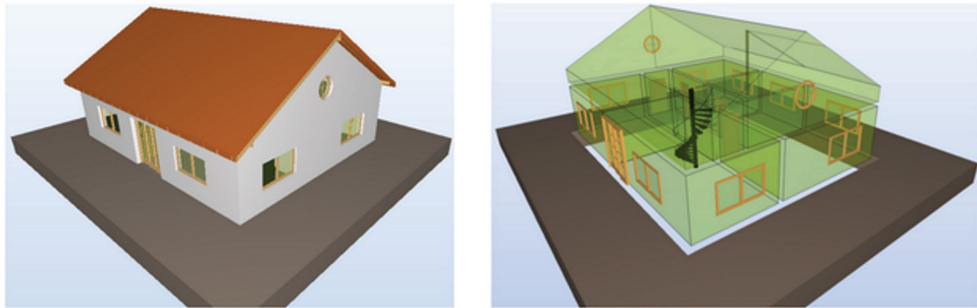


Figure 6.1: *IfcSpaces* in an IFC BIM of a house. Image taken from Diakit  and Zlatanova [2016]



Figure 6.2: *IfcSpace* inheritance graph, source: <http://www.buildingsmart-tech.org/ifc/IFC2x3/TC1/html/ifcproductextension/lexical/ifcspace.htm>, edited by the author.

- **IfcObject: IfcSpace**

**Attributes:**

- **Name:** <IFC object ID>
- **ObjectType:** space function type according to the current building regulations (*bouwbesluit*). Value from the fixed choice list in §4.1.1.  
*Example: verblijfsruimte*
- **LongName:** <space function name>. Free to choose string, but named according to the general requirements: see §2.1.3.  
*Example: kantoormuimte*
- **InteriorOrExteriorSpace:** [INTERNAL|EXTERNAL] according to the current building regulations.
- **BoundedBy: IfcRelSpaceBoundary:** The 2nd level *Space boundary* of the space has been generated.

Figure 6.3: *IfcSpace* usage according to RVB BIM Norm V1.1 article 2.2.7.6 [Rijksvastgoedbedrijf, 2013]

As said, cadastral information as defined in Table 6.1 cannot be stored in an *IfcSpace* entity. Therefore an extra set of attributes has to be added to the *IfcSpace* entity. This can be accomplished with so-called property sets (See Section 4.1.2 for more information about property sets.) However, there are no predefined lists with property sets (*Pset\_Common*) created by the IFC with cadastral information. Therefore, a user defined property set is created to add extra cadastral information to the *IfcSpace* entity. A user defined property Set is a custom set of attributes that can be linked to certain elements in the IFC model.

The approach of adding custom attributes to IFC elements is both used by academia [Atazadeh et al., 2016] and private companies [Dura Vermeer, 2015; Terpstra, 2017; Groenewoud, 2018; Terpstra, 2018] to fulfil the requirements as set in the BIM Basic IDM [BIM Loket, 2018, 2016b] and the RVB BIM Norm V1.1 [Rijksvastgoedbedrijf, 2013]. Moreover, adding customised attributes with user defined property sets is also integrated in the IFC standard [buildingSMART, 2019a] making this solution fully compatible with IFC compliant software.

A Cadastral Information user defined property set is created to enrich IFC files with legal space. The contents of it can be seen in Table 6.2. Besides the information derived from requirements stemming from 2D drawings, the complex number has been added. A simplified explanation of the complex number is that it consists of the cadastral parcel number followed by an 'A' (See Section 5.2). Also the *section* and *municipality* attributes are added to enable unique identification. These two attributes are also present on current 2D drawings, as can be seen in the upper right corner of Figure A.1 on page 27.

Attribute	Data type	IFC DataType
spacetype	string (from code list)	IfcLabel
complexnumber	string	IfcLabel
indexnumber	string	IfcLabel
houisnummer	string	IfcLabel
parcelnummer	string	IfcLabel
section	string	IfcLabel
municipality	string	IfcLabel

Table 6.2: Content of cadastral information user defined property Set for the IFC data format.

It should be noted that the BIM Basic IDM of the BIM gateway implicitly has partial cadastral information contained in it, such as address and apartment number, as can be seen in Figure 6.4. Other specifications in the BIM Basic IDM and the RVB BIM Norm completely fulfill requirements for the use of IFC to create a 3D representation for a notarial deed to establish apartment rights. Requirement 9 is fulfilled by the RVB BIM Norm V1.1 specification 2.2.7.6, which states that the building is fully filled by spaces.

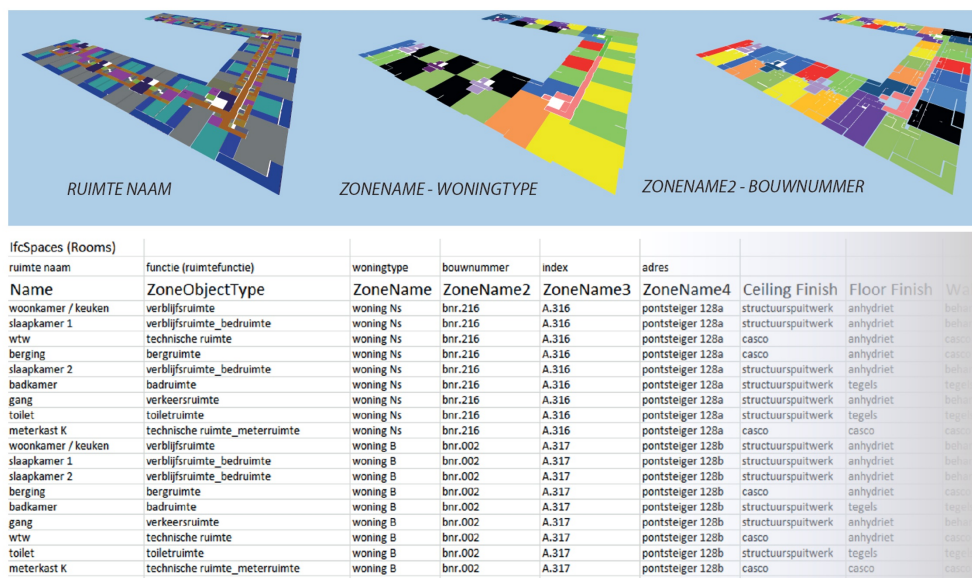


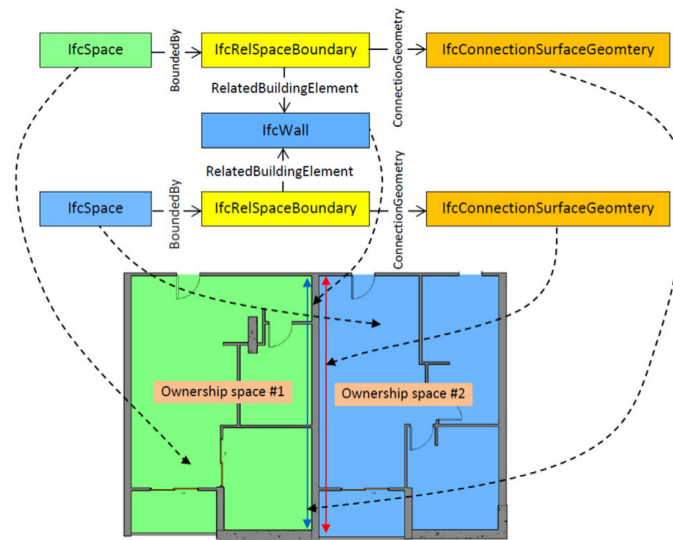
Figure 6.4: The BIM Basic IDM already has some cadastral information added to *IfcSpaces* such as 'adres' and 'index'. Image taken from the BIM Basic IDM support document BIM Loket [2016b] and is edited by the author.

Requirement 12 is fulfilled by the RVB BIM Norm V1.1 item 2.2.7.1, which states an *IfcProject* object needs the inclusion of the *TrueNorth* value as *RepresentationContext*. In other words: when this specification is fulfilled, the IFC is oriented correctly, as is stated in Requirement 12. A legal space can therefore be defined as follows: (1) Check the IFC BIM for the *IfcSpace* element, (2) if the *IfcSpace* element has the cadastral user defined property set, it is a legal space.

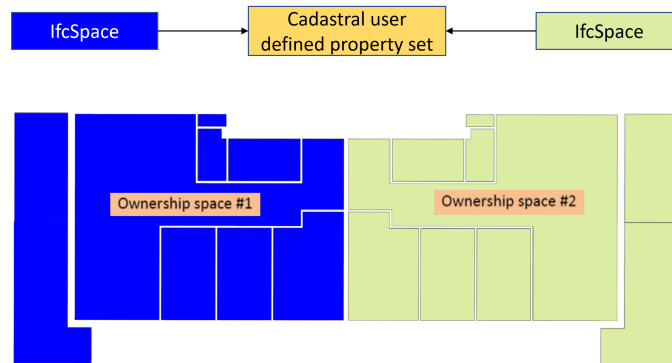
[Requirement 13](#) is fulfilled by article 2.2.7.2 in the RVB BIM Norm V1.1; where it states the *IfcSite* object needs to contain a correctly filled in *RefLatitude* and *RefLongitude* in WGS84, as well as a *RefElevation* in NAP. These three attributes together make sure an IFC is correctly geo-referenced. This also applies to the *IfcSpaces* containing additional cadastral information, which are placed absolutely in relation to this specified coordinate in the *IfcSite* Object.

Enriching *IfcSpaces* with cadastral information by a user defined property set had implications for the way boundaries, such as walls and floors, are modelled. Because only *IfcSpaces* are enriched with legal information, the boundary itself is not modelled. This might look like a limitation in the approach to model legal space, but fits fully in the legal context of apartment rights in the Dutch legal system. In [Chapter 5](#) it is concluded that the ownership situation of boundaries is not part of the 2D drawing in the current system. Therefore, when defining ownership of boundaries (such as walls) in the IFC, one would indirectly create laws. Something that lies beyond the scope of this research, because the proposed solution is designed according to the requirements of 2D drawings.

The boundary modelling does not fall in any boundary model according to [Atazadeh et al. \[2017\]](#). As described in [Section 2.2](#), they created a subdivision of boundaries which can be an interior structural boundary, exterior structural boundary, median structural boundary, projected boundary and fixed boundary. These boundaries are modelled with a topological relationship that can be present in the IFC. The proposed solution of enriching *IfcSpaces* with cadastral information does not make use of topological relationships. The closest model of [Atazadeh et al. \[2017\]](#) compared to the proposed solution is the 'interior structural boundary' model. The main difference again is the presence of topological relationships. Also, boundaries within an apartment are not modelled. A comparison of the 'interior structural boundary model' of [Atazadeh et al. \[2017\]](#) and the boundary of the proposed solution can be seen in [Figure 6.5](#). There are two reasons why the boundaries in the proposed solution are not modelled topological. The first reason is that the way boundaries, such as walls and floors, in the context of apartment rights in the Netherlands are usually described by text in a notarial deed, rather than drawn in detail on the 2D drawing. Secondly, the extraction of legal space with topological properties would take additional research which was not feasible in the period of writing this thesis.



(a) 'Interior structural boundary' as defined by Atazadeh et al. [2017], image taken from [Atazadeh et al., 2017].



(b) Boundaries in the proposed solution, the relationship between the *IfcSpace* and *cadastral user defined property set* in the IFC is simplified.

Figure 6.5: Floor plans of apartment units to illustrate difference of boundary modelling between Atazadeh et al. [2017] (a) and the proposed solution (b)

Even though the boundary modelling in the designed solution does not fit in existing suggestions of IFC usage for cadastral purposes, it is fit to model ownership situations of boundaries for apartment rights in the Dutch legal system. But the cadastral information user defined property set can also be applied to other IFC elements than *IfcSpaces*, such as walls or doors. This is further explained and visualized in the next section in which the designed solution is applied to an IFC BIM.

To put the designed solution into practice in the Netherlands, it should become part of the BIM Basic IDM. To show what this could look like, a concept of legal space being part of the BIM Basic IDM can be seen in Figure 6.6. The original full BIM Basic IDM can be seen in Appendix G. At the time of writing (June, 2019) a new Basic IDM is under development. In this new IDM, according to a BIM modelling specialist (Menno Mekes), there are ideas to add the usage of *IfcSpaces* to the new IDM. However, cadastral information will most likely not be part of this since the BIM basic IDM has to remain more basic for the time being. The first step is to add *IfcSpaces* to the IDM (something which is already present in the RVB BIM Norm V1.1 [Rijksvastgoedbedrijf, 2013]).



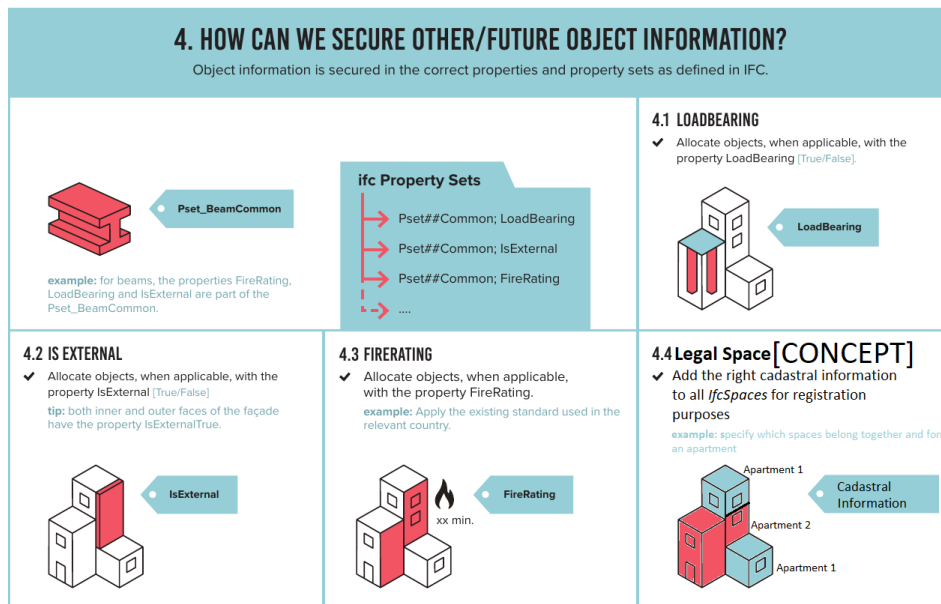


Figure 6.6: The BIM Basic IDM added with cadastral Information user defined property set as concept. Image taken from BIM Loket [2018] and item 4.4 is adapted by the Author. The full and original BIM Basic IDM can be seen in Appendix G

### 6.1.2 Alternative solution

An alternative of using only the *IfcSpace* object is the combination of *IfcSpaces* and *IfcZones*. The *IfcZone* groups *IfcSpaces* together. This has also been described by Atazadeh et al. [2017] and Oldfield et al. [2017]. It is chosen to only work with the *IfcSpace* object for practical reasons. Extracting a legal space which is grouped by an *IfcZone* posed several problems in the extraction process. Also, the BIM editing software (Revit) did not allow for the conversion of IFC files with user defined property sets for *Ifczones*.

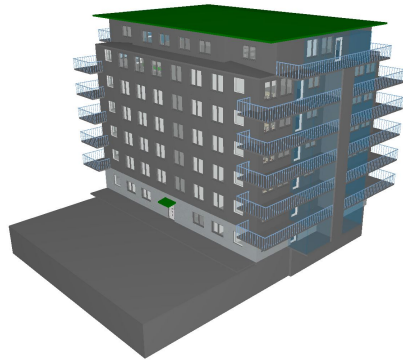
Using *IfcZones* would pose the benefit of grouping *IfcSpaces* in zones in both the BIM and the extracted legal space. Also, mapping to the LADM would be easier, as will be described in Section 6.3. However, the absence of the *IfcZone* in the designed solution did not impair the main goal of this research: using IFC BIM for registration of apartment rights. The usage of *IfcZones* for the registration of apartment rights is set to be part of future work, also described in Section 8.5.

### 6.1.3 Example

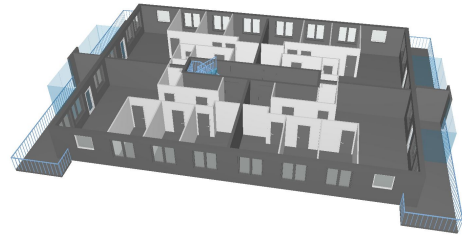
A BIM of an apartment building is enriched with the cadastral user defined property set as has been formed in the previous section to communicate the proposed solution better to the reader. This model is a publicly available<sup>2</sup> Revit [Autodesk, 2019] project format (.rvt) (See also Section 3.1). The file has been enriched with cadastral information in Revit as well, and then was exported to the IFC format. Solibri Model Viewer [Solibri, 2019] is used to visualise the legal space enriched IFC. Solibri Model Viewer does not have the option to visualize *IfcSpaces* based on the values stored in the attributes of the user defined property sets. Therefore, the grouping is visualised with QGIS [QGIS, 2019] in Figure 6.7d. The background of this visualisation is thoroughly explained in Section 6.5.

The design approach of enriching an element in IFC with user defined property sets is also extensible to other legal systems. The scope of this research is enriching

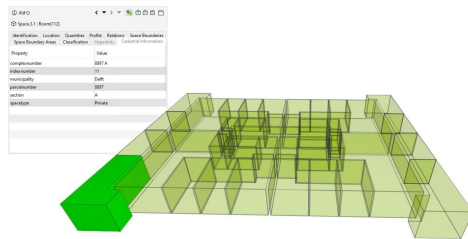
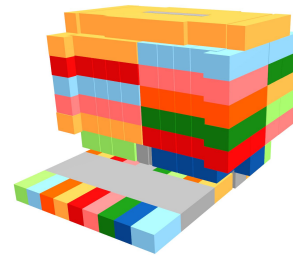
<sup>2</sup> <https://www.bimobject.com/en-us/bimobjectmodels/product/revit-apartment-building>



(a) Overview of apartment building BIM



(b) Level 3 of the building sliced out

(c) The *IfcSpaces* enriched with cadastral user defined Property Set(d) *IfcSpaces* enriched with legal information visualised according to index number of the apartment right in the building complex. More information about the visualisation can be found in [Section 6.5](#).

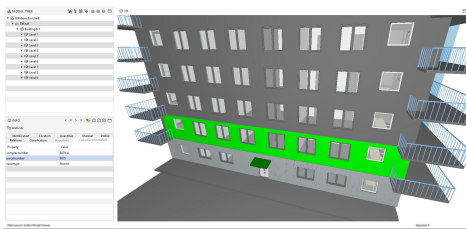
**Figure 6.7:** BIM enriched with legal space through a user defined property set visualised with Solibri Model Viewer [Solibri, 2019]. Figure (d) visualised with QGIS [QGIS, 2019].

an IFC with legal information such that a 3D representation can be created which can be part of a notarial deed to establish apartment rights. For this scope, it is not necessary to enrich other elements than *IfcSpaces* with legal information. However, enriching other elements is possible as can be seen in [Figure 6.8](#), in which walls and floors are enriched with cadastral information. This presents opportunities for other legal systems to enrich IFC BIMs with legal information fitting the local system, and also displays the extensibility of the proposed solution.

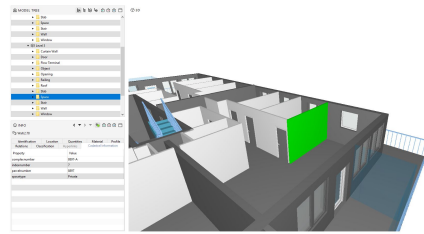
## 6.2 LEGAL SPACE EXTRACTION

This section describes the legal space extraction from an IFC BIM which is created according to the design in [Section 6.1](#). This section also describes how the cadastral information from a legal space enriched IFC BIM is mapped to the conceptual model of the LADM. In [Section 6.3](#) is described how the data is stored in a LADM compliant database, followed by [Section 6.3.1](#) that describes in more detail the geometry extraction and identification of the legal space. [Section 6.3.2](#) gives an overview of the created extraction workflow.

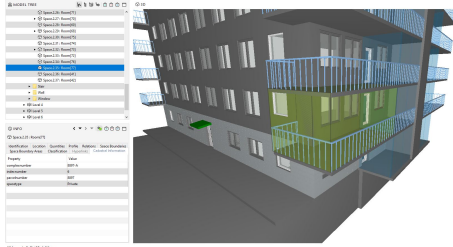
[ISO, 2018a] offers a conceptual framework of mapping BIM to GIS. This standard is still under development at the time of writing (May, 2019) and only offers the mapping at a conceptual level. Therefore, the mapping to the LADM is chosen in this research as a means to show how the proof of concept fits in international standards. However, ISO 19166 offers some guidelines that are used in the extraction process



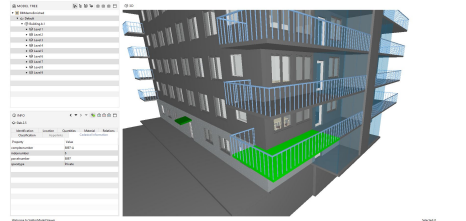
(a) Modelling an exterior wall as shared space



(b) Interior walls can be modeled as private property



(c) Balcony modeled with proposed solution



(d) Balcony structural part modeled as private property

**Figure 6.8:** Extensibility of the cadastral information user defined property set to other legal systems, where for example walls and floors can be given legal ownership information, which differs from the Dutch legal system

to act as a frame of reference in the design choices. An example of this is the geo-referencing and orientation of the extracted geometry. ISO 19166 refers to the buildingSMART standards as being appropriate to be used to geo-reference and orient geometry. This standard is applied to the extraction process as can be read in [Section 6.3.1](#). The second example of ISO 19166 conceptual mapping is the usage of unique identifiers for elements in the BIM. *IfcSpaces* contain such unique identifiers, and therefore these are extracted as can be read in the next section. Besides fitting the (under development) ISO standard, using the unique identifier for *IfcSpaces* has many other advantages, this will also become apparent in the next section.

As can be read in [Chapter 1](#), the LADM is a conceptual information model for land administration and is of great importance of placing developments of land administration systems into an international standardised context. Therefore, the information from the legal space enriched IFC BIM is mapped to the LADM conceptually, and then stored in a LADM compliant database. The LADM allows for multiple ways to represent the cadastral data for apartment rights extracted from enriched IFC BIMs. Two alternatives are presented to show how the data can be mapped.

The relevant cadastral data for this research is depicted in [Figure 6.9](#) in relation to the LADM, the figure shows an overview of all classes in the LADM, together with (in orange) the (cadastral) information which is extracted from the legal space enriched IFC BIM.

[Oldfield et al. \[2017\]](#) has researched the mapping IFC to the LADM, this research continues on the proposal which is defined by them. [Oldfield et al. \[2017\]](#)'s most important proposal related to this research is the mapping of the LA\_SpatialUnit class to the *IfcSpace* element, since in the designed solution the cadastral information is added to the *IfcSpace* element with a user defined property set.

### *LADM mapping Alternative 1*

The information contained in the cadastral information user defined property set is mapped to the LA\_Right subclass and the LA\_BAUnit Class. The LA\_Right class contains the type of right, in this research apartment rights. The LA\_BAUnit is a class that carries per apartment right numbers the spaces that belong to it. There-

IFC Entity Type	LADM
<i>IfcPropertySet</i> : apartment number	LA_Right, LA_BAUnit
<i>IfcPropertySet</i> : space type	LA_BAUnit
<i>IfcSpace</i> : <i>IfcGloballyUniqueId</i>	LA_LegalSpaceBuildingUnit, LA_BAUnit
<i>IfcSpace</i> : geometric representation	LA_LegalSpaceBuildingUnit

Table 6.3: Mapping extracted information of IFC BIM to LADM

fore, a particular *IfcSpace* instance enriched with legal information and viewed as *LA\_LegalSpaceBuildingUnit* can be seen as part of a Basic Administrative Unit. Several *LA\_LegalSpaceBuildingUnits* together then form an *LA\_BAUnit* with the associated apartment right, which is part of the *LA\_Right* class [Lemmen et al., 2015].

The geometry of the *IfcSpace* is mapped to the *LA\_LegalSpaceBuildingUnit* class. An *LA\_SpatialUnit* is a class that models a single area (or multiple areas) of land and/or water and can carry 3D geometry [Stoter et al., 2012]. An overview of this mapping can be seen in Table 6.3.

The identifier of an apartment might consist of the *complexnumber* and the *indexnumber*. The complex number is the cadastral parcel number added with an 'A'. An example can be found in Figure 6.10. *IfcSpaces* can be identified with the *IfcGloballyUniqueId* (IFC.GUID), a unique identifier assigned by IFC to every *IfcSpace*. One or more *IfcSpaces* together form an apartment on which an apartment right can be established. Thus, an apartment right number represents a group of spaces, and every space that is part of the apartment right has a unique identifier. The unique identifier per space is important for four main reasons:

1. When an apartment right is split into two or more apartment rights, the splitting can be conducted by only changing the information in the *LA\_BAUnits* and *LA\_Right* classes, whilst leaving the *LA\_LegalSpaceBuildingUnit* untouched, for they only carry the GUID and geometry of the space. In other words, the apartment right number refers to certain spaces (*LA\_LegalSpaceBuildingUnits*). Changing the contents of the apartment right can be carried out by referring to other *LA\_LegalSpaceBuildingUnits*, without changing data of the *LA\_LegalSpaceBuildingUnit* itself.
2. When the original IFC BIM is altered for e.g. building changes, all spaces belonging to a particular apartment right are known. The *IfcGUID* remains the same as in the IFC model, and therefore can be reused by an external information source, such as a LADM compliant database.
3. The shared space of buildings can potentially differ per apartment right. Such as a balcony shared by two neighbouring apartments, whilst they share the staircase with all apartments in the building. This situation fits within this mapping model because per apartment right number all shared spaces can be referred to by their GUID.
4. The ISO 19166 standard [ISO, 2018a], which is currently being developed, prescribes the maintaining of the unique identifier for mapping BIM data to a GIS environment.

The mapping of the cadastral information extracted from an IFC is shown a UML schema in Figure 6.11. This schema will later serve as storage schema for a LADM compliant database, which is further explained in the next section.

### LADM mapping Alternative 2

This alternative differs from *Alternative 1* in the way the *LA\_BAUnit* class is populated. One could argue a *LA\_BAUnit* should represent one logical unit, in the sense

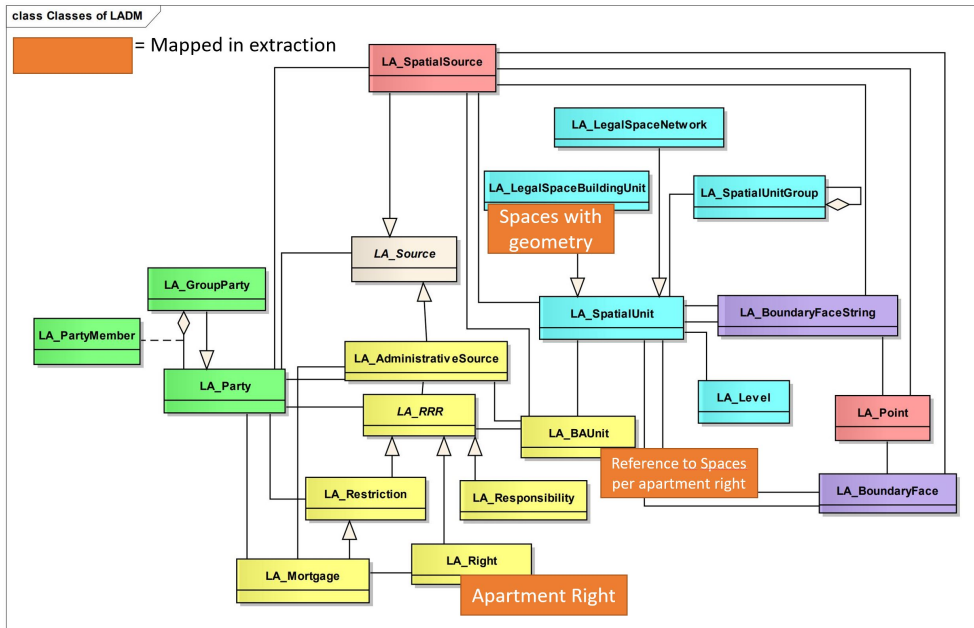


Figure 6.9: Mapping of legal space enriched BIM to LADM, image retrieved from Lemmen et al. [2015] and edited by the author

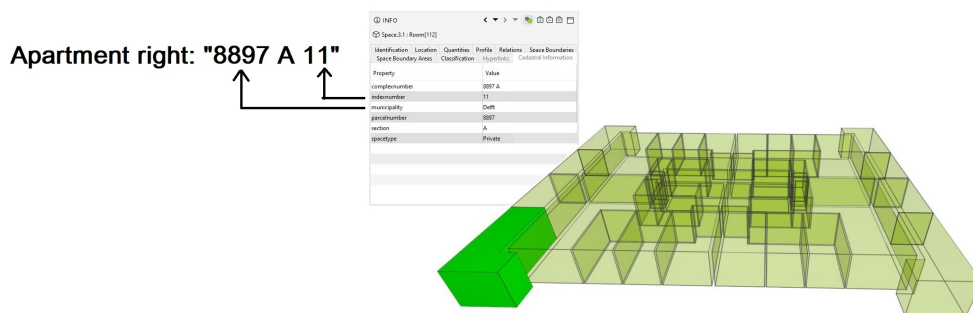


Figure 6.10: The apartment right number is a concatenation of the parcelnumber, "A" (for Apartment) and the indexnumber which are all present in the cadastral user defined property set for *IfcSpaces*.

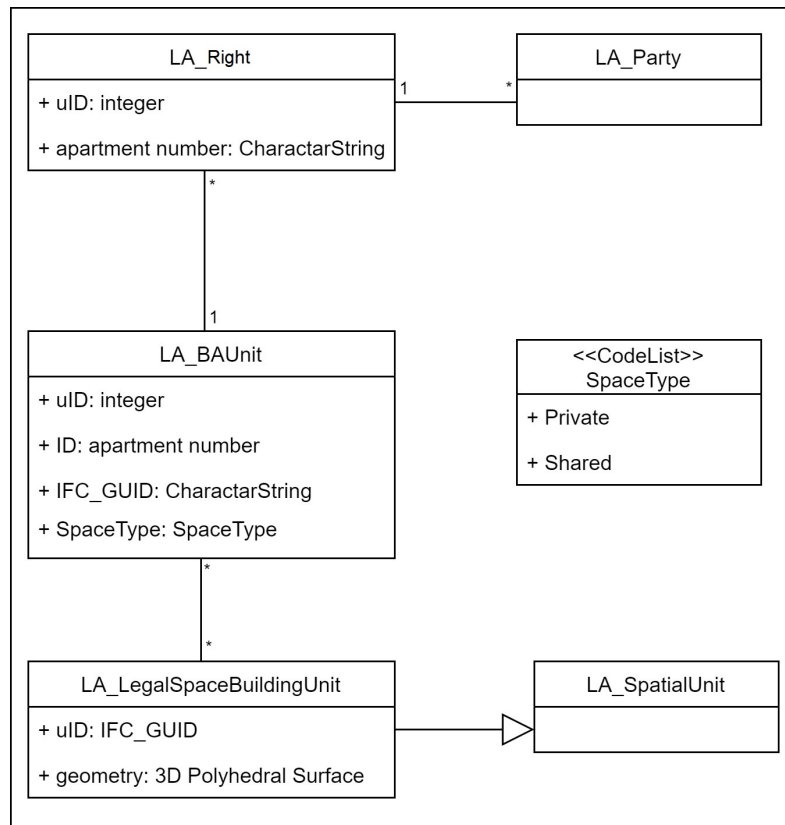


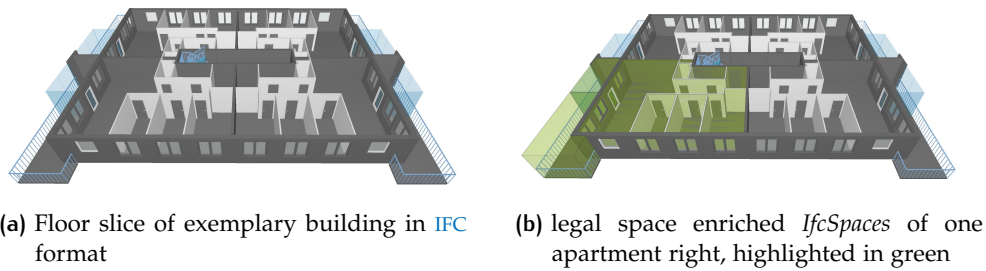
Figure 6.11: UML diagram of the legal space of apartment rights mapped to the LADM

that two neighbouring spaces that belong to each other (i.e. the same apartment right) should be modeled as one LA\_BAUnit, instead of two LA\_BAUnits that, besides the geometry, have the same administrative properties (i.e. same apartment number, same space type).

In this alternative, clusters of neighbouring spaces are modeled as single LA\_BAUnit. For example, an apartment in an apartment building consists of 10 rooms. All these rooms are modelled as individual LA\_BAUnits in *Alternative 1*. However, in this alternative the 10 rooms are modelled as one single LA\_BAUnit that refers to three LA\_LegalSpaceBuildingUnits. The geometry type of the LA\_LegalSpaceBuildingUnit would have to be changed to multi-volumes. The difference of alternatives according to this example is depicted in Figure 6.12.

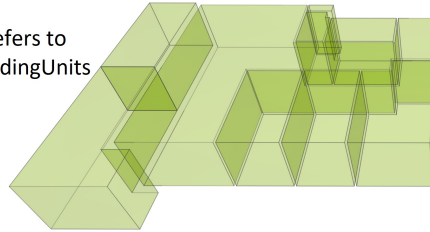
*Alternative 2* is not supported by the current design of the cadastral information user defined property set. As can be seen in Table 6.2, there is no specific attribute designed to designate the type of area, other than 'private' or 'shared'. To be able to cluster *IfcSpaces* automatically based on their logical use, such as 'storage unit', 'parking space' or 'living area', an extra attribute has to be introduced. The design approach of the cadastral user defined property set for the IFC data format is such that it has similar characteristics of the currently used 2D drawing in a notarial deed. These requirements do not contain a description of the usage of the room as an attribute, other than that a space is 'private' or 'shared'. This design choice is made to show that the registration of a 3D representation is not only technically feasible but also possible from a legal point of view.

It is chosen to continue with *Alternative 1* in this research because of the advantages of this mapping in relation to splitting apartment rights and the design of the cadastral user defined property set attributes. As discussed in Section 6.2, splitting apartments only requires the change of LA\_BAUnit class relations to LA\_LegalSpaceBuildingUnits. The act of splitting an apartment would impose more effort than *Alternative 1* because both the LA\_BAUnit and LA\_LegalSpaceBuildingUnits



LADM mapping alternative 1:

10 LA\_BAUnits that refers to  
10 LA\_LegalSpaceBuildingUnits



LADM mapping alternative 2:

1 LA\_BAUnit refers to  
10 LA\_LegalSpaceBuildingUnits

(c) Legal space visualised of one apartment right, in this case 10 *IfcSpaces*. In Alternative 1 every space is a LA\_BAUnit, in alternative 2 the 10 spaces are clustered to one LA\_BAUnit.

Figure 6.12: Two LADM mapping alternatives compared by using legal spaces of one apartment right as example.

need to be changed. Another problem would occur in the automatic clustering of *IfcSpaces* without adding extra attributes to the cadastral user defined property set. Even though the addition of attributes is technically possible, they would not be based on the current requirements of 2D drawings of apartment rights in notarial deeds (see [Appendix D](#) for a full list of requirements).

## 6.3 STORAGE

A storage schema is developed based on the mapping of the cadastral information extracted from an IFC BIM to the LADM. The storage schema is compliant to the 3D cadastre prototype developed by [Cemellini \[2018\]](#), where, among others, building volumes are registered. The extraction process, which is described in more detail in [Section 6.3.2](#), can be fitted in this prototype because the geometry in the IFC of the apartments is extracted to polyhedral surfaces and stored in a PostGIS database. The addition of the extraction of the legal space from an IFC file to the encoding of the 3D cadastre prototype proposed by [Cemellini \[2018\]](#) can be seen on a conceptual level in [Figure 6.13](#). The actual used database schema can be seen on [Figure H.3](#) in [Appendix H](#).

As can be seen in [Figure 6.13](#), QGIS [[QGIS, 2019](#)] is used to inspect the stored data visually, since using the actual Cesium JS web viewer is comprehensive and does not add significant value to this research; the main focus in this research lies on enriching the IFC with legal space in order to create a 3D representation that can be part of a notarial deed to establish apartment rights. However, this research serves as a proof of concept of using IFC data for cadastral registration that can be viewed in 3D. Therefore, the data is stored in a LADM compliant database to facilitate future research and proof that the enriched IFC BIMs can serve as a source of cadastral data, for example in the 3D cadastre prototype of [Cemellini \[2018\]](#). In the visualisation section of this chapter, the legal spaces are visualized on the Cesium JS platform to show the data can be visualised on this platform.

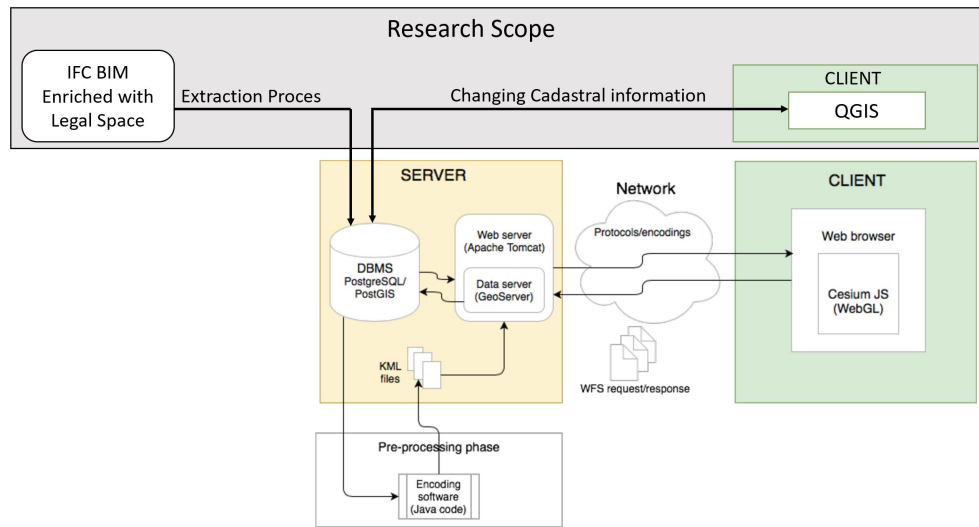


Figure 6.13: Scope of research addition to system architecture of 3D cadastre prototype of Cemellini [2018] and extended by the author (top grey part).

The conversion and encoding of the geometry is part of the research of this scope. Within the prototype of the aforementioned 3D cadastre prototype, this data falls under the 'building format spatial unit' section. In Cemellini [2018] this data either comes in the form of paper, .pdf or .tiff format. This research's proposal is to use IFC BIMs as source to submit data to the cadastral database (which later can be visualised) (Figure 6.14). More details about this process can be found in Section 6.3.2 and populated database tables can be seen in Figure 6.20.

### 6.3.1 IfcSpace geometry

Geometry of IFC is ISO 16739 [ISO, 2018b] standardised and physical elements in the IFC can be modelled in four ways: Primitive instancing, CSG and Boolean Operations, Sweep volumes and B-rep. Most IfcSpaces are modelled as B-rep [Diakit  and Zlatanova, 2016], and therefore only this type of geometry is used in the created automatic workflow to extract IfcSpace geometry.

With FME [Safe Software, 2019] the B-rep geometry of IfcSpaces are converted to polyhedral surfaces. The polyhedral surfaces have faces, which can be mapped to the LA.BoundaryFace class and serve as format for 3D geometry in the LA.LegalSpaceBuildingUnit class (A specialisation of the LA.SpatialUnit class) in the LADM [Thompson et al., 2016]. A simplified storage schema of this concept can be seen in Figure 6.15.

The polyhedral surfaces are geo-referenced by utilising the IfcSite element in IFC. Each IfcSpace is placed locally in the IFC, which means the position relative to the origin of the local coordinate system in the IFC is known. The origin of the local coordinate system of the BIM can then refer to a coordinate in WGS 84. This way, an IfcSpace can be georeferenced through a known point in the BIM, see Figure 6.17 for a visual representation of this concept.

The scope of this research is creating a 3D representation for apartment rights in the Netherlands, therefore in the extraction process WGS84 coordinates are translated to the EPSG:28992. According to the assumption that an IFC BIM is geo-referenced correctly<sup>3</sup>, the Z coordinate (the height) of the BIM is in NAP (Dutch local height). In this research, it is chosen to set the height of the bottom IFC extract to 0 in WGS 84. This is chosen because the visualisation of the apartment rights can then be placed on top of the cadastral parcel map. The Dutch cadastral map does

<sup>3</sup> Correct geo-referencing is a mandatory requirement for an IFC file before it can be enriched with legal space, see RVB BIM Norm V1.1 Article 2.2.7.2 and Section 6.1.1



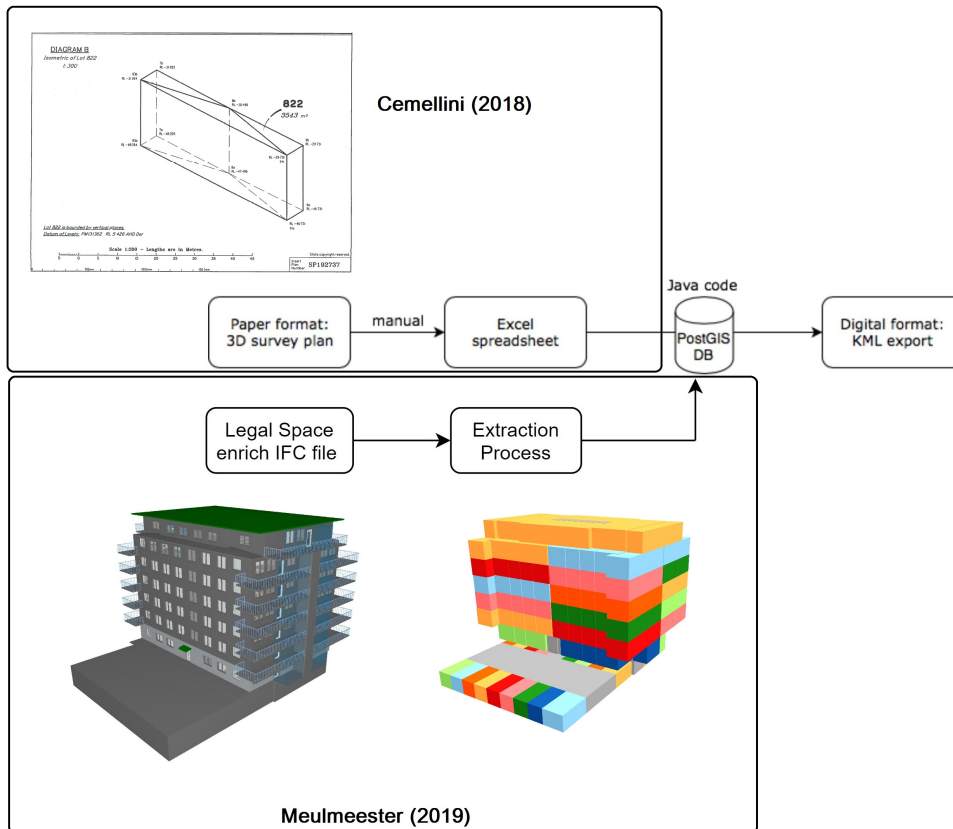


Figure 6.14: Diagram showing the encoding process of legal space enriched IFC files in a 3D Cadastre prototype proposed by Cemellini [2018], image taken from Cemellini [2018] and extended by the author.

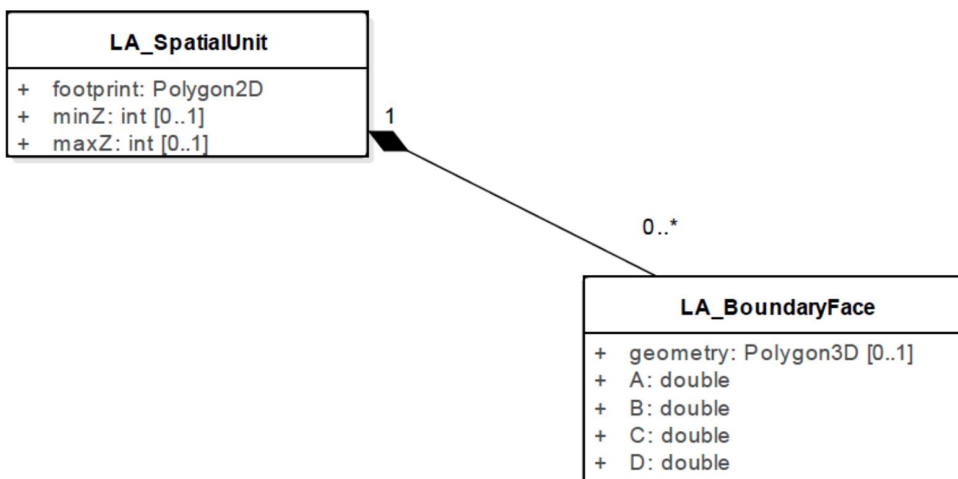


Figure 6.15: Simplified schema for database storage of new concept legal space geometry in LADM compliant cadastral database, image taken from Thompson et al. [2016].

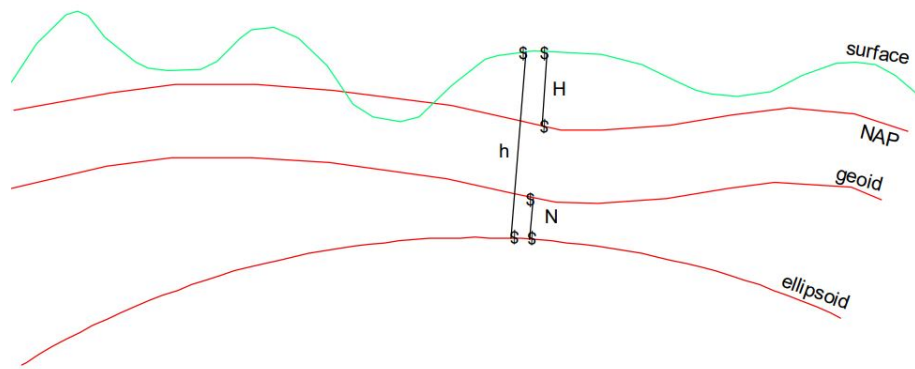


Figure 6.16: Relation between height definitions in CRS relative to NAP, image taken from <http://www.johannespostgroep.nl/wp-content/uploads/2008/10/rijksdriehoeksstelsel.pdf>.

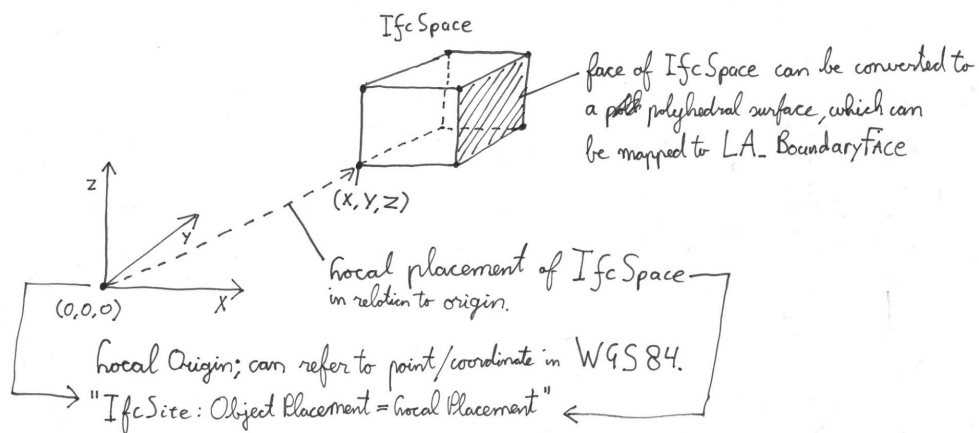


Figure 6.17: *IfcSpace* geo-referenced according to local placement of the *IfcSpace* in the IFC model. The *IfcSite* element carries the WGS 84 coordinates of the reference point in the IFC together with the elevation in NAP.

not contain height. However, it should be noted that adding a correct height according to NAP is fully possible in an IFC BIM and is also a requirement according to the RVB BIM Norm V1.1. Setting the height value to 0 in the extraction is conducted by raising the Z-element in the coordinates with 43.5 meters. This value is the approximate difference between the ellipsoid of the WGS 84 CRS and the EPSG:28992. The difference between the ellipsoid and NAP can be seen in Figure 6.16.

### 6.3.2 Extraction Process

FME [Safe Software, 2019] is used to load spaces together with the cadastral information user defined property set of the spaces. A full overview of the workbench can be seen in Appendix H, a summarized workflow of the performed operations can be seen in Figure 6.18.

The first step in this process is to load the IFC in FME. IFC files are composed of many elements which are embedded in a hierarchical structure (See Chapter 4). The parts that have to be extracted are: (1) the *IfcSpace* elements, (2) the cadastral user defined property set which applies to the *IfcSpaces*. This is carried out by loading the user defined property sets as 'traits' in FME. That means that all attributes added to the *IfcSpace* by the user defined property set, now become part of the *IfcSpace* feature in FME. This is an important step, because in the IFC file structure a property set is modelled separately from the *IfcSpace* element, and is linked to the *IfcSpace* element

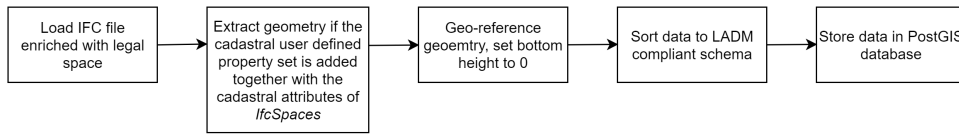


Figure 6.18: Simplified diagram of legal space extraction process

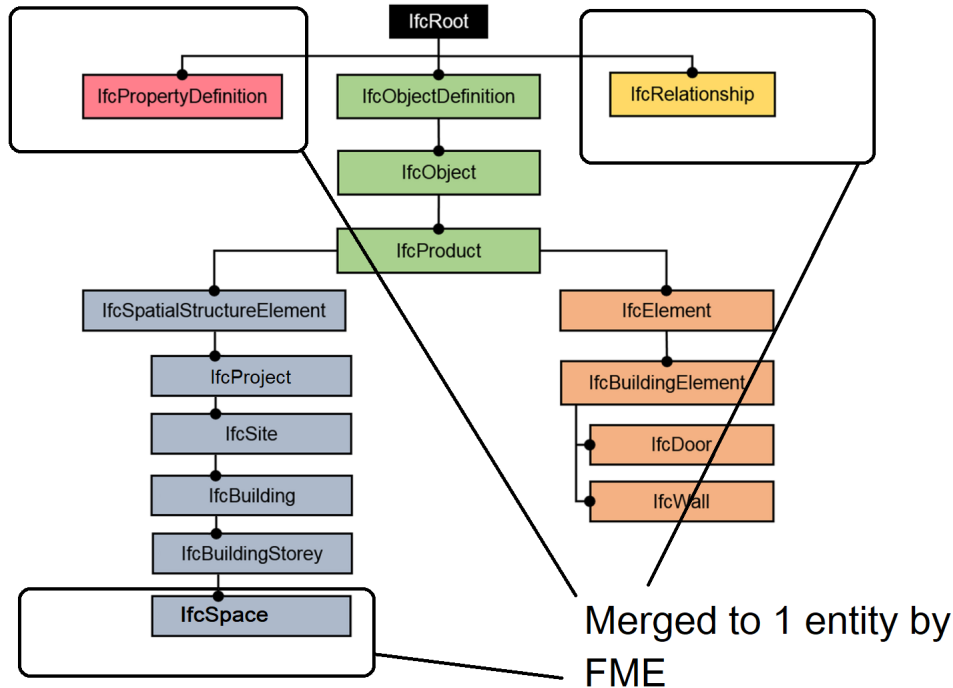


Figure 6.19: IFC file structure, *IfcSpace* geometry and user defined property set attributes per *IfcSpace* element are merged to one entity using the *IfcRelationship* with FME [Safe Software, 2019].

with a relationship entity, see Figure 6.19. This approach of decomposition of IFC elements merged into one entity in FME is also part of the methodology described in Floros et al. [2018].

After extraction of all *IfcSpace* data, the geometry of the newly build entities is reprojected from WGS 84 to EPSG:28992. Next, the height level of the bottom of the IFC is determined and set to 0 in order to visualise in a later stage on top of a cadastral parcel map. After that, the data from the user defined property set is sorted to fill the LADM compliant database's LA.Right, LA.LegalSpaceBuildingUnit and LA.BAUnit table (see Figure 6.20 for an overview of the tables in PostgreSQL/-PostGIS filled with exemplary data of an apartment building). In this step, the apartment number per *IfcSpace* is formed by concatenating the parcelnumber with and the indexnumber with an "A" in-between as depicted in Figure 6.10. A step-wise description of the extraction process can also be found Appendix H.

## 6.4 MODEL CHECKS

When an IFC BIM is enriched with legal space (the cadastral information in the user defined property set), the IFC file (EXPRESS encoded) has to be checked. When the legal space is extracted from the IFC BIM as proposed in Section 6.2, the PostgreSQL/-PostGIS database in which the legal space is stored can be checked if the data is

```

1 SELECT * FROM public."LA_Right"
2
    
```

Data Output Explain Messages Notifications Ge

	type_of_right character varying (200)	apartment_number character varying (200)
1	apartment	8897 A 22
2	apartment	8897 A 14
3	apartment	8897 A 12
4	apartment	8897 A 5
5	apartment	8897 A 23
6	apartment	8897 A 4
7	apartment	8897 A 6
8	apartment	8897 A 9
9	apartment	8897 A 8
10	apartment	8897 A 18
11	apartment	8897 A 1

(a) The LA\_Right table in PostGIS

```

1 SELECT * FROM public."LA_BAUnit"
2
    
```

Data Output Explain Messages Notifications Geometry Viewer

	ifc_unique_id text	cadastral_information_space character varying (200)	_gold character varying (200)	apartment_number character varying (200)
1	2Zu4bNNPb2U...	Shared	40A88A0AA222888824388D...	8897 A
2	2Zu4bNNPb2U...	Shared	40A88A0AA222888824388D...	8897 A
3	2Zu4bNNPb2U...	Shared	40A88A0AA222888824388D...	8897 A
4	2Zu4bNNPb2U...	Shared	40A88A0AA222888824388D...	8897 A
5	2Zu4bNNPb2U...	Shared	40A88A0AA222888824388D...	8897 A
6	2Zu4bNNPb2U...	Shared	40A88A0AA222888824388D...	8897 A
7	0Db8VlykPFf...	Private	40A88A0AA222888824388D...	8897 A 14
8	0Db8VlykPFf...	Private	40A88A0AA222888824388D...	8897 A 13
9	0Db8VlykPFf...	Private	40A88A0AA222888824388D...	8897 A 12
10	0Db8VlykPFf...	Private	4222A288A80A888824388D...	8897 A 11
11	0Db8VlykPFf...	Private	4222A288A80A888824388D...	8897 A 10
12	0Db8VlykPFf...	Private	40A88A0AA222888824388D...	8897 A 9
13	0Db8VlykPFf...	Private	40A88A0AA222888824388D...	8897 A 8
14	0Db8VlykPFf...	Private	40A88A0AA222888824388D...	8897 A 7
15	0Db8VlykPFf...	Private	40A88A0AA222888824388D...	8897 A 7

(b) The LA\_BAUnit table in PostGIS

```

1 SELECT * FROM public."LA_LegalSpaceBuildingUnit"
2
    
```

Data Output Explain Messages Notifications Geometry View

	ifc_unique_id text	geom geometry
1	2Zu4bNNPb2U82IZY8IoPL_196	010F0000A0407100000600000001...
2	2Zu4bNNPb2U82IZY8IoPMS_319	010F0000A0407100000600000001...
3	2Zu4bNNPb2U82IZY8IoPMv_422	010F0000A0407100000600000001...
4	2Zu4bNNPb2U82IZY8IoPMx_525	010F0000A0407100000600000001...
5	2Zu4bNNPb2U82IZY8IoPJE_628	010F0000A0407100000600000001...
6	2Zu4bNNPb2U82IZY8IoPJ8_732	010F0000A0407100000600000001...
7	0Db8VlykPFf9fbTITYLF1_25265	010F0000A0407100000600000001...
8	0Db8VlykPFf9fbTITYLFy_25369	010F0000A0407100000600000001...
9	0Db8VlykPFf9fbTITYLFo_25473	010F0000A0407100000600000001...
10	0Db8VlykPFf9fbTITYLFm_255...	010F0000A0407100000600000001...
11	0Db8VlykPFf9fbTITYLFs_25693	010F0000A0407100000800000001...
12	0Db8VlykPFf9fbTITYLFq_25809	010F0000A0407100000800000001...
13	0Db8VlykPFf9fbTITYLFg_25913	010F0000A0407100000600000001...
14	0Db8VlykPFf9fbTITYLFe_26017	010F0000A0407100000600000001...
15	0Db8VlykPFf9fbTITYLFk_26122	010F0000A0407100000600000001...

(c) The LA\_LegalSpaceBuildingUnit table in PostGIS

Query Editor Query History

```

1 select ST_AsText(geom) as geometry from Public."LA_BoundaryFace"
    
```

Data Output Explain Messages Notifications Geometry Viewer

	geometry text
1	POLYHEDRALSURFACE Z (((85149.9471038371 446971.1909544...
2	POLYHEDRALSURFACE Z (((85154.0350674011 446970.0996131...
3	POLYHEDRALSURFACE Z (((85151.7856679455 446972.6997845...
4	POLYHEDRALSURFACE Z (((85152.760994062 446964.96941637...
5	POLYHEDRALSURFACE Z (((85156.9563954446 446963.9825452...
6	POLYHEDRALSURFACE Z (((85159.3827189884 446966.0628991...
7	POLYHEDRALSURFACE Z (((85142.1235308926 446972.0362970...
8	POLYHEDRALSURFACE Z (((85142.1235308926 446972.0362970...
9	POLYHEDRALSURFACE Z (((85143.7965592276 446970.3157418...
10	POLYHEDRALSURFACE Z (((85145.4990049828 446968.5649336...

(d) Geometry is stored as 3D Polyhedral surface

Figure 6.20: LADM compliant database in PostGIS filled with exemplary apartment rights of a building.

valid. In both formats, it is necessary that the data is compliant with a fixed set of rules to make it possible to create a 3D representation of the apartment. The first step is to check whether the IFC BIM is enriched with legal information in a correct manner. To do so, a rule set is created to check the IFC BIM. However, the same rules can later be roughly translated to apply to the database in which the cadastral information is stored. The following rule set for IFC files enriched with legal space is developed:

1. The model contains *IfcSpaces*
2. The *IfcSpaces* are linked to the Cadastral Information property set (Some *IfcSpaces* may have other purposes and do not have cadastral information).
3. These *IfcSpaces* are not overlapping
4. Of the Cadastral Information user defined property set, the following information has to be present:
  - the cadastral parcel number (`parcelnumber`)
  - the complex number (`complexnumber`)
  - the space type (`spacetype`) has to be either 'Private' or 'Shared'

In this rule set, the presence of an `indexnumber` is left out, because shared spaces do not have an index number. This absence of an index number in shared spaces is derived from the current requirements to register apartment rights. This is also illustrated in [Appendix A](#), which is a 2D drawing that is part of a notarial deed, where the shared space does not have an index number. It should be noted that the absence of the index number of a legal space does not imply it is not identifiable. The LADM compliant storage schema ([Figure 6.11](#)) makes it possible to both link shared and private spaces to a specific apartment right, and shared spaces can be part of multiple apartment rights.

Solibri Model Checker [[Solibri, 2019](#)] is a IFC BIM checking software capable of checking the legal space enriched IFC BIM for these rules. It is assumed that IFC files that are enriched with legal space are also compliant to the guidelines described in the RVB Bim Norm V1.1 [[Rijksvastgoedbedrijf, 2013](#)] and the BIM Basic IDM [[BIM Locket, 2018, 2016b](#)]. Some of these guidelines are also part of the ruleset to check whether the IFC is filled with legal space, such as the presence of *IfcSpaces* in the model instance and that the *IfcSpaces* do not overlap. Unfortunately, it is not possible yet to check with the Solibri Model Checker software in an automated way whether the IFC model instance has complete coverage of building with *IfcSpaces*. Yet it is demanded in the RVB BIM Norm V1.1 section 2.2.7.6 [[Rijksvastgoedbedrijf, 2013](#)] for the model instance to be completely filled with *IfcSpaces*.

The ruleset created for checking IFC files could be added to the existing rule set to check whether a IFC file is compliant to the BIM Basic IDM [[BIM Locket, 2018](#)]. The private company Root BV [[Root B.V., 2019](#)] developed such a ruleset which is publicly available [[Groenewoud, 2018](#)]. The cadastral rules can be added to this ruleset. In combination with the added requirements in the BIM Basic IDM as proposed in [Figure 6.6](#), this would form a complete proposal to add legal space in practice for current IFC usage standards in the Netherlands. A concept of what this ruleset looks like in Solibri Model Checker can be seen in [Figure 6.21](#).

The Solibri Model Checker software does not check whether the *IfcSpaces* geometric representation is correct. [Diakité and Zlatanova \[2016\]](#) researched *IfcSpace* usage for indoor navigation purposes, but the outcomes are highly relevant for this research. They developed a method to check whether the geometric representation of *IfcSpaces* were sufficient to facilitate indoor navigation. They concluded that *IfcSpaces* often have errors, such as wrongly oriented faces, face overlap or face intersections within one *IfcSpace*. These errors are also encountered in this research, as can be seen in [Figure 6.22](#) where the geometry of incorrectly modelled *IfcSpaces*

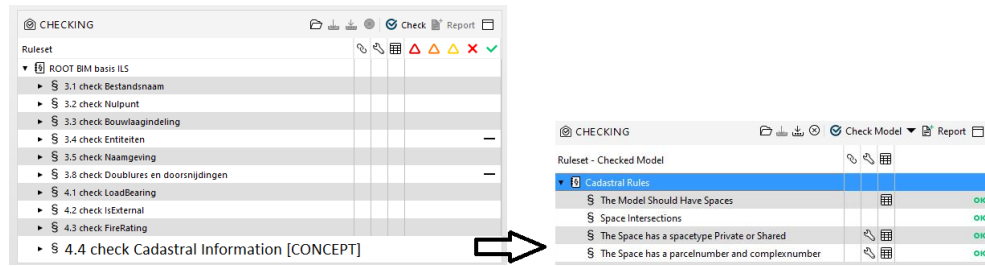
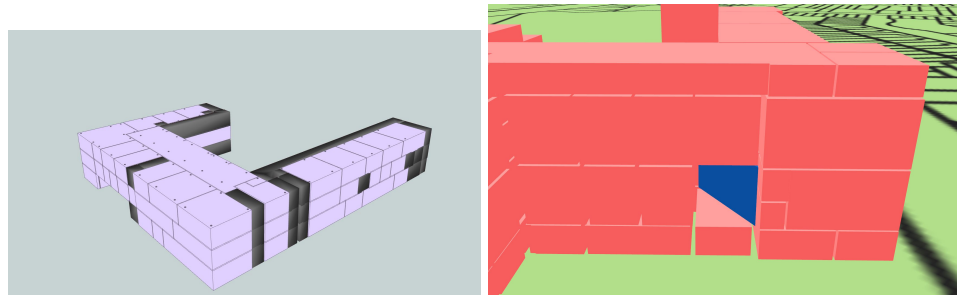


Figure 6.21: BIM Basic IDM [BIM Loket, 2018] ruleset [Groenewoud, 2018] for IFC files with added cadastral information checks



(a) Geometry of incorrectly modelled *IfcSpaces* cannot be extracted to a PostgreSQL/PostGIS database as polyhedral surfaces. The grey spaces are modelled correct, the purple spaces are incorrect. Visualised with FME [Safe Software, 2019]

(b) Extracted legal space from incorrectly modelled *IfcSpace*, the blue space is triangular instead of rectangular.

Figure 6.22: Examples of incorrect geometry of *IfcSpaces* encountered during this research

is visualised. In Figure 6.22a a building is shown which contains mostly incorrect modelled *IfcSpaces*, those could not be extracted with the designed workflow described in Section 6.2. Figure 6.22b shows incorrectly modelled geometry which cannot be checked for automatically: the geometry is valid, but does not represent the legal space as intended.

The method developed by Diakit  and Zlatanov  [2016] could be incorporated in future research to make sure the extracted legal space contains the correct geometry. In this proof of concept the geometry is only checked for overlap automatically, other geometric errors had to be identified with visual inspections.

### Database checks

When the legal space is extracted from the IFC and stored in a PostgreSQL/PostGIS database, the geometry should not overlap with other legal spaces that are already present in the database. The legal spaces of a single building are already checked for overlap with other rooms (*IfcSpaces*) in the same building with Solibri Model Checker as described in the previous section. However, the overlap between different buildings should be checked in the cadastral database. In other words, before apartment rights are registered in the cadastral database, they should be checked for overlap with existing apartment rights. This potential overlap in the cadastral PostgreSQL/PostGIS database can be checked with a *ST\_3DIntersection* query. This query returns the geometry of overlapping areas. In case of no overlap, an empty geometry collection is returned.

Besides checking for overlapping geometry, the cadastral database can be checked if the legal spaces contain data. Again, this is also checked in the IFC file, but can be checked again with a 'IS NULL' condition in the query. This query checks if the

mandatory fields of the cadastral information user defined property set (`parcelnumber`, `spacetype`, `indexnumber`) are filled in. Again, this is also checked beforehand in the IFC with the developed ruleset. It can be concluded that the database checks' most important task is to check for overlapping buildings since this is not possible in the IFC file itself. The database checks also function as a second check for the presence of cadastral information, also to make sure there is no data lost during the conversion.

With this approach it is still necessary to have a human check the cadastral information for complete correctness, the automated checks can only check whether the information is filled in or not, and if there is geometric overlap. Future research could establish automated checks for the contents of the legal information, such as index numbers of the added apartment rights in the cadastral database form a continuous ascending series of natural numbers (Article 6.1.f in the *Uitvoeringswet Kadaster*, Chapter 1. See also [Appendix C](#)).

## 6.5 VISUALISATION & DISSEMINATION

This section describes the visualisation process of the legal space enriched IFC BIMs. As has been thoroughly described in the scope ([Chapter 1](#)), visualisation of legal space enriched IFC BIMs are part of this research, but not the primary goal. To visualise legal space enriched IFC BIMs, the 3D cadastre prototype of [Cemellini \[2018\]](#) can be used. ?? describes how the data of the legal space enriched IFC BIMs are stored in a LADM compliant database. [Cemellini \[2018\]](#) uses Cesium JS in which KML files are loaded as a viewer.

For this research, initially QGIS [[QGIS, 2019](#)] is used as visualisation tool. The 3D cadastral viewer developed by [Cemellini \[2018\]](#) is less suitable for database transactions, and therefore QGIS is used as a viewer. QGIS is capable of transactions in the database. However, the cadastral data extracted from the IFC can be visualised on the Cesium JS platform as proposed by [Cemellini \[2018\]](#) which can be seen in [Figure 6.23](#). Instead of converting the legal spaces extracted from the IFC to KML, the concept legal space is converted to B3DM with FME [[Safe Software, 2019](#)]. The code of the viewer, as well as the data of some example buildings is made publicly accessible by the author<sup>4</sup>. The viewer can be accessed on <http://pakhuis.tudelft.nl:8080/edu/cesium/apps/bimlegal/>.

### QGIS

QGIS is a GIS, and therefore built to operate on a different scale than BIM viewing software, such as Solibri Model Viewer. However, due to the many advantages and ease of use, QGIS is used for visualisation in the developed proof of concept. An advantage of QGIS is that it can visualise WFS layers. For the 3D representation to be part of a notarial deed to establish apartment rights, it is required to show the cadastral parcel on which it is established together with the situation plan as stated in [Section 5.2 Requirement 3](#). QGIS is capable of connecting to a PostgreSQL/PostGIS database, which is used to store the extracted cadastral information from IFC BIMs, as described in the previous section ([Section 6.3.2](#)). Besides the use of QGIS as viewer, another simplification is applied in this research which is flattening the database for visualisation purposes. This means all cadastral and geometric information in the database is aggregated to a single table, rather than the multi-table LADM compliant storage schema as is presented in [Section 6.3](#). The 'flat' table can be seen in [Figure 6.24](#).

As discussed, a downside of using QGIS as a viewer is that it is not part of the 3D cadastre prototype of [Cemellini \[2018\]](#). However, *IfcSpaces* enriched with cadastral information can be fully visualised in the Cesium JS platform (See [Figure 6.23](#)).

<sup>4</sup> <https://github.com/TUdent/BimLegalDemo>





Advantage	Disadvantage
Easy visualisation of 3D concept legal space	Viewer is not browser based
PostgreSQL/PostGIS connection and query tool	QGIS is expert software
Easy WFS connections	2D polygons have blurred lines
	2D polygons are not transparent
	Underground geometry not visible

**Table 6.4:** Advantages and disadvantages of using QGIS as viewer for legal space enriched IFC BIM extracts

Another disadvantage is that the QGIS viewer is that it is not browser-based, which restricts the dissemination capabilities of this proof of concept during the development phase. An overview of all the advantages and disadvantages of using QGIS as a viewer in this research can be seen in [Table 6.4](#).

### *Example buildings in QGIS*

This section shows legal space enriched IFC BIMs of an apartment building and the Faculty of Architecture of the TU Delft after the extraction process, visualised in QGIS. Since the Faculty of Architecture is an existing building, the IFC is geo-referenced beforehand in Autodesk Revit [[Autodesk, 2019](#)], according to the guidelines described in the RVB BIM Norm V1.1 [[Rijksvastgoedbedrijf, 2013](#)]. The apartment building is a fictional building, but is placed on parcel 8897, next to the Faculty building. [Figure 6.25](#) shows the 2D visualisation of the extracted legal spaces on the cadastral parcel map in QGIS. The footprint is a top view of all spaces which contain cadastral information. The cadastral parcel map is retrieved through a WFS and has the cadastral parcel number as a label. The cadastre also has a publicly accessible dataset with footprints of buildings (BAG) [[Kadaster, 2019a](#)], these footprints are also visualised. Notice how the geo-referenced building of the Faculty nearly fits within the footprint provided by the cadastre. In [Figure 6.25](#), the apartment building also carries the complex number as label (8897-A).

[Figure 6.26](#) shows the same situation as in [Figure 6.25](#) but viewed in 3D using the '3D view' function in QGIS. The legal spaces are coloured according to the apartment right number in the apartment building, the Faculty building is given one color since no apartment rights are established on this building. The 3D viewer of QGIS is not capable of showing labels, therefore the cadastral parcel map has no visible parcel numbers. However, they can be queried by clicking the parcel in the viewer using the 'identity' function to display all attributes, as can be seen in [Figure 6.29](#).

Because the workflow as described in [Section 6.2](#) is used, the IFC BIM extract contains geo-referenced geometry. This is already apparent because the extract is plotted on top of the cadastral parcel map, but to emphasize this the extract is also placed on aerial imagery and viewed in 3D ([Figure 6.27](#)). This aerial imagery is, similar to the cadastral parcel and building map retrieved via a WFS.

QGIS allows for connections to a PostgreSQL/PostGIS database and perform transactions through a Graphical User Interface (GUI). This functionality is, among others, used to retrieve all spaces that belong to a specific apartment right, as can be seen in [Figure 6.28](#). Besides these queries, QGIS can also retrieve information from the PostgreSQL/PostGIS database by clicking a space in the viewer ([Figure 6.29](#)) with the 'identity' function. Besides the visualisation of a specific apartment right, QGIS can also display all the mandatory context<sup>5</sup> by displaying the surrounding buildings and cadastral parcels ([Figure 6.30](#)).

<sup>5</sup> The situation plan is a mandatory part of a notarial deed to establish apartment rights on a part of a building. Summarised it is an overview of neighbouring cadastral parcels and other parts of the building. More information about the situation plan can be read in [Chapter 5](#)

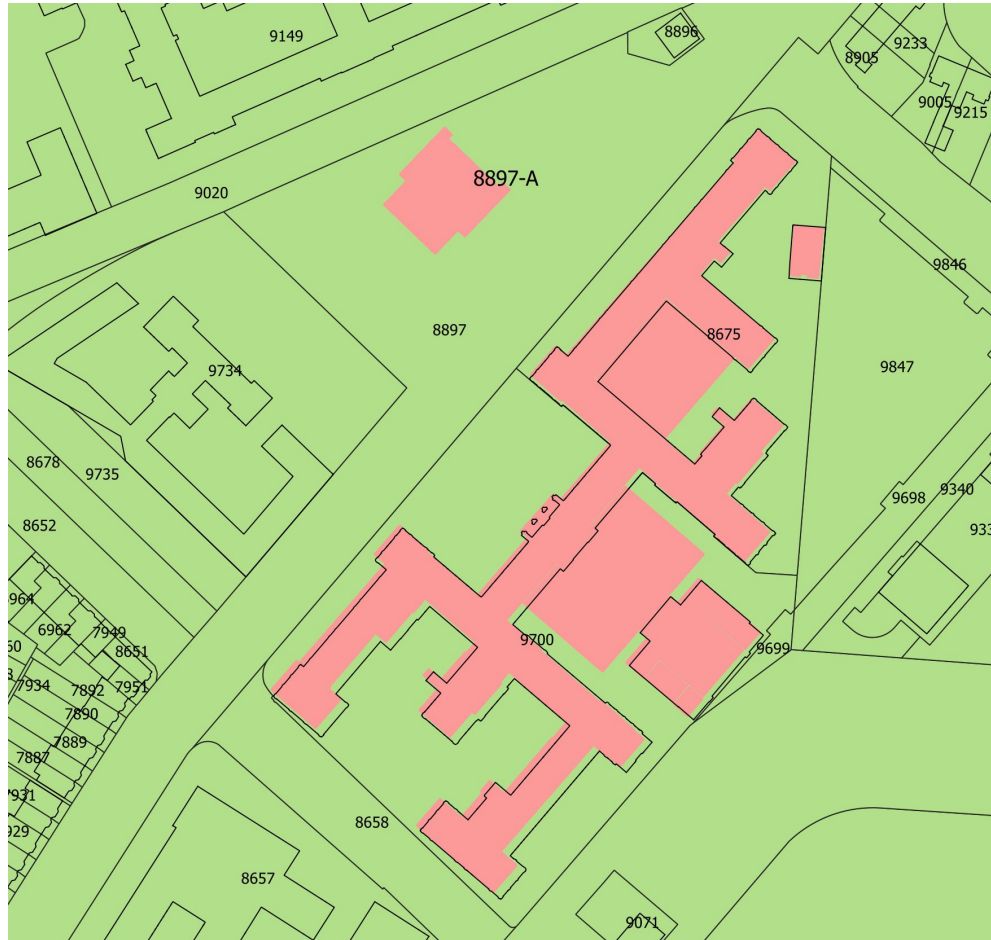


Figure 6.25: 2D Footprint of legal space enriched IFC BIM in GIS environment (QGIS) on cadastral parcel map via a WFS.

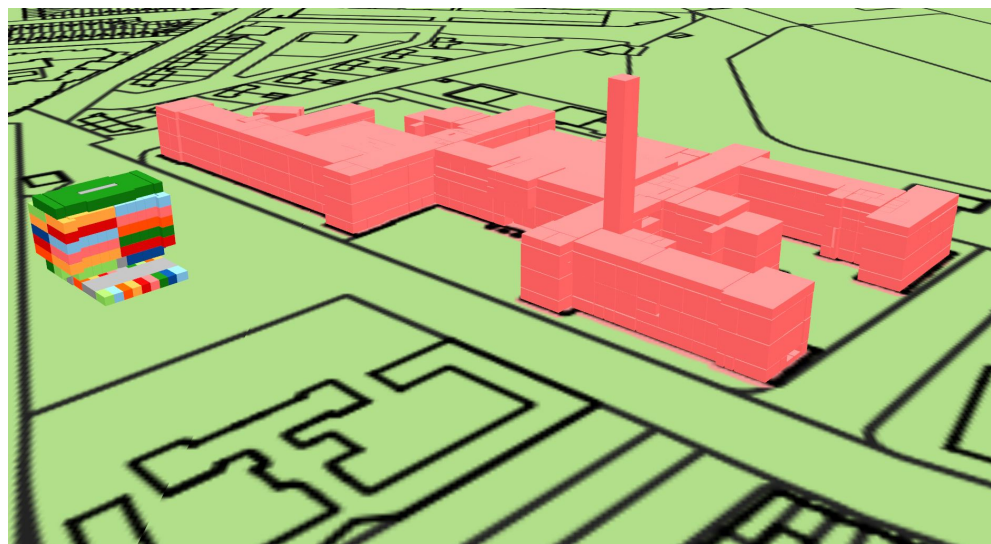


Figure 6.26: 3D visualisation of apartment rights in GIS environment together with cadastral parcel map retrieved through WFS. Unique apartment rights are colored, shared space is grey.

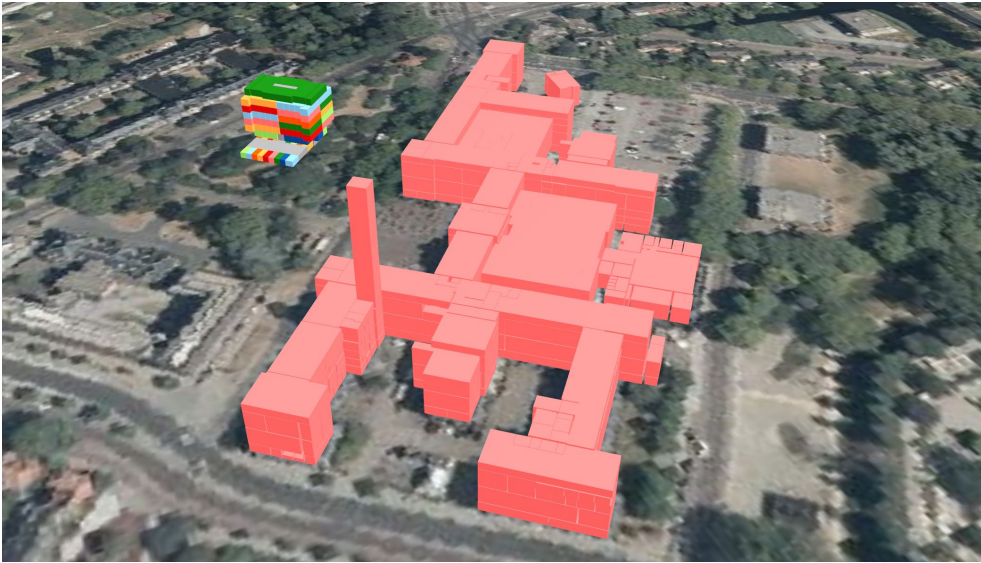


Figure 6.27: Geo-referenced geometry allows for integration of various types of data, such as aerial imagery.

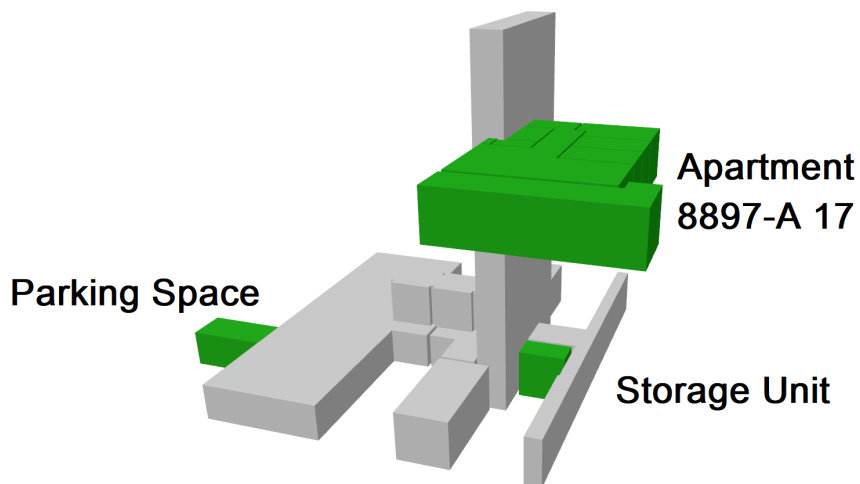


Figure 6.28: GIS environment QGIS can query the PostgreSQL/PostGIS database through a GUI and search for a particular apartment right number. In this example apartment number '8897 A 17'. Grey areas are shared space, green areas are private space. Labels are added by hand to depict the three private areas.

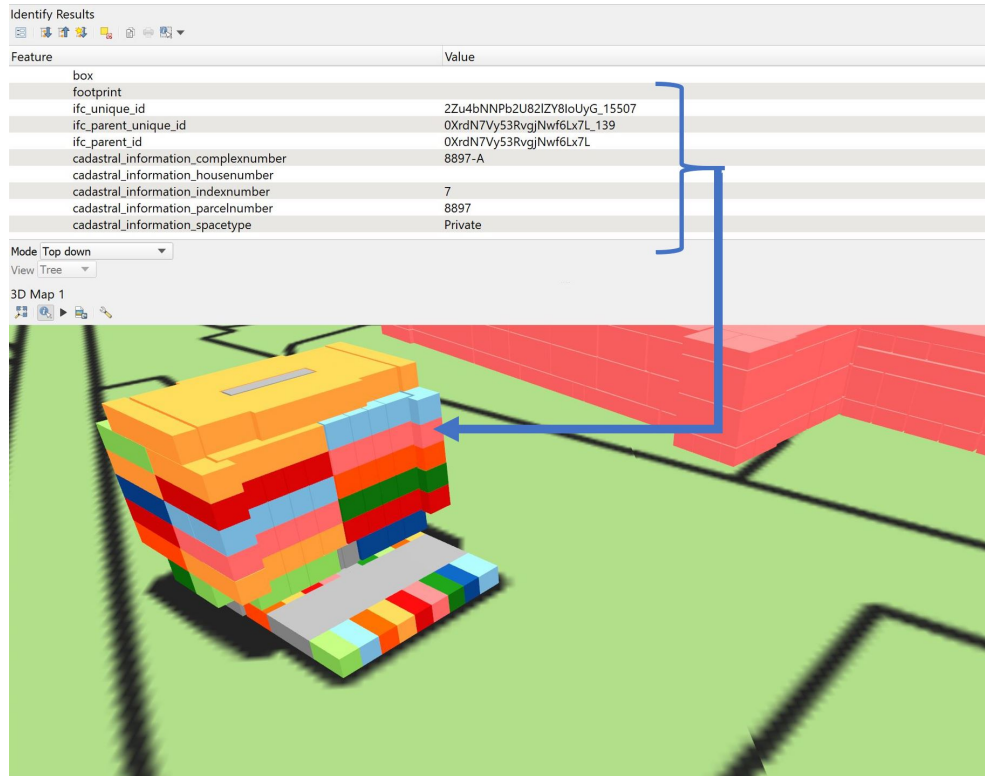


Figure 6.29: GIS environment QGIS can query the PostgreSQL/PostGIS database through a GUI by clicking an apartment with the 'identify' function, all elements belonging to a space are retrieved from the database and visible in the table.

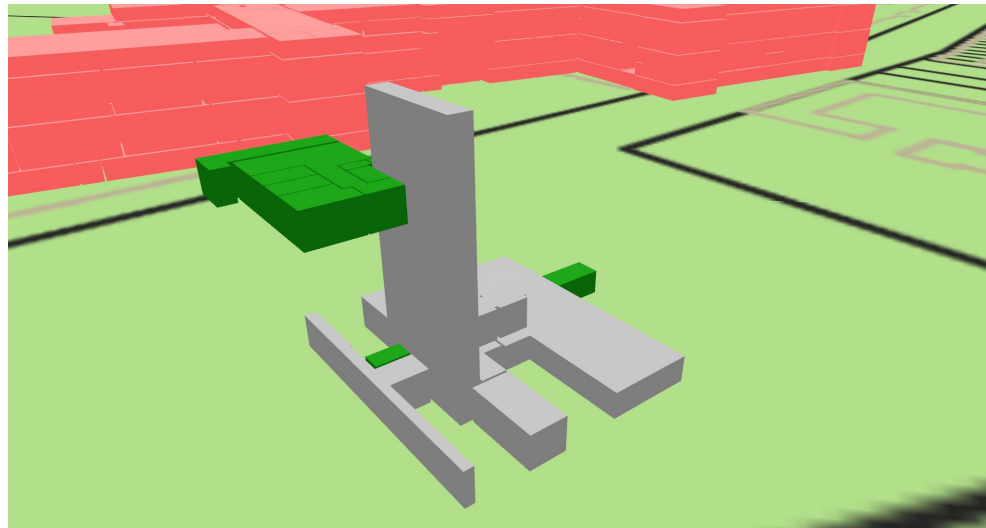


Figure 6.30: GIS environment QGIS can query the PostgreSQL/PostGIS database through a GUI to search for a particular apartment right number (private space is green, shared space is grey) and simultaneously show the surrounding buildings (as a situation plan). In this case the TU Delft faculty of Architecture can be seen in the background and the 2D cadastral parcel which serve as context.

## 6.6 SPLITTING

An important functionality of QGIS in this proof of concept is the PostgreSQL/PostGIS connection. This is used to change cadastral information of the legal spaces. This is important in multiple steps of the registration of apartment rights. The Splitting of apartment rights can be conducted by changing the apartment index number. In the 3D viewer of QGIS, a legal space can be selected. All information of this particular legal space is then retrieved from the database. The values in the database can be changed, sending them to the cadastre for approval. The full chain of events necessary to establish apartment rights can be read in [Chapter 7](#).



# 7

## CHAIN OF EVENTS AND CASE STUDIES

This chapter describes the developed legal space concept in [Chapter 6](#) by the application in two case studies. First, the chain of events of registering apartment rights in the Netherlands is described in [Section 7.1](#), this includes both the current situation and describes a future chain of events on a conceptual level. [Section 7.2](#) describes the steps in the future chain of events related to the registration of apartment rights in two fictional buildings. [Section 7.3](#) evaluates the two use cases by analysing the feedback of experts in the field, which are a notary, cadastre employees and members of the Nederlands Centrum voor Geodesie en Geo-informatica (Netherlands Center for Geodesy and Geo-Informatics) (NCG) Commission for Core Spatial Data.

### 7.1 GENERAL CHAIN OF EVENTS

The workflow for current registration of apartment rights for a new apartment complex [[Kadaster, 2019b](#)] with a 2D drawing is as follows:

1. A draftsman sends the digital 2D drawing of the apartment to the notary.
2. The notary sends the drawing to the cadastre with a request for reservation of a complex number (Usually the parcel number followed by an 'A')
3. The cadastre takes the drawing in depot and sends the declaration of the complex number and depot number of the drawing to the notary.
4. The notary and parties sign the authentic deed on paper with, as an attachment, a print of the digital drawing. In the text, the notary refers to the deceleration of the apartment designation.
5. The notary creates a digital version of the authentic deed with an equivalence declaration with a referral to the depot number of the drawing which has to be declared equivalent.
6. The cadastre collects the drawing form the depot, adds it to the deed and registers them into the public registers.

As expected, this workflow is designed for 2D drawing. The proposed chain of events is designed to stay as close as possible to the current process. This is done for two reasons: (1) the developed proof of concept has to fit in current practices in order to show that IFC BIMs can be used to register apartment rights in 3D. (2) It maximizes the acceptance of and minimizes the learning curve of the new workflow for stakeholders, such as BIM Modellers, notaries, cadastre employees, etc. However, because the registration of 3D geometry requires certain digital infrastructure such as web servers and web viewers, these elements are assumed to be developed in order to make this proof of concept work. After the chain of events, the assumptions for this digital infrastructure are enumerated. A visual overview of the steps that are to be taken can be seen in [Figure 7.1](#).

1. An IFC file compliant with the RVB Bim Norm V1.1 [[Rijksvastgoedbedrijf, 2013](#)] and the Bim Basic IDM [[BIM Loket, 2018, 2016b](#)] of the apartment building is sent to the notary. The IFC is also enriched with legal space, meaning

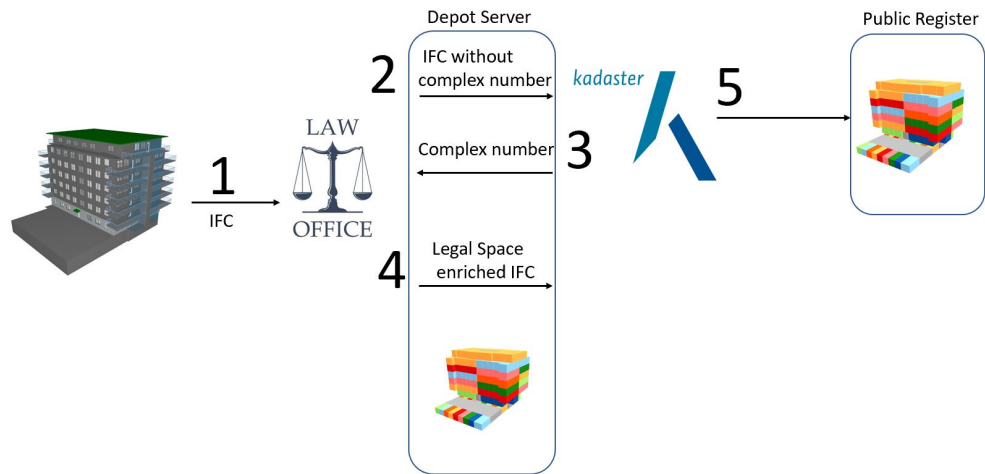


Figure 7.1: Chain of events for registering 3D apartment rights. This figure will be improved for the final version of this report.

that the relevant *IfcSpace* contains the Cadastral Information user defined property set. The attributes space type, index number, and parcel number have to present. The notary can check for this information by using Solibri Model Checker or other IFC checking software with a 'Cadastral Information ruleset' (Described in Section 6.4).

2. The notary uploads the IFC file to the cadastral 'depot' server. The legal space is extracted automatically on the server and stored in the cadastral database. The cadastral information is visualised on the cadastral parcel map in the viewer. The notary can review and edit the parcel number, index number and spacetype of all the spaces in the building via the viewer (system architecture explained in Section 6.3).
3. The notary requests a complex number for the published building. The cadastre can give a complex number based on the request and the published data.
4. The notary adds the complex number to all spaces on the server and confirms this officially to the cadastre. Together with this confirmation, the written notarial deed is created by the notary and sent to the cadastre.
5. The cadastre registers the notarial deed together with the IFC file in the public register and stores the geometry of the legal space in the cadastral database that now has 3D geometry.

The assumptions in the developed workflow concerning the presence and workings of a cadastral digital infrastructure are the following:

1. The source IFC BIMs are created according to the BIM Basic IDM [BIM Loket, 2018] and RVB BIM Norm V1.1 [Rijksvastgoedbedrijf, 2013] together with the cadastral information as proposed in Section 6.1.1
2. Notaries have sufficient knowledge of Solibri Model Checker to check IFC files with the ruleset proposed in Section 6.4
3. The cadastre hosts a depot server, which is a server linked to a online accessible PostgreSQL/PostGIS database in which IFC legal space is extracted and stored. The extraction process on this server is described in Section 6.2 and the storage schema in Section 6.3. Notaries have access to this server and are allowed to edit data.



4. Notaries have sufficient knowledge of QGIS to manipulate legal spaces of apartment rights on the depot server.
5. The cadastre has sufficient knowledge of QGIS to check and manipulate legal spaces of apartment rights on the depot server.
6. The cadastre has a Public register database that allows for the storage of IFC files. Also, the cadastral parcel which is in 2D until now, can be visualised with the extracted 3D legal space on top of the map.

The next section will illustrate the use of the proposed workflow by describing the registration of apartment rights on two fictional buildings.

## 7.2 CHAIN OF EVENTS FOR TWO CASE STUDIES

This section describes two use case studies to register apartment rights with a 3D representation. The first use case describes the workflow for a new building, the second use case will describe the workflow for the sub-splitting of apartment rights.

### 7.2.1 Case Study 1: New building

This case study describes the chain of events for the registration of apartment rights of a new apartment building, the IFC BIM of this building can be seen in Figure 7.2a. In the scenario of this fictional case study, three roles are present: a notary, an architect and the cadastre.

#### *Step 1*

First the IFC BIM of the new building that is compliant with the RVB Bim Norm V1.1 [Rijksvastgoedbedrijf, 2013] and the Bim Basic IDM [BIM Locket, 2018, 2016b] and enriched with legal spaces are sent to the notary by the architect of the building. The notary loads the .ifc file in Solibri Model Checker and checks two things: is the cadastral information user defined property set filled in correctly by applying the rule set, and are the apartments that are to be registered assigned the correct information (Figure 7.2c). If this is not the case, the notary can edit the IFC file with BIM software, or send it back to the creators of the IFC BIM for the required alterations.

#### *Step 2*

The notary publishes the IFC file to the 'depot' server of the cadastre, together with a request for a complex number. The legal space is extracted on the server and visualised in QGIS (Figure 7.2d). Both the cadastre and notary can access the server and view the extracted legal space.

#### *Step 3*

The cadastre receives the request for the complex number and accesses the depot server. In this server the legal space extracted automatically and can be viewed, the cadastre can determine the complex number. The data is already geo-referenced, so the cadastre can easily see where the apartments are located in relation to the cadastral parcels. An impression of the depot server can be seen in Figure 7.4. The cadastre can see the parcel on which the building is located, and based on this can assign the complex number. Other neighbour apartment rights are also visualised, in order to visually check for potential overlap of apartment rights. The overlap can also be checked automatically with database queries as described in Section 6.4. In this use case, the parcel number on which the apartment right has to be registered

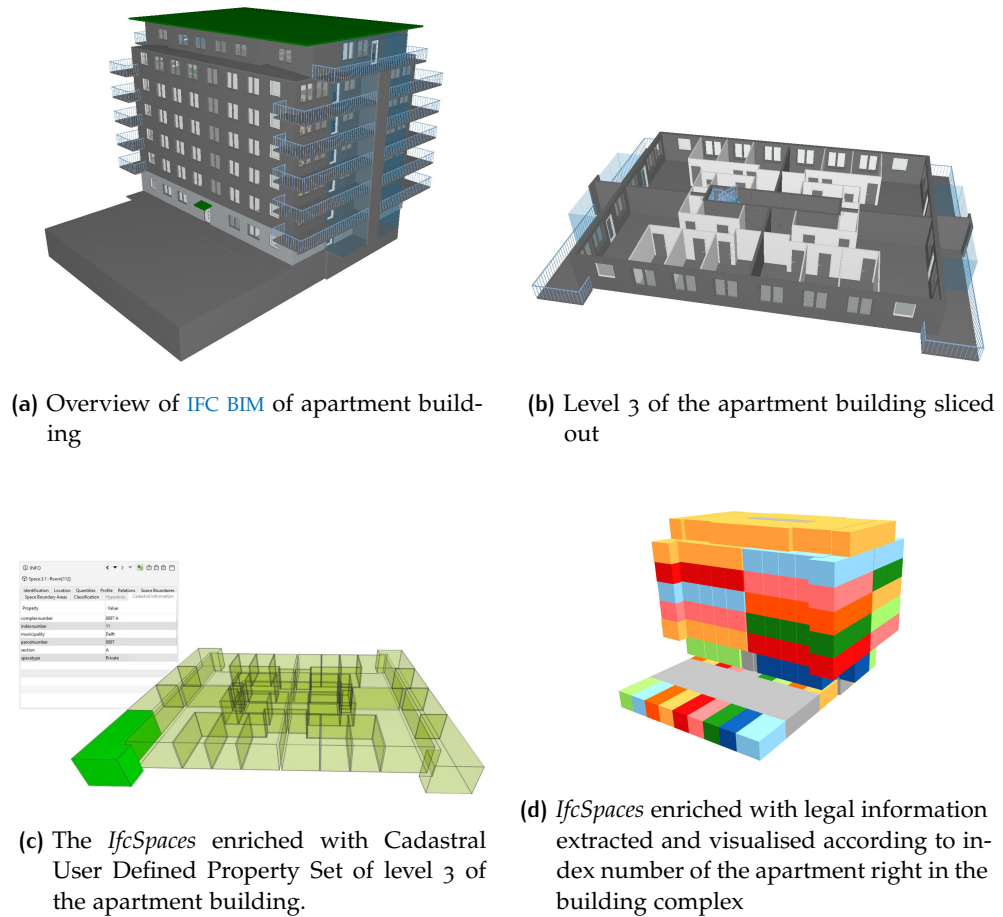


Figure 7.2: IFC BIM enriched with legal space through a user defined property set visualised with Solibri Model Viewer (a, b, c) [Solibri, 2019] and QGIS [QGIS, 2019] (d)

is '8897'. This number is present in the extracted legal space, but also visible in the cadastral parcel map. Therefore, the complex number becomes '8897 A'. This complex number is then added to the PostgreSQL/PostGIS database via the QGIS. After the cadastre added the complex number, the notary is notified.

#### Step 4

When the notary receives the confirmation of the complex number, he or she can create the notarial deed of the apartment complex. An example of a screenshot of the 3D representation for one apartment right in can be seen in Figure 7.5. However, the true data of the geometry of the apartment right is stored in the PostgreSQL/PostGIS database as LADM compliant geometry, and therefore has various viewing options. These viewing options are also a requirement for the 3D representation that is part of a notarial deed. For example, the entire building has to be part of the 3D representation, and the surrounding area of the building (the situation plan) has to be present. All these requirements are fulfilled, because the entire building can be visualised (Figure 7.2d). Also the spaces (exclusively) accessible for the owner (the private and shared space, as seen in Figure 7.5) are visualised. The surrounding area is visible because the cadastral parcel map can be plotted together with the apartment rights, as can be seen in Figure 7.6, due to geo-referenced geometry.

CHECKING		Check Model	Report
Ruleset - Checked Model			
▼ Cadastral Rules			
§ The Model Should Have Spaces			OK
§ Space Intersections			OK
§ The Space has a spacetype Private or Shared			OK
§ The Space has a parcelnumber and complexnumber			OK

Figure 7.3: Legal Space enriched IFC BIM is checked for correctness with a rule set in Solibri Model Checker [Solibri, 2019]

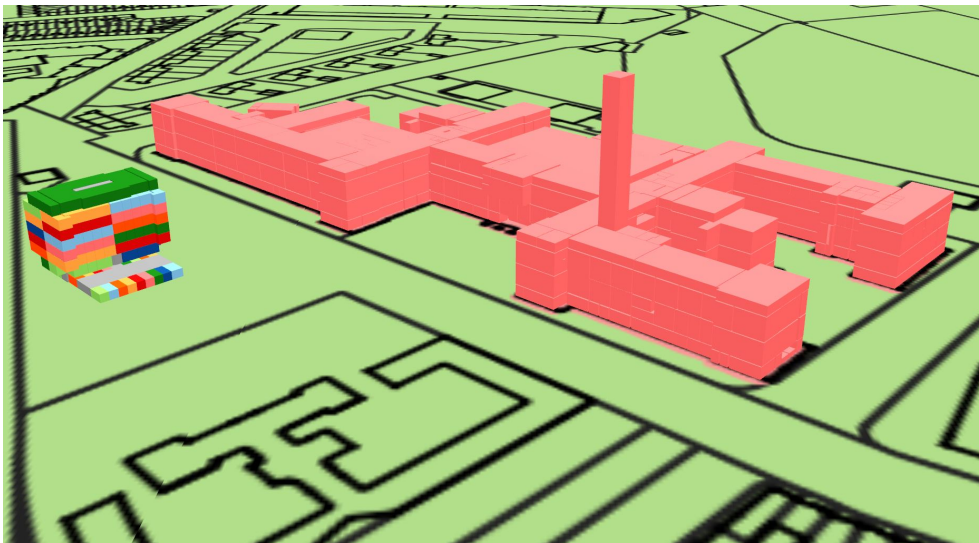


Figure 7.4: 3D visualisation of apartment rights in GIS environment. Unique apartment rights are colored accordingly

### Step 5

The cadastre receives the notarial deed with a reference to the apartment rights in the depot database. The cadastre stores the notarial deed in the public registers and transfers the 3D geometry to the cadastral database which completes the transaction.

#### 7.2.2 Case Study 2: Sub-splitting Apartments

This case study describes the sub-splitting of apartment rights in a fictional office complex. In this case study, it is assumed the building complex is already registered in the public registers to serve as 3D representation for notarial deeds of apartment rights. In this case study one particular apartment right for an office space will be split into two apartment rights. The original IFC BIM can be seen in Figure 8.2a. This fictional case study is conducted to show how apartment rights can be split, a practice which is common in the Netherlands [CBS, 2016]<sup>1</sup>. The office building is placed near the apartment building that is registered in case study 1 on parcel 9734.

<sup>1</sup> When apartment rights are formed, an owner association is established (mandatory). In the Netherlands, there are 142.705 owner associations registered. This implies the act of sub-splitting is common practice due to this large number.

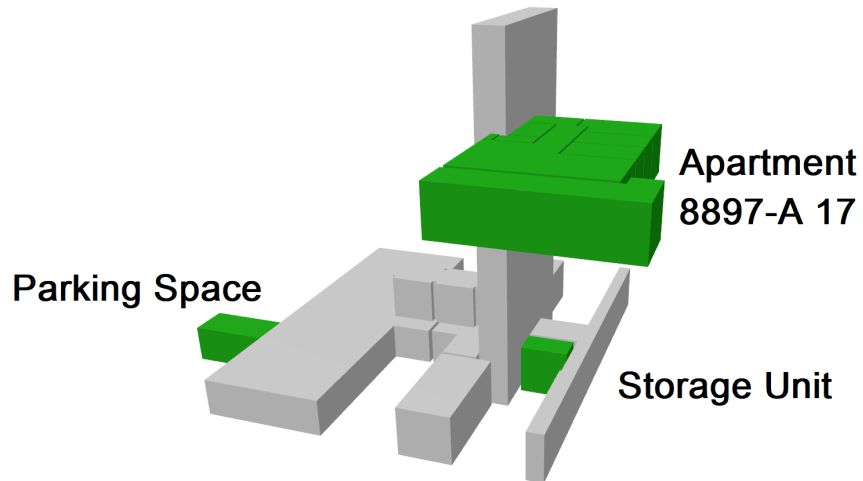


Figure 7.5: Single apartment right visualised in GIS environment. Textual depiction added in later stage by the Author. Apartment complex 8897-A with all apartment rights and context (parcel map, other buildings) can be seen in [Figure 6.26](#)

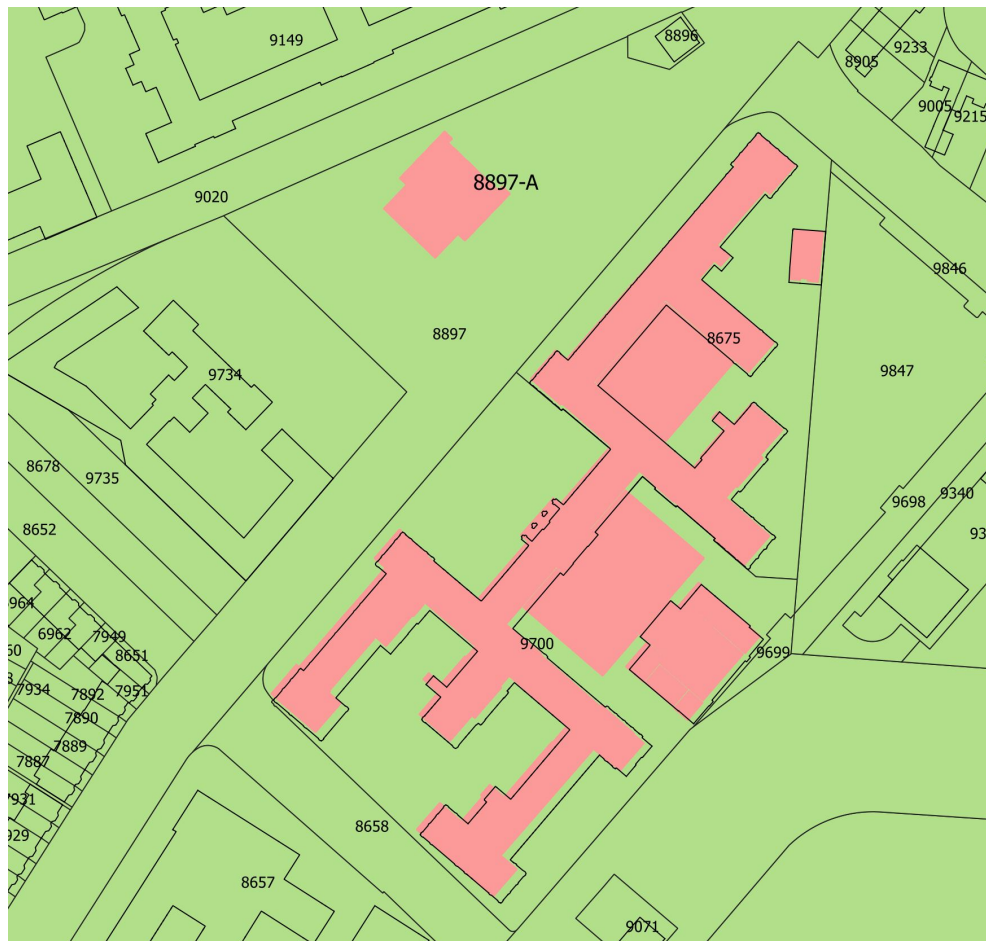


Figure 7.6: 2D Footprint of legal space enriched IFC BIM in GIS environment (QGIS) on cadastral parcel map via a WFS.

**Step 1**

The notary accesses the cadastral information of the building complex in the public register database for the source of the apartment rights and the cadastral database for the geometry. In the viewer of the cadastral database, the apartment rights are visualised on top the cadastral parcel map, together with other building footprints, as can be seen in [Figure 7.7b](#).

**Step 2**

The notary switches to from 2D to 3D viewing in QGIS and inspects the building complex ([Figure 7.7c](#)). The notary changes the index number of the apartments through the QGIS viewer by changing values in the PostgreSQL/PostGIS database. First, the existing apartment right is queried ([Figure 7.7d](#)) to show both the private and shared space that is part of the apartment right. In this case, the index number of the original apartment is 5. This will be changed into 6 and 7, because the apartment numbers have to be unique and differ from the indices of the original situation. They also should form a logical enumeration [[Kadaster, 2019b](#)]. The notary changes the index numbers in the database through the viewer. The changes are not permanent yet, they first have to be reviewed by the cadastre.

**Step 3**

The notary notifies the cadastre of the changes in index numbers as a result of the proposed split. The cadastre reviews the changes, and can approve of them or not. When the changes are reviewed, the notary is notified.

**Step 4**

The notary creates the notarial deeds of the new apartments and refers in the notarial deeds to the new apartments of the building complex as they are stored in the cadastral database.

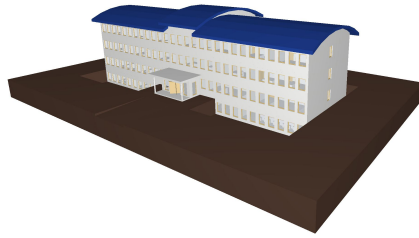
**Step 5**

The cadastre stores the changes in the cadastral database, and stores the notarial deed in the public registers.

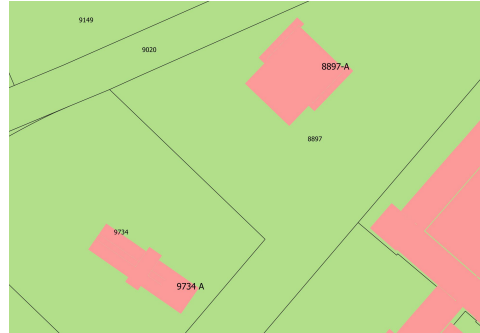
This use case is also visualised in the Cesium JS platform ([Figure 7.8](#)) to proof that enriching IFC BIMs with legal space is viewer independent, but could fit in the 3D cadastral viewer prototype as described in [Cemellini \[2018\]](#).

## 7.3 EVALUATION

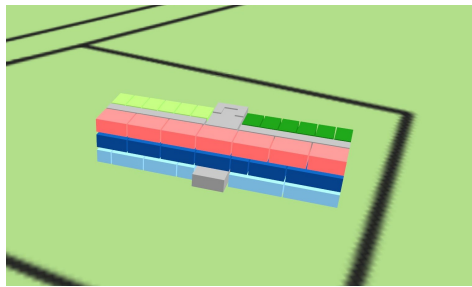
The developed workflow has been presented to several experts. An overview of the experts and most important comments can be seen in [Table 3.1](#). Mr. Boellaard, a notary who is also a member of the innovation committee of The Royal Dutch Association of Civil-law Notaries (KNB) had positive comments. He mentioned that the main benefits come from the aspect of visualisation: the current 2D drawings often do not offer 'easy' insight in complex ownership situations. A second benefit is a reduced workload for the notarial office. The 2D drawing is usually created by external draftsmen. When the proposed workflow is put in practice, the creation of the 3D representation is performed automatically in an online environment that can be checked by notaries, clients, and the cadastre. The only additional task for creating the 3D representation is assigning legal information to the *IfcSpaces*. Right now that is still a task for experts, but can be simplified by creating a web interface



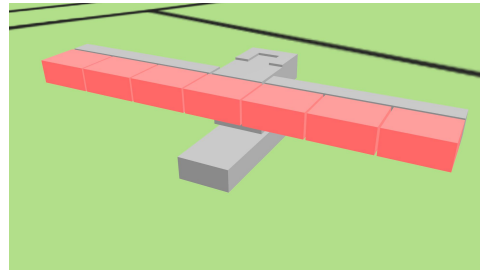
(a) Original IFC BIM of office complex, from which the legal space is extracted and present in the cadastral database



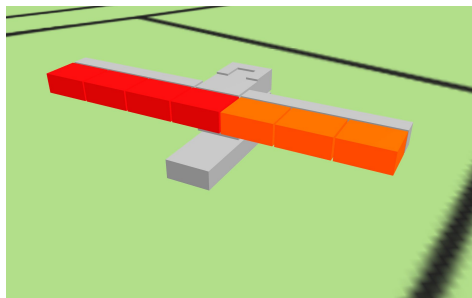
(b) Footprint of office complex in cadastral map with complex number as label. This footprint is visualised on the cadastral parcel map, with parcel numbers as label. Notice the presence of the registered building in Case Study 1 in the right upper corner.



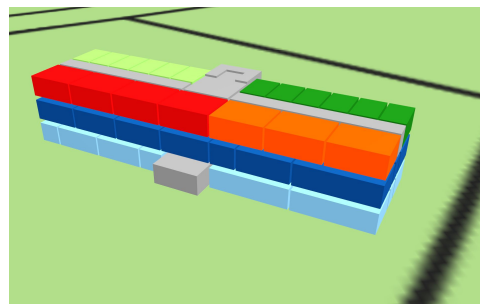
(c) Overview in 3D of legal space of office complex. The private spaces are colored according to their index number, shared spaces are grey



(d) Private space of apartment right "9734 A 5" in pink, together with in the shared space of the building complex. This apartment will be split into apartment "9734 A 6" and "9734 A 7"

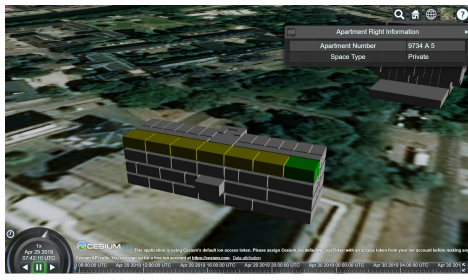


(e) Apartment "9734 A 5" split into "9734 A 6" (private space in orange) and "9734 A 7" (private space in red). The shared space is grey.

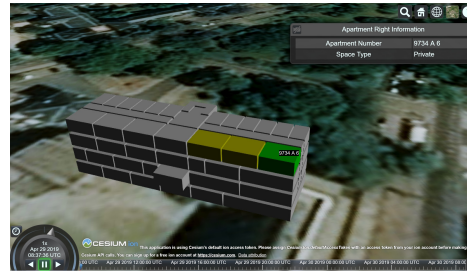


(f) Overview of new legal situation of complex "9734 A".

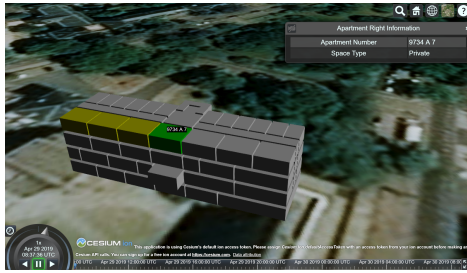
Figure 7.7: Visualisation of sub-splitting an apartment right in two apartment rights in 3D



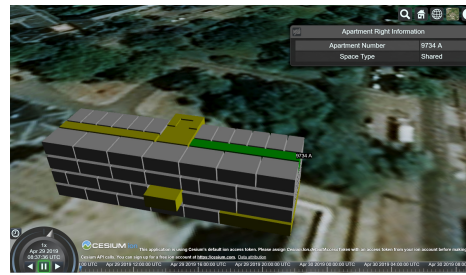
(a) Office building with apartment 5 before the split



(b) Apartment 6 highlighted



(c) Part of apartment 7 highlighted



(d) Part of shared space of building complex '9734 A' highlighted

Figure 7.8: Office splitting sequence of case study 2 visualised in Cesium JS

for notaries to do so. It can be concluded that the usage of a legal space enriched IFC BIM could be very beneficial for the registration process for apartment rights.

Another important advantage that has not been considered in this proof of concept is the registration of floor space, and the fraction of the floor space of a specific apartment right in relation to the entire building complex. This fraction is important because it can determine the apartment owner's shared costs of the building maintenance and service costs (i.e. heating and cleaning of shared spaces). Calculating these fractions can be performed automatically with a few modifications to the developed workflow in FME [Safe Software, 2019], because the *IfcSpace* element also carries the floor space in it. This can be added to the cadastral information user defined property set. In the extraction process, the floor space of apartment rights can be calculated by aggregating the floor space of all *IfcSpace* elements of a specific apartment right number. The floor space of the entire building can also be calculated by aggregating all floor space. This complete area, divided by the apartment rights' floors space, will be the fraction of that apartment right.

Two experts of the Dutch cadastre (Eric Hagemans, Gerard Dabroek) were also interviewed. They also were positive, but stated that this development should be placed within a development framework of three stages of development of a 3D cadastre. Stage one would be to add the 3D representation of apartment rights to the notarial deed, comparable to the use case of Stoter et al. [2012] of the railway station in Delft. The second stage will be the integration of the 3D representation of the apartment rights on top of the cadastral parcel map. In this stage the 3D representation would act as an index to the source (the notarial deed) which contains the IFC file, similar to the role of parcels in the cadastral parcel map. The third and final stage of the 3D cadastre the extracted legal space of the BIM is of such quality that the geometry in the notarial deed is equal to the geometry on the cadastral map.

After presenting the findings of this research to the NCG Commission for Core Spatial Data it is determined their most valuable comment was to describe how the difference between the 'as designed' and 'as built' discrepancy is treated. In this research, this is left outside of the scope. However, it is a direction for future research.

Expert Group	Comment(s)
Notary (Mr. Boellaard)	3D visualisation of apartment rights beneficial for communication of ownership situation. Potential time and effort savings due to automatic extraction of legal space. This research can be the start of using BIM for other ownership related issues, such as maintenance.
NCG	How is the discrepancy between the 'as designed' and 'as built' dealt with?
Kadaster	IFC BIM could be good for source data of geometry of a 3D representation. For usage of IFC BIM in registration, clear views on the future 3D cadastre have to be developed. Describe the role of 3D geometry as a stepwise implementation: first 3D geometry in the notarial deed, later 3D geometry in the cadastral parcel map.

Table 7.1: Comments of various expert groups on proposed workflow

## 7.4 CASE STUDY CONCLUSIONS

The case studies showed that it is possible to register apartment rights with a 3D representation in the notarial deed at the general workflow level. Both the process of registration of a new building and the sub-splitting of apartment rights have been described in a stepwise manner. The new concept legal space in the IFC developed in this thesis is applied to fictional buildings and filled with fictional apartment rights for these case studies. It has also been demonstrated that the concept legal space fits in the 3D cadastral viewer developed [Cemellini, 2018]. However, in the case studies, QGIS is primarily used as viewer since this software offers easy integration of WFS layers and the possibility to conduct transactions on a PostgreSQL/PostGIS database. A browser-based 3D visualisation is developed but is not capable of splitting apartment rights.

The developed workflow has been presented to multiple experts in the field such as a notary, employees of the cadastre and NCG members. The comments were mostly positive, and provided insight for future work directions, which are all listed in Section 8.5.



# 8

## CONCLUSIONS

The main goal of this research is to enrich the IFC data format with legal space in order to register apartment rights in the Netherlands with a 3D representation instead of a 2D drawing in the notarial deed. Therefore, both the IFC data format has been researched and the Dutch law concerning apartment rights. From this law analysis, requirements are formed for registering apartment rights with a 3D representation instead of a 2D drawing. This 3D representation is extracted from an IFC file that is enriched with legal space. This legal space is added in such a manner that it conforms to the current IFC standards that are present in the AEC industry in the Netherlands.

The concept of legal space in the context of apartment rights is defined as the exclusive usage and access rights to a particular area of a building. In the Dutch legal system, an owner of an apartment right in a building owns the entire building, but only has access to the areas which are described in the notarial deed. These areas are often visualised through a 2D floorplan. The aforementioned areas are either shared space, such as hallways and stairwells, or private space, such as the dwelling area and storage units or parking spaces. An example of this 2D drawing can be seen in Figure 8.1.

### 8.1 RESEARCH QUESTIONS

To draw conclusions from this research, the research questions stated in Section 1.3 are answered. The main question of this research was:

*How can the IFC data model possibly be extended to automatically extract legal spaces for apartment rights for registration in the Dutch cadastre?*

The legal space is added to the IFC data format with a cadastral information user defined property set. This is a customised set of attributes that are added to the *IfcSpace* element. This allows for the possibility to identify the legal situation of all spaces that form a building. All required information that is necessary to create a representation that can be part of a notarial deed is present in the attributes of the user defined property set. For instance the type of the space, whether it is shared or private, and an identifier to which apartment a certain space belongs. This method is developed such that it fits both the IFC data standard and the current guidelines concerning standardised IFC usage in the Netherlands.

To show the IFC file enriched with legal space can be used to register apartment rights, a proof of concept is developed. The proof of concept describes the complete process that starts with enriching an IFC file with legal space and ends with apartment rights registered by the cadastre with a 3D representation. Two use cases have been described to show how this process would work with IFC BIM files.

But before the chain of events can be described of this proof of concept, it is import to specify what exact additions are required to enrich an IFC BIM with legal space in the first place, and what this legal space exactly entails. Therefore, the first subquestion is answered:

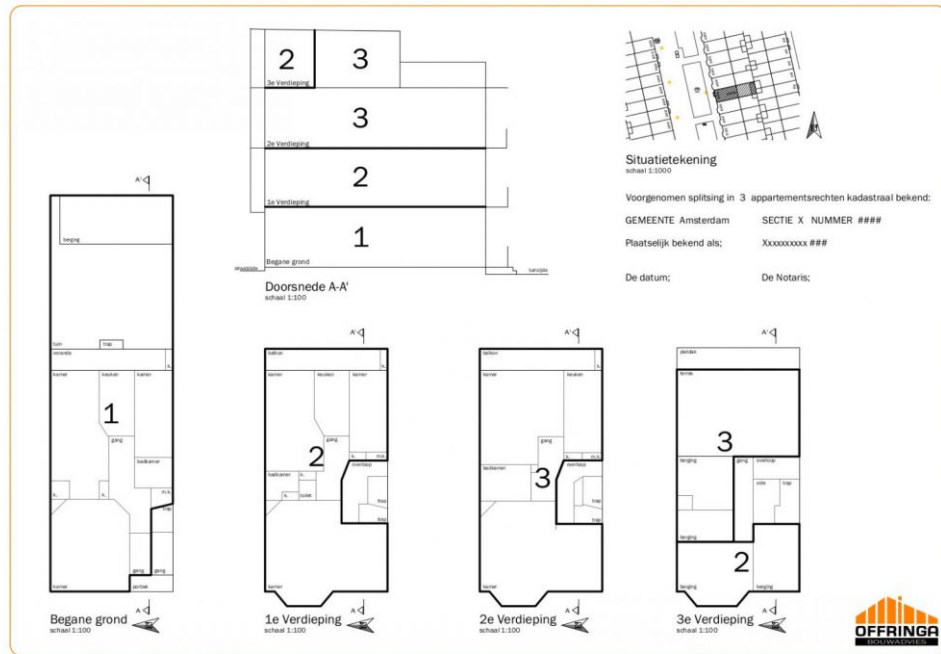


Figure 8.1: Example of 2D drawing in notarial deed, retrieved from <https://offringa-bm.nl/splitsingstekening/>.

1. What model additions or guidelines can be part of future registration in order to add legal spaces to the IFC data model?

A cadastral information user defined property set is created to add legal spaces to the IFC data model. The element *IfcSpace* in the IFC data format is the geometric representation of legal space in the proposed solution. This element is found to be the best fit to represent legal space in the context of the registration of apartment rights in the Dutch legal system. To register apartment rights, a notarial deed has to be formed. According to the current requirements of 2D drawings in the Dutch law, new requirements have been proposed to apply to a 3D representation. This design choice is made by the author for two main reasons.

The first reason is the scope of this research: the IFC should be used to form 3D information about registered apartment rights, but should not change the contents of apartment rights. The second reason is a pragmatic one. In case a legal registration method is changed, there should always be overlap during the transition. That means that the 'old' and 'new' form of registration should be operational at the same time. By proposing a solution that does not alter the contents of the apartment right laws, the transition is regarded to be more feasible than creating a solution that would require radical legal changes.

The requirements for 2D drawings translated to 3D representations in a notarial deed have lead to the following attributes that are added to the *IfcSpace* element:

- Apartment index number: this is a number to identify to which apartment a space belongs
- Cadastral parcel number: this is added to determine on which cadastral parcel a legal space is situated
- Complex number: this is a number that is assigned by the cadastre to a building complex to identify the relation between the building and the parcel
- Space type: the space is private or shared
- Municipality: the municipality in which the apartment rights is present

- Section: used for unique identification in the current cadastral registration system

To enable this information to be part of future registration, all IFC BIMs have to contain the cadastral information user defined property set applied to all *IfcSpaces*. This can be done by adding cadastral information as a requirement in the BIM Basic IDM [BIM Locket, 2018]. This is a document in which standardised IFC usage for in the Netherlands is described, and agreed to by hundreds of Dutch companies. To this document, the use of the cadastral information property set can be added, a concept of this possible addition is described in this research.

The cadastral information added to *IfcSpaces* should also be usable for other purposes than local visualisation of ownership situations of buildings. Therefore the geometry of the IFC should be extracted or converted in order to use it for other digital visualisation environments, such as cadastral database, GIS or a 3D cadastral viewers. Therefore the second research question was formed as:

*2. How can the new concept IFC legal space reuse geometric data from the existing concepts in IFC related to the physical objects?*

The new concept legal space is the *IfcSpace* element with the cadastral information user defined property set added to it. The geometric data of the *IfcSpace* element can be extracted and used in the 3D representation of a notarial deed to register apartment rights. It is assumed the IFC files that are enriched with legal space are compliant with the BIM Basic IDM. A result of that is that the IFC file is geo-referenced correctly, and therefore the *IfcSpace* elements part of the file are also geo-referenced correctly. This leads to the possibility of legal spaces to be registered with geometry that can be referenced to with the real world coordinate system on the ground by adding the cadastral user defined property set.

The geometric data of the *IfcSpace* elements is converted to a LADM compliant geometry definitions. That means the geometry is stored in a standardised way and can be recognised and used internationally. This also allows for the geometry to be used in visualisation tools such as GIS systems and many other visualisation tools. To be sure the correct information is reused, and that the legal space is defined in a correct manner in order to serve cadastral registration, the third sub-question is:

*3. How can the IFC files enriched with legal spaces be checked for consistency and correctness?*

The specifications for the cadastral information are put in a ruleset to which an IFC file can be tested. The ruleset is a commonly used testing mechanism for IFC files, and the cadastral information can also be tested this way as well. A cadastral ruleset is developed in this research in order to test whether the legal space is modelled correctly in the legal space enriched IFC. This ruleset has been conceptually added to an existing ruleset that tests for the requirements of the BIM Basic IDM. When the legal space is checked within the IFC file and found to be correct, the legal space is extracted to a LADM compliant database. In this database, the legal space is checked for overlap. This overlap with other legal spaces cannot be checked in the IFC, because the IFC BIM only is a model for one building. The extracted legal space in the cadastral database represents all apartment rights, and new legal space that is requested to be registered can only be added if there is no overlap with existing apartment rights.

## 8.2 CASE STUDIES

Two case studies are carried out in this research in order to show that the proposed solution of adding a cadastral information user defined property set can be used for the registration of apartment rights with a 3D representation. The workflow is based on the current process to register apartment rights, but has been adapted to use the legal space extracted from IFC files instead of 2D drawings.

The case studies showed that it is possible to enrich an IFC BIM with legal space, automatically extract the legal space to a (LADM compliant) database and visualise it. The first case study can be seen in Figure 8.2. An IFC BIM (Figure 8.2a) is enriched with legal space. All *IfcSpaces* (Figure 8.2b) are enriched with the cadastral information user defined property set (Figure 8.2c). The legal space is automatically extracted (Figure 8.2d) and visualised, together with other existing apartment rights, in a 3D viewer (Figure 8.2e). Experts have evaluated the proof of concept as promising for a base for future research involving IFC BIM in cadastral registration.

## 8.3 DISCUSSION

The developed proof of concept covers the entire chain of events for the registration of apartment rights with a 3D representation in the notarial deed that is extracted from an IFC BIM that is enriched with legal space. However, some parts of this proof of concept are only briefly described or on a conceptual level. Therefore, criticism on this research has to be pointed out.

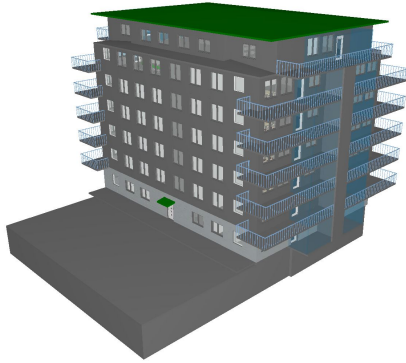
First of all, many assumptions had to be made to sketch a scenario in which it is possible to register 3D apartment rights. This research focused mainly on enriching the IFC file format with legal space. However, the proposed solution is only as valuable as the way it is communicated to others. Therefore, a more clear framework of a 3D cadastral system should have been designed to communicate the proposed solution more understandably.

Another point of criticism is that only the *IfcSpace* element in combination with a user defined property set is used to model the new concept legal space. When these legal spaces are extracted, an apartment building has limited details. For placing this research in academic context, it was initially the plan to use the full 3D cadastral viewer prototype of Cemellini [2018], but due to time limitations, only the same visualisation platform (Cesium JS) is used for visualisation in the research, see Figure 8.2f. Having a working Cesium JS viewer with the same capabilities as the 3D viewer prototype could help to communicate the findings in this research in a better way.

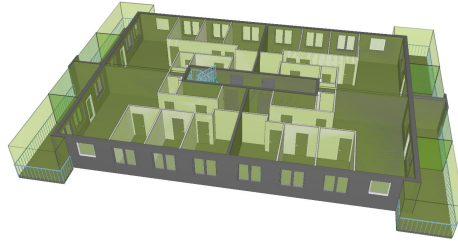
Criticism regarding the proposed chain of events in the developed proof of concept is that the legal space extraction method is unidirectional. IFC files can be enriched with legal space, this legal space is extracted and stored in a database. However, the proof of concept does not provide information in the other direction. Therefore, the legal space in the database cannot be used directly to automatically create an IFC file that is enriched with legal space.

## 8.4 CONTRIBUTION AND REFLECTION

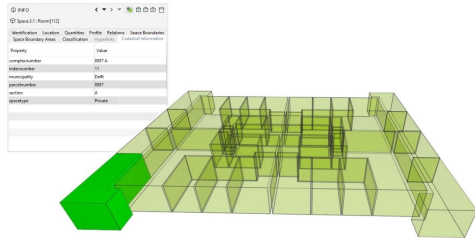
In this thesis a proof of concept is developed to show how IFC BIMs can be enriched with legal space and used as 3D representation in a notarial deed to register apartment rights. The proof of concept adds to the field of Geomatics that it shows a potential method on how use the IFC data format to register legal space for land administration purposes, in particular apartment rights in the Netherlands. However, it also offers a context for definitions of legal space in other legal systems by



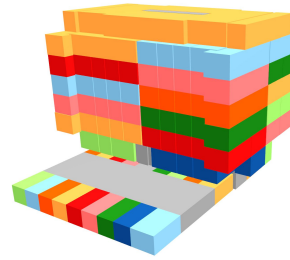
(a) IFC BIM of apartment building



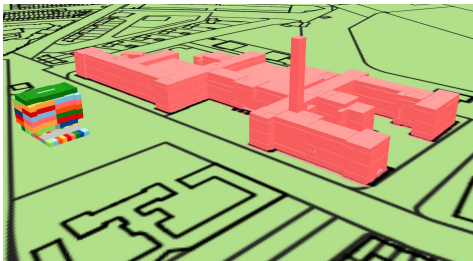
(b) IfcSpaces of third floor of the apartment building. IfcSpaces highlighted in green.



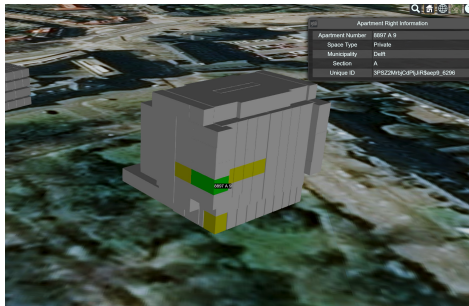
(c) IfcSpaces enriched with legal space



(d) Extracted legal space



(e) Legal space of apartment building together with the legal space of the TU Delft Architecture faculty on the cadastral parcel map



(f) Legal space of apartment building visualised in Cesium JS

Figure 8.2: Visualisation of enriching an IFC BIM with legal space, extracting the new concept legal space, and visualisation. Figure (a), (b) and (c) visualised in Solibri Model Viewer [Solibri, 2019], Figure (d) and (e) in QGIS [QGIS, 2019] and Figure (f) in Cesium JS [Cesium, 2019]

showing the extensibility of the cadastral user defined property set by applying it to other elements than *IfcSpaces*, such as *IfcWall* and *IfcFloor* elements. After researching the Dutch law, it was determined that for apartment right registration in the Netherlands the *IfcSpace* element was sufficient to create the new concept legal space.

In a broader academic context, this thesis showed the conclusions of [Oldfield et al., 2017] concerning IFC usage for cadastral registration was a good base to continue research on. This thesis also showed the potential of the IFC BIM usage as source data for the 3D cadastral viewer prototype developed by [Cemellini, 2018]. For future research, i.e. by Kalogianni [OTB, 2018], this thesis could be used to show the value of reusing geospatial data of the IFC for land administration.

## 8.5 FUTURE WORK

Many future research directions can be identified in this thesis. This future research segment aims to show which parts of this research could be extended. To structure the future research directions, three general topics have been identified: (1) legal, (2) technical/BIM, (3) standardisation.

### 8.5.1 Legal future work directions

These topics concern the legal aspects of this research.

- Research on the explicit and implicit links between the physical objects and the legal space. In this thesis, the *IfcSpace* object is used to model the legal space, and it is proposed to identify them as private space or shared space as meant in the Dutch Civil code. This is a specific way of modelling the legal space in relation to the *IfcSpace*, but it is important to be aware that there can be a difference between a physical object (with geometry) and a legal object, such as ownership [Aien et al., 2013]. These differences in other legal systems concerning the definition of legal space have to be further researched in order to make the proposed solution better extensible to other systems.
- Defining other legal space objects than *IfcSpaces*: i.e. airspace, water, underground or unbounded objects such as a rooftop terrace. This research has been focused on apartment rights in building complexes, which resulted in the description of spaces with physical boundaries, such as walls, floors, and ceilings. However, apartment rights can also be applied to unbounded objects such as a rooftop terrace. Further research is necessary to describe such spaces in an IFC BIM whilst fitting as much as possible in the current legal situation.
- Research the legal status of boundaries in other countries where there are other rules for defining boundaries or non-physical boundaries. The scope of this research is the legal situation concerning apartment rights in the Netherlands. However, the usage of IFC BIM to describe legal space should also be applicable to other systems than the Dutch legal system. Therefore, research has to be conducted to the describing, amongst others, the boundary description in other legal systems.
- Future research for in the Dutch context could be more focused on the addition of 3D representations in a notarial deed for the registration of apartment rights. A research question for that topic could be: *How can 3D geometry extracted from an IFC BIM enriched with legal space as described by Meulmeester (2019) be embedded in the Dutch law to be part of a notarial deed to register apartment rights?*

### 8.5.2 Technical and BIM future work direction

The following research directions focus on the IFC BIM aspect and other technical topics:

- Research to improve the browser-based viewer: research on an interface and system architecture for transactions in the Cesium JS viewer to change legal information of apartment rights, such as the initial registration and splitting of apartment rights. This interface could allow notaries and the cadastre to register apartment rights in 3D, and assign complex numbers to buildings. In this research, QGIS is used, but this is expert software and not browser based. The viewer should also support the creation of new boundaries for the purpose of sub-splitting existing apartment rights. A possible research question could be: *What requirements can be identified for a 3D cadastral system that allows for the digital registration of apartment rights in the Netherlands in the developed prototype of Cemellini [2018].*
- In this research, it is assumed that IFC BIMs are created according to guidelines ([BIM Locket, 2018; Rijksvastgoedbedrijf, 2013]). But when the IFC BIM is used for land administration purposes, checking procedures will have to be designed due to the important role of the BIM, such as registering ownership situations. Basic checks have been designed during this research, but not all possible checks have been designed. One of these checks that still needs to be developed is to assess with an automated process if the coverage of legal space of the building is complete.
- Research the 'as designed and as built discrepancy'. As has been pointed out during an expert session with the NCG, differences between the designed IFC BIM and the building after construction can occur. These differences have to be processed or registered in order to correctly use the IFC BIM as a source for legal space.
- The usage of the *IfcZone* object for grouping of spaces. The most important reason is to model disconnected parts of an apartment (such as the storage unit and parking space).
- Research the requirements for the precision and accuracy of the geometry in an IFC BIM. This has been left outside of the scope of this research. However, it is important to have a known accuracy and precision in the geometric representations of legal spaces when they are used for the registration of ownership rights. Also, the conversion implications of the reprojection of WGS 84 coordinates to RD (EPSG:28992) and NAP (Dutch local height datum) for correct geo-referencing have to be researched.

### 8.5.3 Standardisation future work directions

These future research topics concern the standardisation of the usage of legal space:

- Make the proposed cadastral property set not user defined but an official IFC standard. When this property set would become part of the standard property sets in the IFC, it can serve land administration systems worldwide.
- The LADM mapping of legal space in the IFC with help of *IfcZones* for grouping of *IfcSpaces* as one LA\_BAUnit. In this research, only the *IfcSpace* object has been used to develop a new concept legal space in the IFC. But *IfcZones* can group the *IfcSpaces* into zones, these grouping then have to be mapped such that an *IfcZone* can represent a LA\_BAUnit.





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- Vandysheva, N., Sapelnikov, S., Van Oosterom, P., De Vries, M., Spiering, B., Wouters, R., Hoogeveen, A., and Penkov, V. (2012). The 3D cadastre prototype and pilot in the Russian Federation. *Proceedings FIG Working Week 2012, Territory, environment and cultural heritage, Rome, Italy, May 6-10, 2012*.
- Vonthron, A., Koch, C., and König, M. (2018). Removing duplicated geometries in IFC models using rigid body transformation estimation and flyweight design pattern. *Visualization in Engineering*, 6(1):2–2.
- Wix, J., Nisbet, N., and Liebich, T. (2008). Using constraints to validate and check building information models. In *ECPPM 2008 Conference, Sophia Antipolis, France*, pages 467–476.



# A | 2D DRAWING

In [Figure A.1](#) a 2D drawing can be seen that could be part of a notarial deed to register apartment rights. All legal requirements, as can be read in [Section C.2](#), are met.

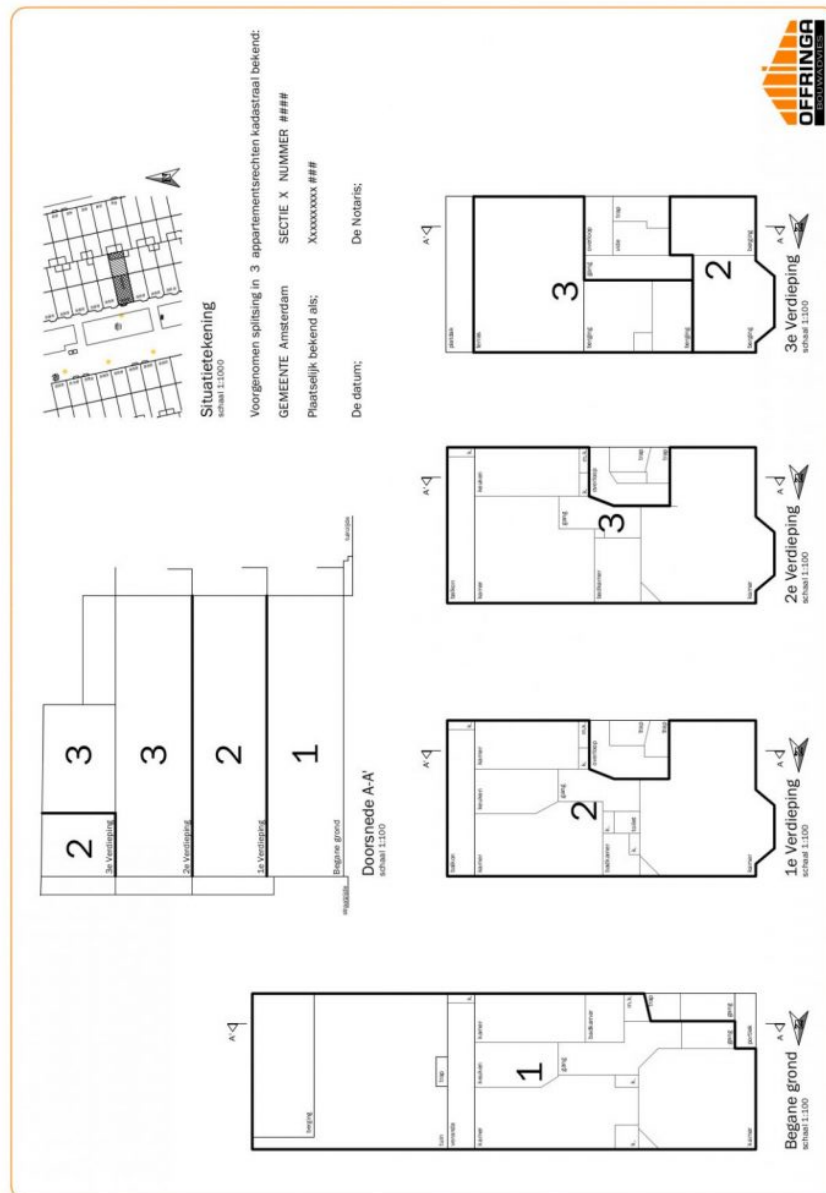


Figure A.1: 2D drawing of an apartment in a notarial deed. Retrieved from <https://offringa-bm.nl/splitsingstekening/>





# B

## COMMON PROPERTY SET: PSET SPACE COMMON

This appendix contains an IFC common property set of the *IfcSpace* element. This property set is formed by the buildingSMART consortium.

Name	Property Type	Data Type	Definition
Reference	IfcPropertySingleValue	IfcIdentifier	Reference ID for this specified type in this project (e.g. type 'A-1')
Category	IfcPropertySingleValue	IfcLabel	Category of space usage or utilization of the area. It is defined according to the presiding national building code.
FloorCovering	IfcPropertySingleValue	IfcLabel	Label to indicate the material or finish of the space flooring. The label is used for room book information and often displayed in room stamp.
WallCovering	IfcPropertySingleValue	IfcLabel	Label to indicate the material or finish of the space flooring. The label is used for room book information and often displayed in room stamp.
CeilingCovering	IfcPropertySingleValue	IfcLabel	Label to indicate the material or finish of the space flooring. The label is used for room book information and often displayed in room stamp.
SkirtingBoard	IfcPropertySingleValue	IfcLabel	Label to indicate the material or construction of the skirting board around the space flooring. The label is used for room book information and often displayed in room stamp.
GrossPlannedArea	IfcPropertySingleValue	IfcAreaMeasure / AREAUNIT	Total planned area for the space. Used for programming the space.
NetPlannedArea	IfcPropertySingleValue	IfcAreaMeasure / AREAUNIT	
PubliclyAccessible	IfcPropertySingleValue	IfcBoolean	Indication whether this space (in case of e.g., a toilet) is designed to serve as a publicly accessible space, e.g., for a public toilet (TRUE) or not (FALSE).
HandicapAccessible	IfcPropertySingleValue	IfcBoolean	Indication whether this space (in case of e.g., a toilet) is designed to serve as an accessible space for handicapped people, e.g., for a public toilet (TRUE) or not (FALSE). This information is often used to declare the need for access for the disabled and for special design requirements of this space.
ConcealedFlooring	IfcPropertySingleValue	IfcBoolean	Indication whether this space is declared to be a concealed flooring (TRUE) or not (FALSE). A concealed flooring is normally meant to be the space beneath a raised floor.
ConcealedCeiling	IfcPropertySingleValue	IfcBoolean	Indication whether this space is declared to be a concealed ceiling (TRUE) or not (FALSE). A concealed ceiling is normally meant to be the space between a slab and a suspended ceiling.

Figure B.1: Common Space Property Set. Source: [http://www.buildingsmart-tech.org/ifc/IFC2x3/TC1/html/psd/IfcProductExtension/Pset\\_SpaceCommon.xml](http://www.buildingsmart-tech.org/ifc/IFC2x3/TC1/html/psd/IfcProductExtension/Pset_SpaceCommon.xml)



**C.1 DUTCH CIVIL CODE; BOOK 5, REAL PROPERTY RIGHTS,  
TITLE 5.9 APARTMENT RIGHTS, SECTION 5.9.1 GEN-  
ERAL PROVISIONS.**

The English translation of the Dutch Civil Code Book used for this theses and partially present in this Appendix is written by [Goossens \[2014\]](#).

**c.1.1 Article 5.106, Paragraph 4**

An apartment right is a share in the assets (registered properties) which are involved in a split up, and which share includes the exclusive right to use certain parts of the building, which parts are to be used, according to their functional arrangement, as a separate private unit. The share may include the exclusive right to use certain parts of the land belonging to that building. In the situation referred to in paragraph 2 the share includes the exclusive right to use certain parts of the bare land plot, which parts are to be used, according to their functional arrangement or denomination, as a separate private section of land.

*Authentic text: "Onder appartementsrecht wordt verstaan een aandeel in de goederen die in de splitsing zijn betrokken, dat de bevoegdheid omvat tot het uitsluitend gebruik van bepaalde gedeelten van het gebouw die blijkens hun inrichting bestemd zijn of worden om als afzonderlijk geheel te worden gebruikt. Het aandeel kan mede omvatten de bevoegdheid tot het uitsluitend gebruik van bepaalde gedeelten van de bij het gebouw behorende grond. In het geval van lid 2 omvat het aandeel de bevoegdheid tot het uitsluitend gebruik van bepaalde gedeelten van het stuk grond, die blijkens hun inrichting of aanduiding bestemd zijn of worden om als afzonderlijk geheel te worden gebruikt."*

**c.1.2 Article 5.108, Paragraph 1**

The owners have towards each other the duty to realise and preserve the construction and functional arrangement of the building and of the relating land in accordance with the applying provisions of the notarial deed by which their apartment rights have been established.

*Authentic text: "De appartementseigenaars zijn jegens elkander verplicht de bouw, de inrichting van het gebouw of de inrichting of aanduiding van de grond tot stand te brengen en in stand te houden in overeenstemming met het daaromtrent in de akte van splitsing bepaalde."*

**c.1.3 Article 5.109**

1. The split up is effectuated by a notarial deed, drawn up for this purpose, followed by its registration in the public registers for registered property.
2. A drawing is attached to the original notarial deed by which the apartment rights are established, indicating the boundaries of the different parts of the

building and of the related land that are to be used as separate private units and of which, according to the notarial deed, the exclusive right of use is included in one individual apartment right. The drawing must meet the requirements of law referred to in Article 3:16, paragraph 2, of the Civil Code as set for registrations in the public registers for registered property.

3. Where the provisions of this Title speak of a notarial deed by which the apartment rights have been established, this includes the drawing meant in the previous paragraph, unless the contrary appears from a provision.

Authentic text:

1. *"De splitsing geschiedt door een daartoe bestemde notariële akte, gevolgd door inschrijving van die akte in de openbare registers."*
2. *"Aan de minuut van de akte van splitsing wordt een tekening gehecht, aangevende de begrenzing van de onderscheidene gedeelten van het gebouw en de grond, die bestemd zijn als afzonderlijk geheel te worden gebruikt en waarvan volgens de akte het uitsluitend gebruik in een appartementsrecht zal zijn begrepen. De tekening dient te voldoen aan de eisen, krachtens de wet bedoeld in artikel 16 lid 2 van Boek 3 voor de inschrijving daarvan te stellen."*
3. *"Waar in de bepalingen van deze titel wordt gesproken van de akte van splitsing, is hieronder de tekening begrepen, tenzij uit de bepaling het tegendeel blijkt."*

#### c.1.4 Article 5.111

The notarial deed by which the apartment rights are established must contain:

- (a) a description of the place where the building and related land is located;
- (b) a precise description of the parts of the building and related land that are to be used as separate private units, which may occur by referring to the drawing meant in Article 5:109, paragraph 2, and an allocation of these parts to the individual apartment rights (making it clear that a specific apartment right encloses the exclusive right to use that part as private unit);
- (c) the cadastral number and description of the different apartment rights, with indication of the apartment owner of each individual apartment right;
- (d) the internal arrangements applying to the apartment owners, that have to entail the provisions of a precise defined standard regulation which is registered in the public registers at the place where the notarial deed itself must be registered.

Authentic text: *"De akte van splitsing moet inhouden:*

- (a) *de vermelding van de plaatselijke ligging van het gebouw of de grond;*
- (b) *een nauwkeurige omschrijving van de onderscheiden gedeelten van het gebouw of de grond, die bestemd zijn om als afzonderlijk geheel te worden gebruikt, welke omschrijving kan plaatsvinden door verwijzing naar de in artikel 109 lid 2 bedoelde tekening, alsmede de vermelding voor elk dier gedeelten, tot welk appartementsrecht de bevoegdheid tot gebruik daarvan behoort;*
- (c) *de kadastrale aanduiding van de appartementsrechten en de vermelding van de appartementseigenaar;*
- (d) *een reglement, waartoe geacht worden te behoren de bepalingen van een nauwkeurig aangeduidmodelreglement dat is ingeschreven in de openbare registers ter plaatse waar de akte moet worden ingeschreven."*

### c.1.5 Article 5.112, Paragraph 4

The internal arrangements may include as well a regulation for the use, management (administration) and maintenance of the individual parts which are intended to be used exclusively by the apartment owners as their own separate private units. Such a regulation can imply that the General Meeting of Owners is competent to deny an apartment owner, or the one who exercises his rights, the possibility to use his private unit in a specific way, although this may only be the case for important reasons to be mentioned in the arrangements itself.

Authentic text: *"Het reglement kan inhouden een regeling omtrent het gebruik, het beheer en het onderhoud van de gedeelten die bestemd zijn om als afzonderlijk geheel te worden gebruikt. Een zodanige regeling kan inhouden dat de vergadering van eigenaars bevoegd is een appartementseigenaar of degene die zijn rechten uitoefent, om nader in het reglement aangegeven gewichtige redenen het gebruik van deze gedeelten te ontzeggen."*

## C.2 UITVOERINGSREGELING KADASTERWET 1994

Authentic text, taken from [https://wetten.overheid.nl/BWBR0006596/2017-03-10/#Hoofdstuk2\\_Artikel16](https://wetten.overheid.nl/BWBR0006596/2017-03-10/#Hoofdstuk2_Artikel16). Text used in this research is translated to english by the author.

*Uitvoeringsregeling Kadasterwet 1994, Hoofdstuk 1, Artikel 6:*

1. *Onverminderd artikel 5, voldoet de tekening, bedoeld in artikel 109, tweede lid, van Boek 5 van het Burgerlijk Wetboek, aan de volgende vereisten:*
  - (a) *elk blad waaruit de tekening bestaat, vermeldt de kadastrale aanduiding van het in de splitsing in appartementsrechten betrokken perceel en elk blad wordt door de betrokken notaris gewaarmerkt;*
  - (b) *de tekening bevat plattegronden van de begane grond en van de ver diepingen en zonodig ook doorsnede en aanzichten van het gebouw, alsmede van de bij het gebouw behorende grond;*  
The drawing shows the differences of distinguishable floor plans of the building and the ground that are meant to be used as separate complete unit. And the exclusive access and usage of the areas in the apartment right will be incorporated as well as the location of these areas in relation to the other areas of the building or ground;
  - (c) *de tekening geeft de begrenzing aan van de onderscheidene gedeelten van de gebouwen en de grond, die bestemd zijn als afzonderlijk geheel te worden gebruikt en waarvan het uitsluitend gebruik in een appartementsrecht zal zijn begrepen, alsmede de ligging van die gedeelten ten opzichte van de overige gedeelten van de gebouwen of van de grond;*  
The drawing shows the differences of distinguishable floor plans of the building and the ground that are meant to be used as separate complete unit. And the exclusive access and usage of the areas in the apartment right will be incorporated as well as the location of these areas in relation to the other areas of the building or ground;
  - (d) *op de tekening is binnen de begrenzing van elk zodanig gedeelte een nummer in arabische cijfers als kenmerk van dat gedeelte aangebracht;*  
In the drawing an index number as characteristic is visible for every separate area with arabic numbers;
  - (e) *voor het geval dat een zodanig gedeelte bestaat uit niet belendende onderdelen of uit onderdelen welke grondvlakken niet in hetzelfde horizontale vlak zijn gelegen, bevat de tekening binnen de begrenzing van elk dier onderdelen hetzelfde*

*nummer als kenmerk van dat gedeelte;*

In case a separate unit as such is built up from spaces that are not neighbouring each other or in the same horizontal plane, every space should have the same index number as identification of the unit identifier;

- (f) *de nummers, bedoeld onder d en e, vormen een met het cijfer één aanvangende, zonder onderbreking opklimmende reeks der natuurlijke getallen;*

The cadastral apartment index number, as meant in item 6.1.d and 6.1.e form a continuous ascending series of natural numbers,;

- (g) *de onder c bedoelde begrenzingen zijn zoveel mogelijk door een onuitwisbare lijn van in het oog vallende dikte aangegeven, welke dikte gelijk is in alle op de tekening voorkomende afbeeldingen, uitgezonderd de in het derde lid bedoelde situatieschets. Daarnaevens zijn ter verduidelijking arceringen toegelaten, afzonderlijk gekozen voor verschillende gedeelten die voor gebruik als afzonderlijk geheel zijn bestemd;*

- (h) *de appartementsindex is aangebracht zoveel mogelijk in het midden binnen de begrenzing van elk voor gebruik als afzonderlijk geheel bestemd gedeelte, en in het onder e bedoelde geval, zoveel mogelijk in het midden binnen de begrenzing van elk der aldaar bedoelde onderdelen;*

The cadastral apartment index number is placed as much within the confines of the areas meant for private usage;

- (i) *de schaal van de op de tekening voorkomende afbeeldingen is niet groter dan 1 : 100 en niet kleiner dan 1 : 200;*

The scale of the map does not exceed 1:100 and is not smaller than 1:200;

- (j) *elk blad waaruit de tekening bestaat, vermeldt de voor de desbetreffende afbeelding gebruikte schaal;*

Every drawing that makes up the map contains the scale that is used.

- (k) *de richting van het noorden is op elk blad van de tekening door een pijl aangegeven.*  
The direction of the north should be present on all drawing that make up the map.

2. *Het is toegestaan dat de in het eerste lid bedoelde tekening van elk gedeelte van de gebouwen, dat voor gebruik als afzonderlijk geheel is bestemd, de onderlinge ligging van alle tot dat gedeelte behorende vertrekken en andere ruimten aangeeft.*

3. *In afwijking van het eerste lid, onder i, kan een kleinere schaal worden gebruikt voor een situatieschets, welke met het oog op het aan het slot van het eerste lid, onder c, omschreven vereiste, op de tekening wordt aangebracht, als overzicht van de overige afbeeldingen.*

4. *In geval van ondersplitsing in appartementsrechten worden de omringde nummers, bedoeld in artikel 28, derde lid, op de tekening gesteld in de linkerbovenhoek van elk van de desbetreffende gedeelten.*

# D | 3D REPRESENTATION REQUIREMENTS

This appendix contains a list of all requirements formed in [Chapter 5](#) for a 3D representation in a notarial deed to establish apartment rights.

1. It should be clear a part of the building is meant for private usage.
2. Distinction between private and shared parts of the building has to be visible.
3. The cadastral parcel number on which the apartment is registered is present in the 3D representation.
4. The spaces which enclose the exclusive right to use as private unit should be identifiable as such and relatable to the contents of the notarial deed.
5. The cadastral apartment index number should be present in all spaces which belong to an individual apartment.
6. The 3D representation should visualise the private and shared spaces as described in the notarial deed.
7. A private area in the 2D drawing has the same meaning and legal values as in the 3D representation.
8. If a space in the 3D representation is not marked as private, it becomes shared space by default.
9. The 3D representation visualises the entire building in which the apartments are located.
10. The location of the private and shared spaces in relation to the rest of the building should be visible.
11. The 3D representation should visualise all spaces belonging to a specific apartment right with the same cadastral apartment index number, even if they are not connected.
12. The 3D representation needs to be oriented in relation to the true North.
13. The 3D representation has to be geo-referenced.
14. The spaces which enclose the exclusive right to use as private unit should contain the address' house number belonging to those spaces. (Optional)





# E | IFC2X PLATFORM ARCHITECTURE

Technical architecture of IFC data model. The Cadastral Domain has been added as concept to show what this architecture would look like if the Cadastral user defined property set would be part of the official IFC standard.

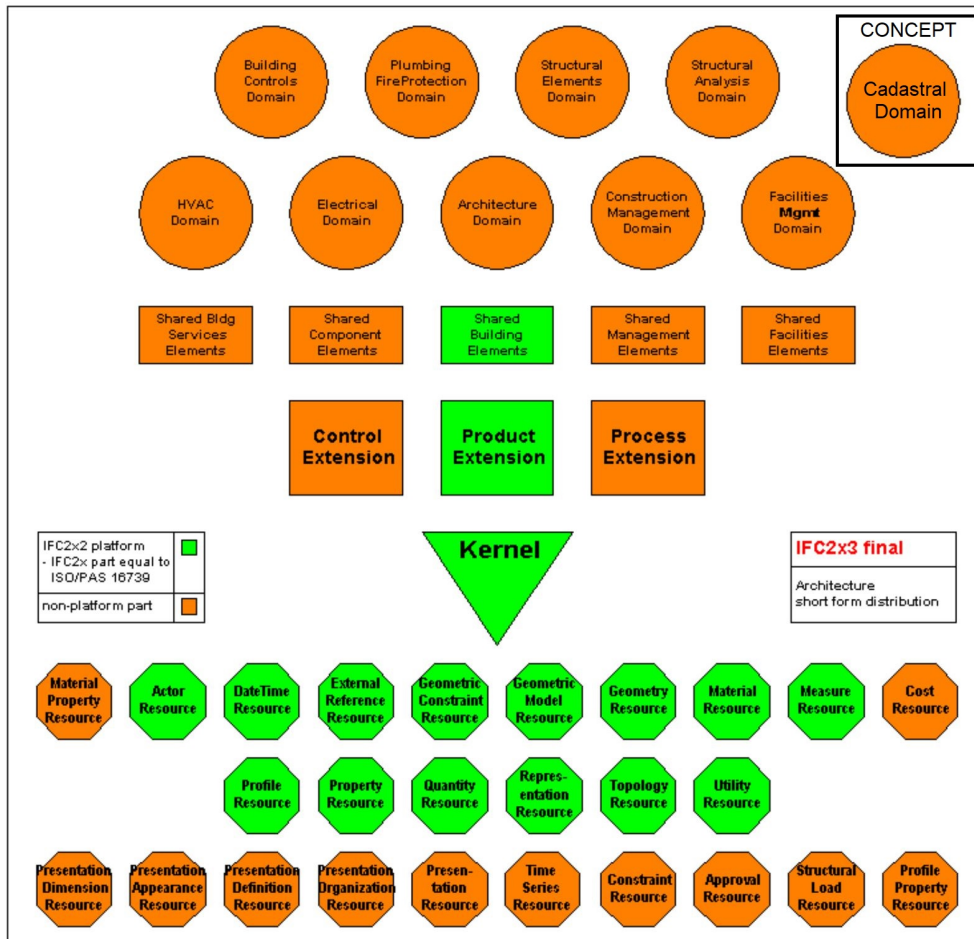


Figure E.1: IFC technical architecture with added concept 'Cadastral Domain'. Image taken from [buildingSMART, 2010] and edited by the author.





# IFC DATA FORMAT HIERARCHY OVERVIEW

This appendix offers background information on contents of the hierarchy model of the IFC.

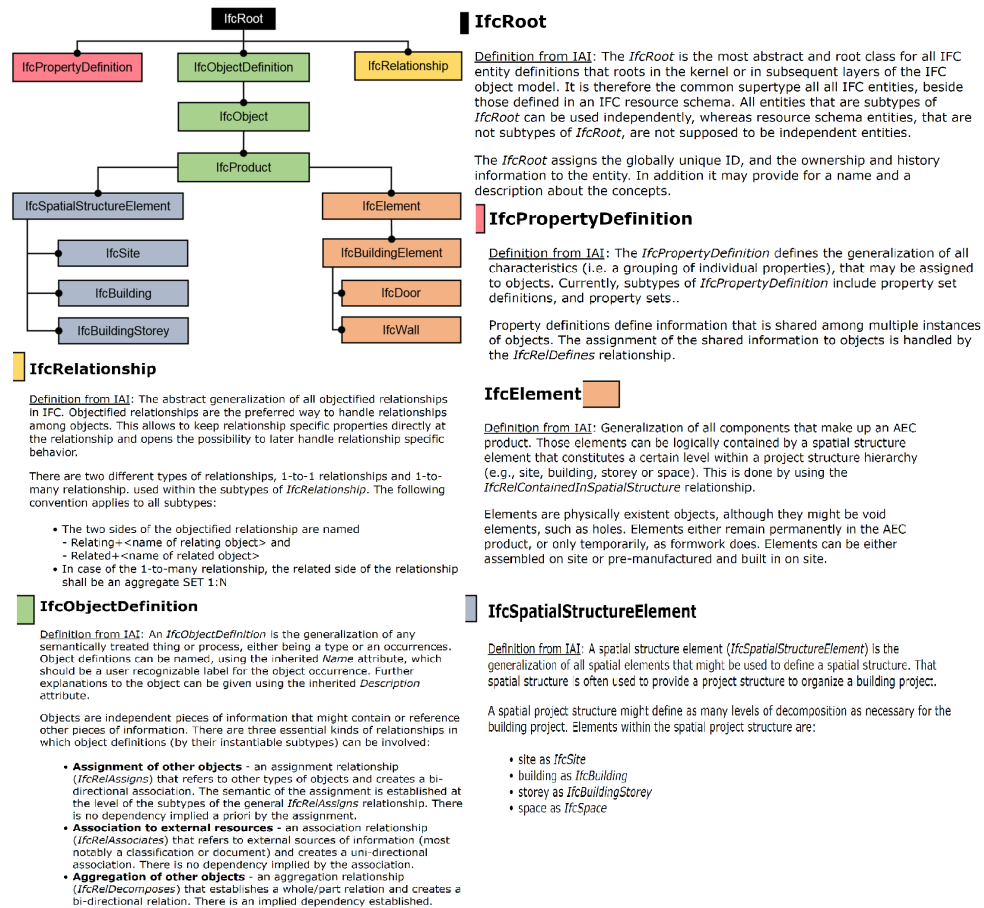


Figure F.1: IFC hierarchy overview with definitions from buildingSMART. Image taken from Vonthron et al. [2018] and <http://www.buildingsmart-tech.org/>, edited by the author.



# G | BIM BASIC IDM

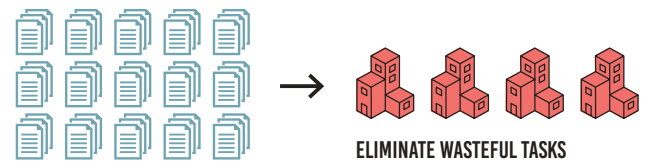
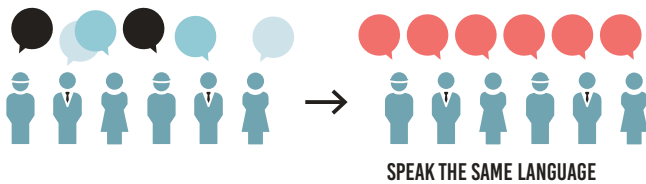
The BIM basic IDM as taken from <https://www.bimloket.nl/upload/documents/downloads/BIMbasisILS/BIM%20basis%20ILS%20EN.pdf> and <https://www.bimloket.nl/upload/documents/downloads/BIMbasisILS/BIM%20van%20structuur%20naar%20de%20gewenste%20output%20obv%20Basis%20ILS.pdf>



# BIM BASIC INFORMATION DELIVERY MANUAL (IDM)

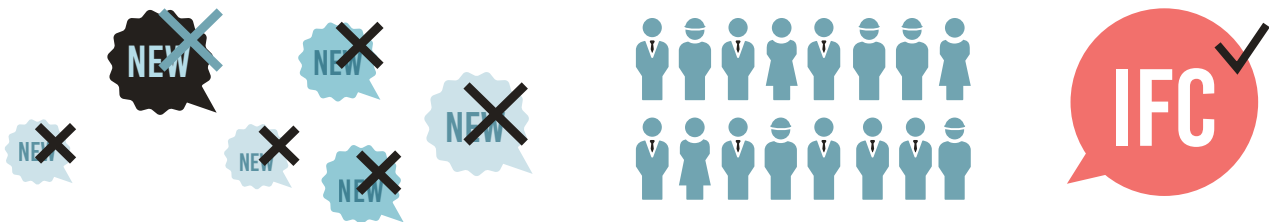
## 1. WHY ARE WE SHARING THIS INFORMATION UNAMBIGUOUSLY?

In order to secure and reuse information more efficiently and effectively.



## 2. HOW ARE WE GOING TO SHARE THIS INFORMATION UNAMBIGUOUSLY?

Knowledge and practical experiences have shown that there is a significant common denominator. We are not developing something new, but rather using existing structures, based on openBIM IFC.



## 3. WHICH STRUCTURE WILL WE USE?

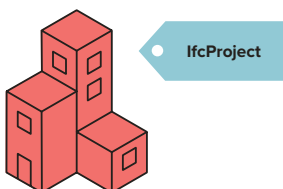
The agreements listed below help ensure that every involved party will always be able to find and supply the right information in the right place.

### Checklist basic information delivery manual

#### 3.1 FILE NAME

- ✓ Ensure that uniform and consistent naming is used for (discipline) models within the project.

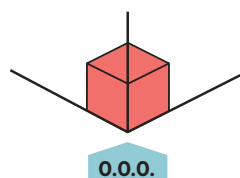
**example:** <Building>\_<Discipline>\_<Component>



#### 3.2 LOCAL POSITION AND ORIENTATION

- ✓ The local position of the building is coordinated and close to the origin.

**tip:** use a physical object as point of origin, positioned at 0.0.0., and also export this to IFC.

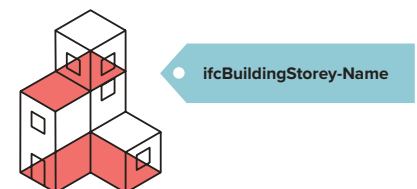


#### 3.3 BUILDING STOREYS AND NAMING

- ✓ Name Building Storeys only as ifcBuildingStorey-Name.
- ✓ Allocate all objects to the correct level.
- ✓ Within a project, ensure that all involved parties consistently use exactly the same naming, that can be numerically sorted with a textual description.

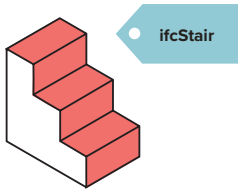
**example 1:** 00 ground floor

**example 2:** 01 first floor



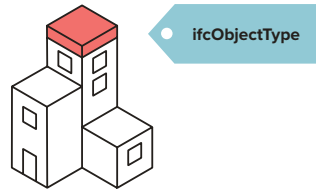
### 3.4 CORRECT USE OF ENTITIES

- Use the most appropriate type of BIM entity, both in the source application and the IFC entity.  
**example:** slab = ifcSlab, wall = ifcWall, beam = ifcBeam, column = ifcColumn, stair = ifcStair, door = ifcDoor etc.



### 3.5 STRUCTURE AND NAMING

- Consistently structure and name objects.
- Correctly enter the object TYPE (ifcType, ifcObjectType or ifcObjectTypeOverride).
- Where applicable, also correctly enter the Name (ifcName or NameOverride).  
**example:** roof insulation, type: glass fibre



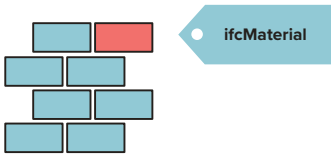
### 3.6 CLASSIFICATION SYSTEM

- Apply the existing classification system used in the relevant country.
- Allocate to each object an element code.  
**example:** 22.11



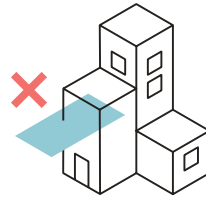
### 3.7 OBJECTS WITH CORRECT MATERIALIZATION

- Allocate objects with a material description (ifcMaterial).  
**example:** limestone



### 3.8 DUPLICATES AND INTERSECTIONS

- There are no duplicates or intersections permitted. Make sure this is checked in IFC.



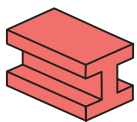
### LEARNING TO SPEAK THE SAME LANGUAGE IS SOMETHING WE DO TOGETHER.

When naming objects, consider whether the name meets the following criteria. Double-check this, and know what information you are sharing.

- Significant
- Understandable
- Logical
- Insightful
- Consistent
- Recognizable

## 4. HOW CAN WE SECURE OTHER/FUTURE OBJECT INFORMATION?

Object information is secured in the correct properties and property sets as defined in IFC.



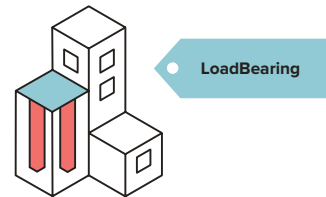
**example:** for beams, the properties FireRating, LoadBearing and IsExternal are part of the Pset\_BeamCommon.

#### ifc Property Sets

- Pset##Common; LoadBearing
- Pset##Common; IsExternal
- Pset##Common; FireRating
- ....

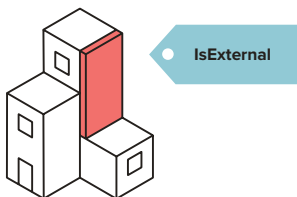
### 4.1 LOADBEARING

- Allocate objects, when applicable, with the property LoadBearing [True/False].



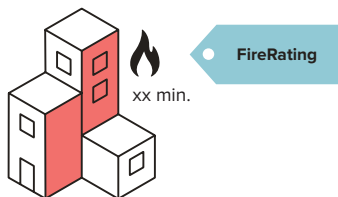
### 4.2 IS EXTERNAL

- Allocate objects, when applicable, with the property IsExternal [True/False]  
**tip:** both inner and outer faces of the façade have the property IsExternalTrue.



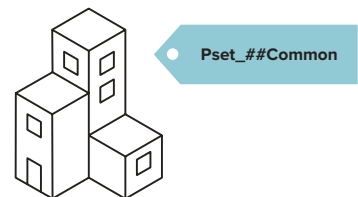
### 4.3 FIRERATING

- Allocate objects, when applicable, with the property FireRating.  
**example:** Apply the existing standard used in the relevant country.



### 4.4 PROJECT SPECIFIC

- Define which IFC properties you are using for each specific project.







This appendix contains a description and screendump of the developed FME [Safe Software, 2019] workbench that can automatically extract legal space from IFC files and store them in a LADM compliant database. With minor changes this workflow can also convert the *IfcSpaces* to a B3DM file to use in browser based 3D visualisation on the Cesium JS platform. The following list describes in a stepwise fashion how legal space enriched IFC files can be converted, the screen dump of this workbench can be seen in Figure H.4.

1. Load the IFC that is enriched with legal space. It is important to set the 'Read IfcSpace geometries' to 'Yes', and 'Read property/quantity sets as' to 'Geometries'. These settings allow for loading the IfcSpaces together with the cadastral user defined property set into the workbench and can be seen in Figure H.2.
2. Merge the geometry together with attributes with a GeometryPropertyExtractor transformer to create one entity per *IfcSpace*. This entity consists of the geometry of an *IfcSpace* with the attributes of the cadastral user defined property set.
3. With the 'Attribute Exposer' transformer, all required attributes of every *IfcSpace* become visible to the workbench, see Figure H.1.
4. Extract the geometry of the *IfcSpace* with an XQuery via a 'GeometryExtractor' transformer:

```
for $geom in //geometry
where $geom/@fme_geometry_name = 'Body'
return number($geom/fme_id)
```

The output is extruded solid geometry.
5. Coerce the geometry of the *IfcSpace*, this will convert the solid geometry to the type `fme_composite_surface`. In PostGIS, this geometry is of 'PolyhedralSurfaceZ' type.
6. Reproject the coordinates from WGS 84 to ETRS:28992 (Dutch local projection). When the conversion is done for visualisation in Cesium JS, keep the CRS WGS 84.
7. Set height to zero. Elevation could be extracted from the *IfcSite* object in IFC, but is not performed in this workbench.
8. Create the apartment number of the space by concatenating the parcel number, 'A' and the index number.
9. Remove unnecessary data of the *IfcSpace* with 'Attribute Remover' transformers
10. Store data in PostGIS/PostgreSQL database with 'PostGIS' writers, the database schema can be seen in Figure H.3.
11. For Cesium JS visualisation: create a B3DM tileset with the 'Cesium 3D tile' writer.

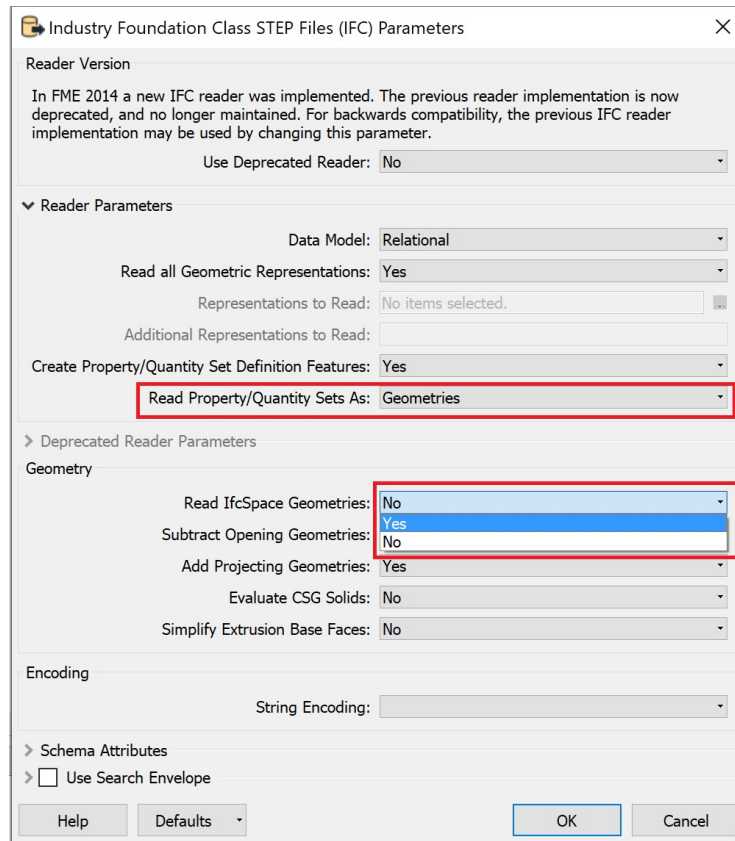


Figure H.1: FME settings that enable to read the geometry if *IfcSpaces* and the attributes of the cadastral user defined property set

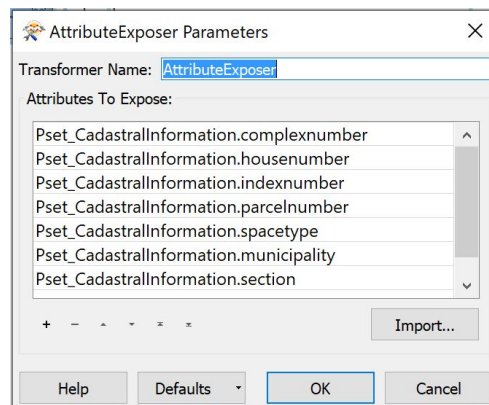


Figure H.2: With the 'Attribute Exposer' transformer the cadastral user defined property set attributes are added to the *IfcSpace* entity

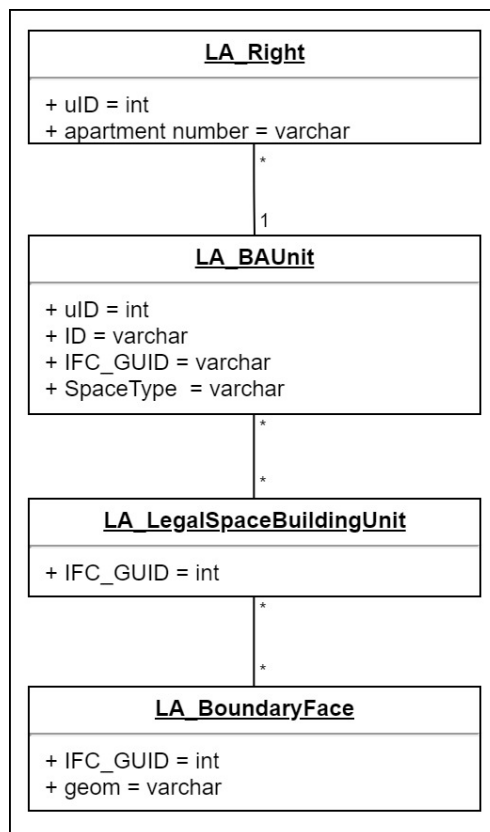


Figure H.3: Database Schema

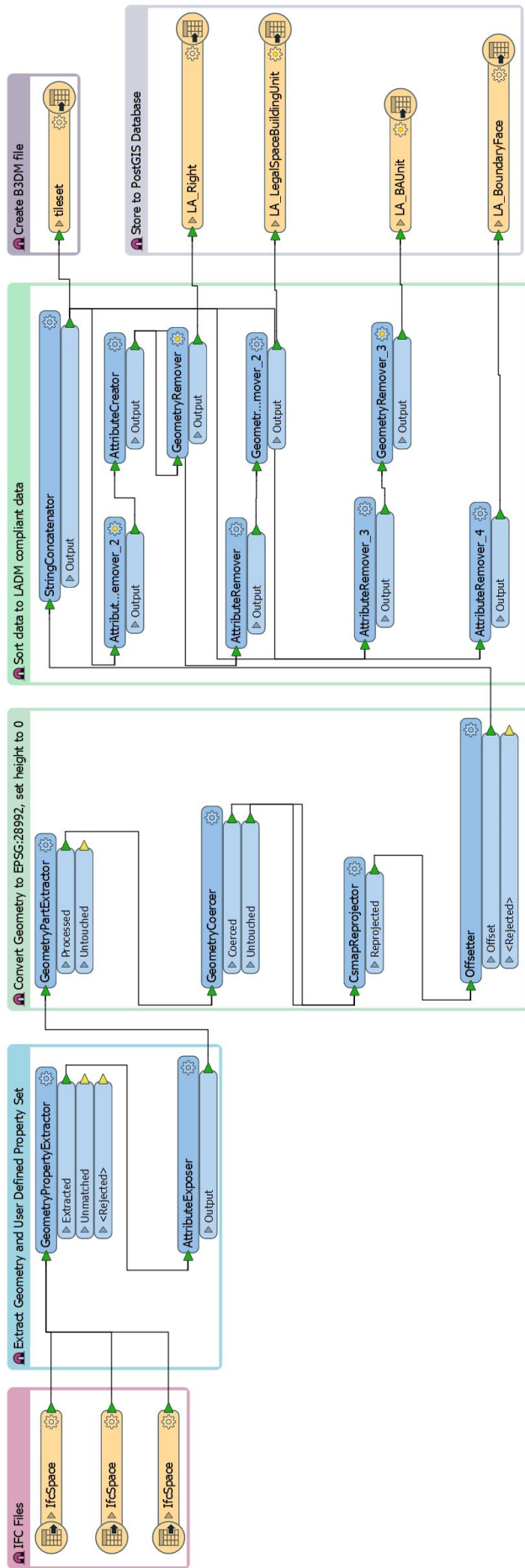


Figure H.4: FME Workbench overview.

## COLOPHON

This document was typeset using L<sup>A</sup>T<sub>E</sub>X. The document layout was generated using the `arsclassica` package by Lorenzo Pantieri, which is an adaption of the original `classicthesis` package from André Miede.



