Can Data from BIMs be Used as Input for a 3D Cadastre?

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Key words: BIM, Open BIM, Industry Foundation Classes (IFC), Business Process Modelling Notation (BPMN) Information Delivery Manual (IDM), Smart Cities, 3D Cadastre, as-designed BIM, as-built BIM

SUMMARY

Much work has already been done on how a 3D Cadastre should best be developed. An inclusive information model, the Land Administration Model (LADM ISO 19152) has been developed to provide an international framework for how this can best be done. While this generic framework encompasses a wide range of eventualities, it does not prescribe the data format. One existing source from which data could be obtained is 3D Building Information Models (BIMs), or more specifically in this context, BuildingSMART's Industry Foundation Class (IFC). Obtaining data is only one part of the process from moving from a 2D to a 3D Cadastre. An efficient collaborative workflow, preferably digital, also needs to be developed. This digital workflow would determine what the 3D Cadastre needs from a 3D BIM and the process of extracting it in addition to exchange requirements. Foundations, however, would need to be laid in order to facilitate this process. To begin with, in spite of the fact that the Industry Foundation Class (IFC) is already quite an extensive model, in order to satisfy the requirements of cadastral legal spaces it would need to be enriched further. Enriching it would enable data for a 3D Cadastre to be extracted from both as-designed and as-built BIMs. Experience has shown that process harmonization between organizations is non-trivial and dependent on specific organizations within countries Standardizing at an international level is therefore something wiser to avoid. However, a collaborative workflow described in BuildingSMART's Information Delivery Manual (IDM) is a useful illustration of how the involved actors could collaborate. Moreover, communicating the information extraction process of BIM data to 3D parcels to actors in the building world using their own *lingua franca* could be beneficial.

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1. INTRODUCTION

The twenty-first century is the century of Smart Cities, cities which are mapped to the last detail and which are used by a broad tapestry of stakeholders for seamless communication throughout the lifecycle of buildings (or other constructions) and cities at every level. Smart Cities are mapped in 3D and have buildings designed and managed by means of Building Information Models (BIMs). The mapping of buildings into 3D BIMs needs a 3D Cadastre or Land Registry to complement it with respect to the legal status of the objects, land and space. While this need has long been acknowledged in the densely-populated countries (areas), the Cadastral map remains based on 2D in spite of the fact that in reality property units include both height and depth. Creating a 3D system, as is being pioneered in several countries around the world, would have many advantages. One simple, cost-effective way to achieve a 3D Cadastre could be to adapt / design a development workflow from which it is possible to (re-) use information from existing BIMs to create 3D parcels.

Sections 2 and 3 of this paper further introduces the reader to respectively BIM and 3D Cadastre (and to the various open standards which would be used to achieve the goal of reusing data). In Sections 4 and 5 a specific use case and then a colloborative workflow are described to illustrate how this could be achieved in practice. Section 6 contains our main conclusions.

2. BACKGROUND BIM

The Building Information Council of the Netherlands (BIR) and the Dutch BIM Gateway (BIMLoket) define BIM as follows:

- Firstly, as the Building Information Model. This is a digital representation of how a (physical) building (including its facilities) is designed, is realized and how it ends up.
- Secondly, Building Information Modelling places more emphasis on the process, both alone and in partnership. It is about working independently and cooperatively on building projects with the help of exchanging/ sharing digital information models.

These two aspects of BIM have been developed by the industry with the aim of bringing the numerous threads of different information used in construction into a single environment' (BuildingSMART, Norway 2007). In turn, the need for many – often paper-based – documents is either eliminated or reduced by exchanging digital documents. BIM is also used to improve communication between parties. When it is used properly, good quality information which can be understood by all is on hand when it is needed. This is something which improves the construction process overall.

The world of BIM encompasses proprietary BIM, such as the products produced by Bentley or Autodesk and open BIM, represented by BuildingSMART. BuildingSMART's BIM standards, which are used in this research, are illustrated in Figure 1 below. It should be noted that the commercial products are increasingly supporting open BIM standards.

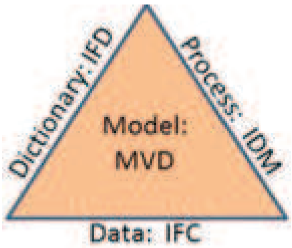

Figure 1. BuildingSMART's main open standards

The two standards used in particular in this article are the Information Delivery Manual (IDM) and the IFC (Industry Foundation Class).The IDM is a methodology used to capture and specify processes and information flow during the lifecycle of a facility (www.buildingsmart.org). The creation and maintenance of a facility, for example a complex construction project, involves many different participants. Knowing what information needs to be communicated between them and when is important. The IDM makes use of Business Process Modelling Notation (BPMN) and templates for Exchange Requirements in order to facilitate this process.

The IFC is a common data schema that makes it possible to hold and exchange relevant data between different software applications (www.buildingsmart.org). It promotes interoperability within the industry. The Lake Restaurant data set, for example, was made using Autodesk's Revit and then made available to all using the IFC standard. This standard allows it to be imported back into Revit but into many other applications as well.

3. BACKGROUND 3D CADASTRE

Land administration involves maintaining a cadastral mapping agency and a Land Titles office or Land Registry. In some countries these roles are maintained by a single organization, in others they are separate. These organizations involved are considered the governmental authority in each region or country where they administer land. As such, they have a pivotal role in the Smart City concept as a coordinating institution. It makes sense, therefore, that where possible, its data should be managed and maintained through the use of semantically-rich 3D Models. This will bring it in line with other developments in this field, for example BIM. Not only would it bring it in line, but reusing the rich content of BIM models based on open exchange standards would save on costs and provide an interoperable result. For instance, BIM geometry could be reused for 3D cadastral parcels. A considerable increase in property values, both public and private, mean that a clearer picture with relation to their property rights, restrictions and responsibilities – the 3D RRRs of the Cadastral world (Aien et al 2011) – is needed. For example, a 3D spatial representation derived from a BIM of an apartment spread across multiple rooms but belonging to one owner, could bring clarity to ensuing legal issues.

While BIM could be used to provide the geometry for a 3D Cadastre, the spaces themselves can be different from those defined by the BIM. While BIMs work with complex physical spaces, for example the rooms, corridors, walls and floors of a building, the legal space needs to work with only one space for a single property. This is in spite of this space containing a number of physical spaces (rooms) or parts of physical spaces (to the middle of the wall space). In this new legal space the boundary surface binds and defines the size of the spatial unit, and thus the right that an entity such as an owner can claim on it. This new legal space can be amply represented in open BIM exchange models.

A further example is the space which might need to be left around a pipe. Imagine a pipe situated at the bottom of someone's garden. The title deed specifies a restriction. This restriction is that nothing can be built over the pipe so that access can always be gained to it. Thus the legal space is not the pipe itself, but an certain extended space around it.

While BIM models physical infrastructure, the Land Administration Domain Model (LADM) works from the perspective of legal spaces. Its focus is on the 'rights, responsibilities and restrictions which affect land or water and that land's geometrical components' (Lemmen 2015). The LADM ISO 19152 is an open standard which has been adopted by the International Organisation for Standardisation (ISO). The LADM is a conceptual or information model but is not a data product specification. Thus, it does not detail how to deal with what it describes in practice, nor does not provide any region-specific solutions. For example, it does not provide any encoding during exchange using XML or data storage in a database. It is a 'descriptive standard' rather than a 'prescriptive standard' (Lemmen et al, 2015). Part of the challenge of extracting data from BIM for use in a 3D Cadastre is mapping the IFC information model to the LADM.

4. USE CASE: LAKESIDE RESTAURANT

The Lake Restaurant is a data set made available as an IFC file by the United Kingdom's National Building Specification. This specification is a case study project for the National BIM Library which is used to market the National BIM Library. This library contains proprietary and non-generic objects which are free to use and platform neutral so that they can be imported into BIM design projects (National Building Specification 2016). The data set is a complex design which is modelled down to the last detail. The data set is used within this paper to illustrate how legal spaces can best be taken from 3D BIMs. (National Building Specification 2016)

4.1 The Lakeside Restaurant in a 2D Cadastre

Buildings built above water pose a particular problem to a 2D Land Administration System. Imagine a situation where a privately owned parcel is situated above water belonging to the city council (government). Only the stilts that the building is built on make contact with the ground. Figure 2 illustrates how it could be registered. This method was used for a similar building in Amsterdam which was positioned above an underground carpark (Stoter et al 2012).

The round circles in Figure 2 represent 39 separate spatial units or parcels. There are a number of problems with this solution. The first is that on the basis of these records someone studying the records can only guess at what the building (Figure 3) looks like. The second lies in the maintenance of the records. Each one includes the rights, responsibilities and restrictions associated with the whole building. Not only would updating them all be prone to error but one could easily be inadvertently skipped while transferring the deed.

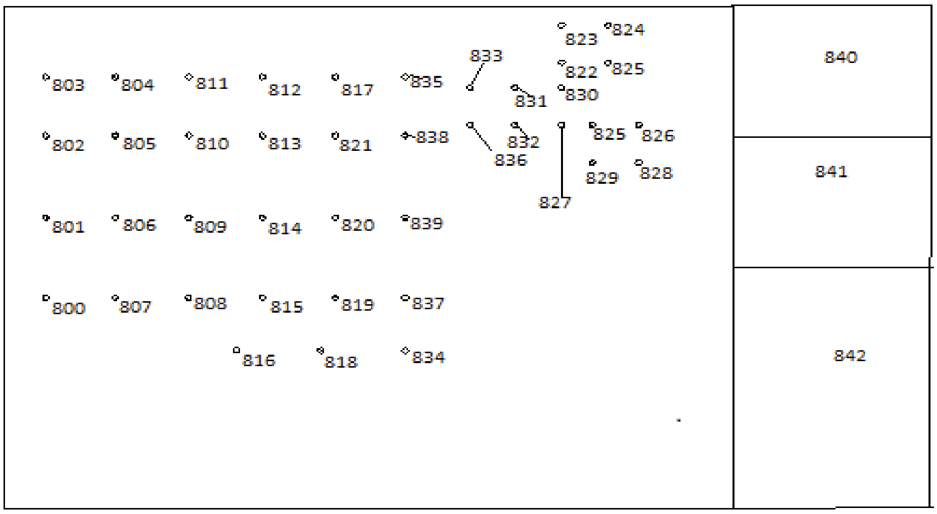

Figure 2. A construction built above water registered in a 2D Land Administration System. A separate spatial unit has been created for every pile foundation in the water

Figure 3. The Lakeside Restaurant thenbs.com

4.2 Industry Foundation Class's (IFC) Zones and Spaces Objects

IFC classes can also encompass virtual spaces (in addition to the physical spaces). While a physical space may be a room, a virtual space may be a collection of rooms grouped together for a specific purpose such as an energy analysis (Weise 2009). In turn spaces can be grouped together to form zones, such as one put together to assess the fire safety of a building. While the spaces within a zone are generally positioned adjacent to one another, they do not have to be (Liebich 2009). As a legal space is quite similar to such a virtual space, which can also encompass a number of volumes. Therefore, these spaces and zones are of particular interest in the context of a 3D Cadastre. IFC space boundaries can be defined at different levels. A first level space boundary is simply a shell, with no references to spaces outside it. A second level space boundary, however, does reference objects around it and is thus topological (Liebich 2009). Figure 4 illustrates how this works. Whereas a first level space boundary only references the six surfaces of Space 005 (floor, ceiling and four walls), second level space boundaries add an extra surface by means of more connection geometry to reference the existence of the wall between Space 003 and Space 004.

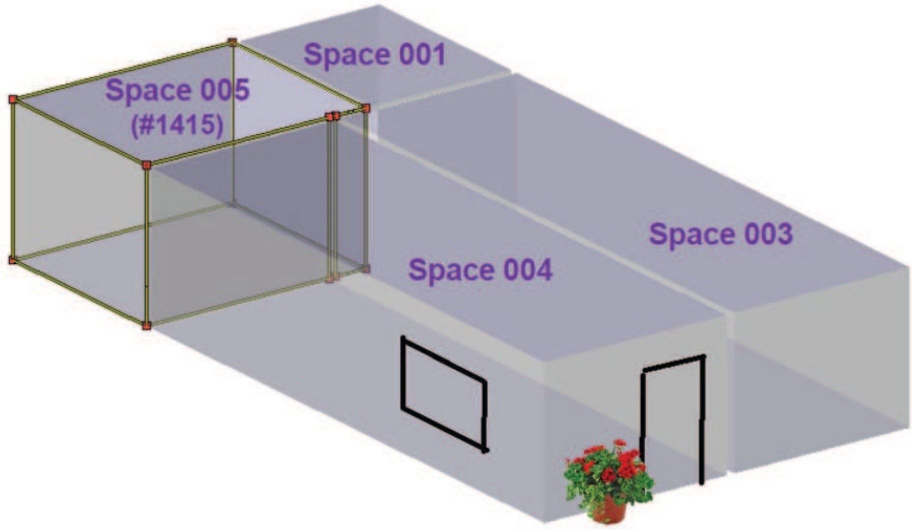

Figure 4. IFC topological 2nd level space boundaries (Weise 2009) with additions by author

4.3 The Lakeside Restaurant in a 3D Cadastre

An alternate method of registering the Lakeside Restaurant would be to do so in a 3D format. The data could be extracted from a 3D IFC model for use by a 3D Cadastre. The Lakeside Restaurant would be a particularly interesting space to register. To begin with, it is positioned above water. Not only is it positioned above property belonging to someone else but the boundary between the two properties is what could be described as an 'ambulatory natural boundary' (Thompson 2015). This means that the water levels beneath the building are not fixed, but rise and fall depending on the weather.

A further issue is that not only does the building encompass an open air (no top) outdoor deck, positioned above the water but that a number of other spaces within the building are not fully enclosed. One such space can be seen on the left in Figure 3 where an outdoor eating area is shielded by a roof and partially covered walls. The closed part of the Lakeside Restaurant can be mapped to an *IfcSpace* object. This space object could be enclosed by Space Level 2 boundaries (see Figure 4), thus making it a topological volume. Figure 5 illustrates such a conceptual mass. In it, the restaurant has been redrawn as a closed volume. The terrace has also been reformed, to illustrate that it is a limited space both below and above.

How can a legal 3D volume with the rights attached best be extracted from an existing IFC model? Virtual spaces/zones are a solution, but would need to be done manually by the building's designer (and reusing building geometry).

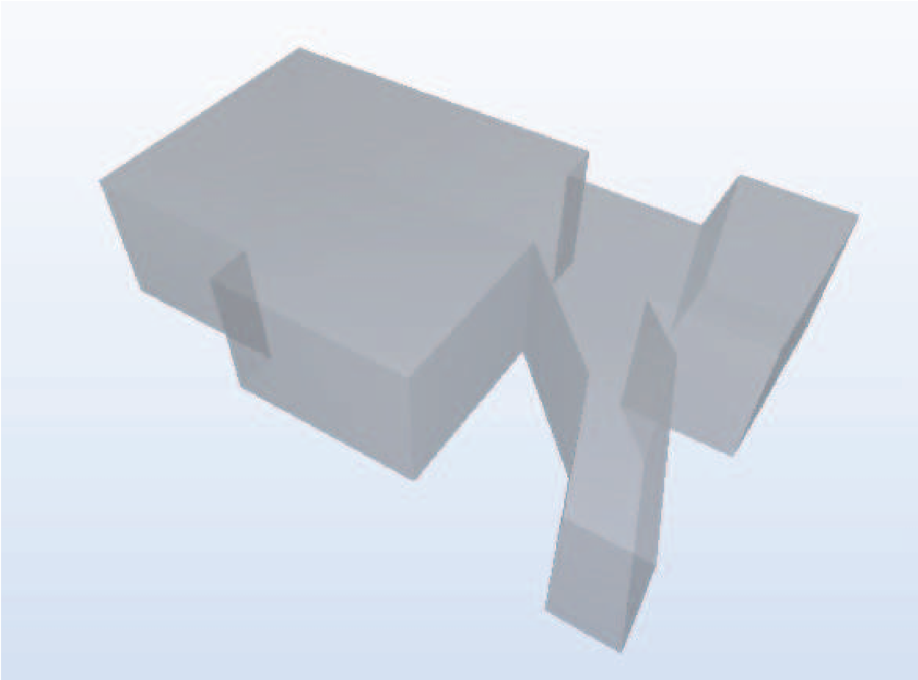

Figure 5. Conceptual Mass as IfcSpace object

The Lake Restaurant is a complex volume composed of partially-open and fully-enclosed spaces as well as fully-open spaces such as the outdoor terrace (Figure 7). One way in which to represent this would be through the use of the IFC's virtual spaces and zones, briefly introduced in 4.2. Using this capability, existing outdoor and indoor spaces could be connected up and stored with IFC second level boundaries. Zones can be virtual spaces, which makes them ideally suited to the concept of legal spaces. Unfortunately, as can be seen from Figure 6, the Lakeside Restaurant dataset does not include spaces and zones which means that this use case cannot illustrate their extraction.

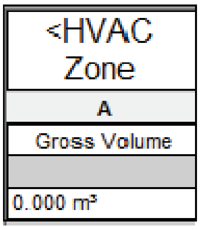

Figure 6. Illustration from Lakeside Restaurnt dataset which led to the conclusion that there are no zones (or spaces) to extract as no 'heating ventilation and airconditioning' zones have been defined

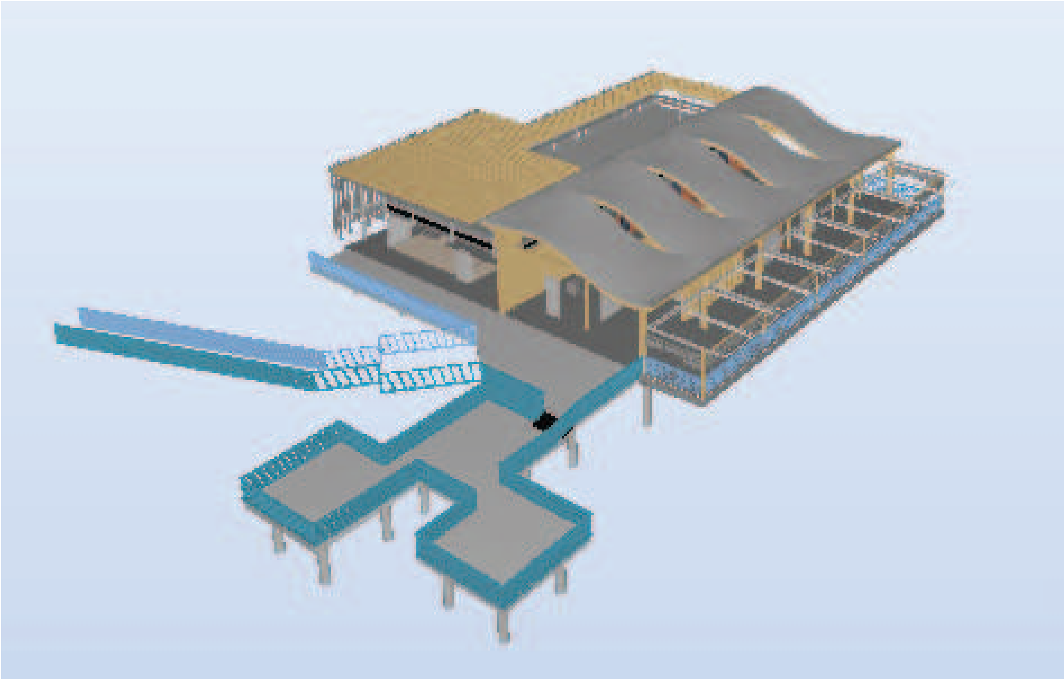

Figure 7. Pared back Lakeside Restaurant in IFC format showing fully-open outdoor areas

The second challenge, that of mapping the soft or ambulatory boundary formed by the water's surface to an *IfcSpace* level 2 space boundary, could be solved by adding a description, something which is allowed by both *IfcSpace* (Liebich 2009) and the LADM (Thompson 2015). *IfcSpace* has the following attributes *Name, Description, LongName* and *ObjectType*. The description attribute is illustrated a by the following example (Figure 8). As there are no restrictions on what can be put here (Liebich 2009) the fact that the space has a soft boundary could be mentioned. Ideally, however, a description would be added as an attribute to the level 2 boundary itself rather than to the space. At this point there are two descriptions, 2a and 2b. 2a, for example, 'occurs when there is a space on the opposite side of the building element providing the space boundary' (Weise 2009). Adding an attribute to the IFC data model would mean contributing to an already continually ongoing process. Initial discussions with a member of the IFC community have suggested the creation of a new topic for the Land Registry System would not be out of the question. Figure 8 shows how this adapted model with newly defined optional attributes for the Lake Restaurant's ambulatory boundary would look. Rather than mentioning that the space had a soft or ambulatory boundary in place of the ' Leisure and Dining' description, the description symbolised by a ' 3' would replace the ' 2a' in IfcRelSpaceBoundary.

```
#285=IFCSPACE('3LweZaMsz0nR$8x1w5Bjie', #6, 'W-001', $, 'Leisure and Dining',
#284, #300, 'Restaurant', .ELEMENT., .EXTERNAL., 0.0);
```

Figure 8. IfcSpace with Leisure and Dining attribute

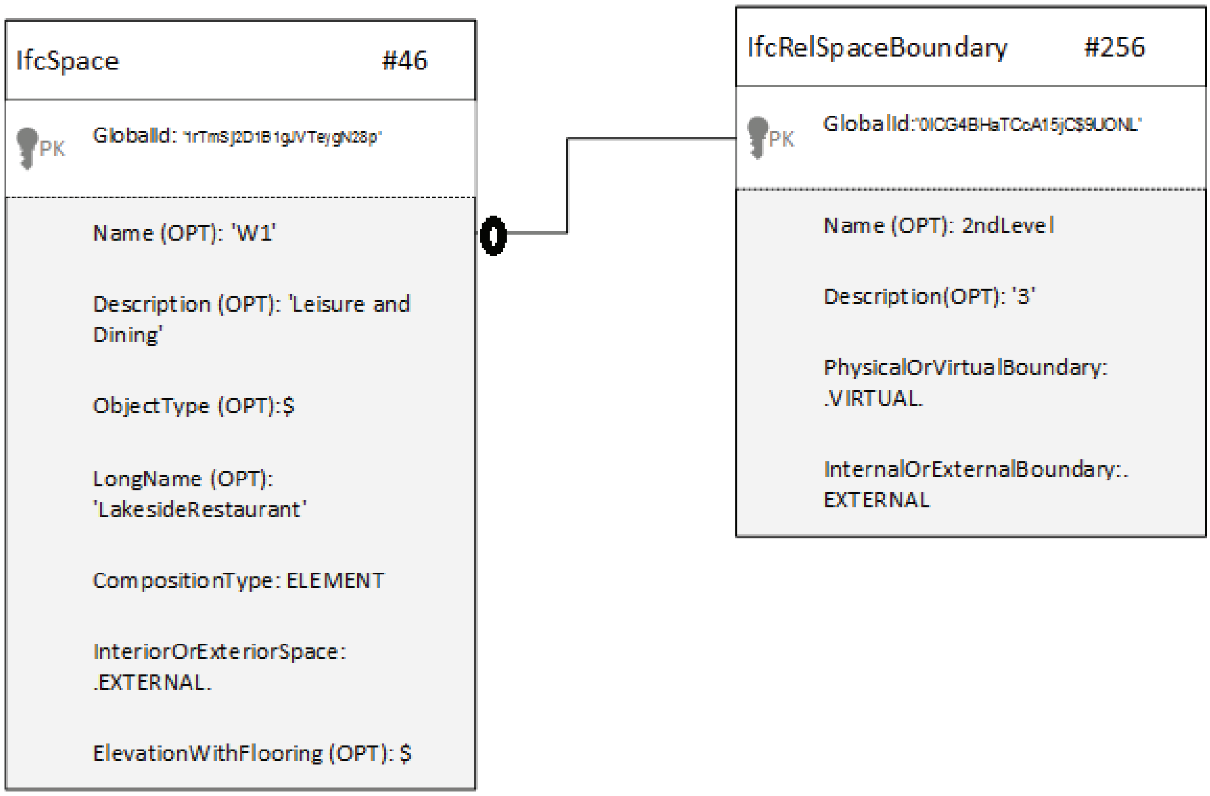

Figure 9. Extract from IFC model showing *IfcSpace* with attributes for a conceptual mass of the Lake Restaurant. The '3' in the IfcRelSpaceBoundary entity represents a proposed new description for an ambulatory boundary and replaces the original ' 2a'

5. MODELLING THE COLLABORATIVE PROCESS WITH IDM

A central goal of the presented research is obtaining 3D parcel data from BIMs already in existence. Key features would be selected from BIMs and recycled as legal spaces for input into a cadastral database. A collaborative workflow would further support the reuse of BIM data for 3D Cadastre purpose by improving the alignment of activities. Part of the process of gaining a building permit for a building would involve providing the Land Administration System with appropriate legal spaces. Figure 10 and Figure 11 illustrate this process. In order to make the process as clear as possible, text which would usually be referred to from the diagram itself using a number system has been left in the diagram.

Someone wanting to build or to renovate a house first seeks advice for example what can be built where and what cadastral regulations they should adhere to. They are also given access to a digital file of what has already taken place. They then set to work on a 3D BIM for the house. Part of this process is to create a number of space objects grouped into a zone to represent the legal spaces in the building. The resulting 3D BIM is tested digitally to see if it conforms to the advice the Land Registry gave in the original file. A definitive permit is requested and when it has been received the building is then constructed according to the design which has been submitted. During the building process things change, and the BIM which serves as the central point for the collaborative building process, with it. The 'as built' BIM becomes different to the BIM which was initially submitted to the authorities. The building is inspected and, where necessary, the cadastral regulations are enforced.

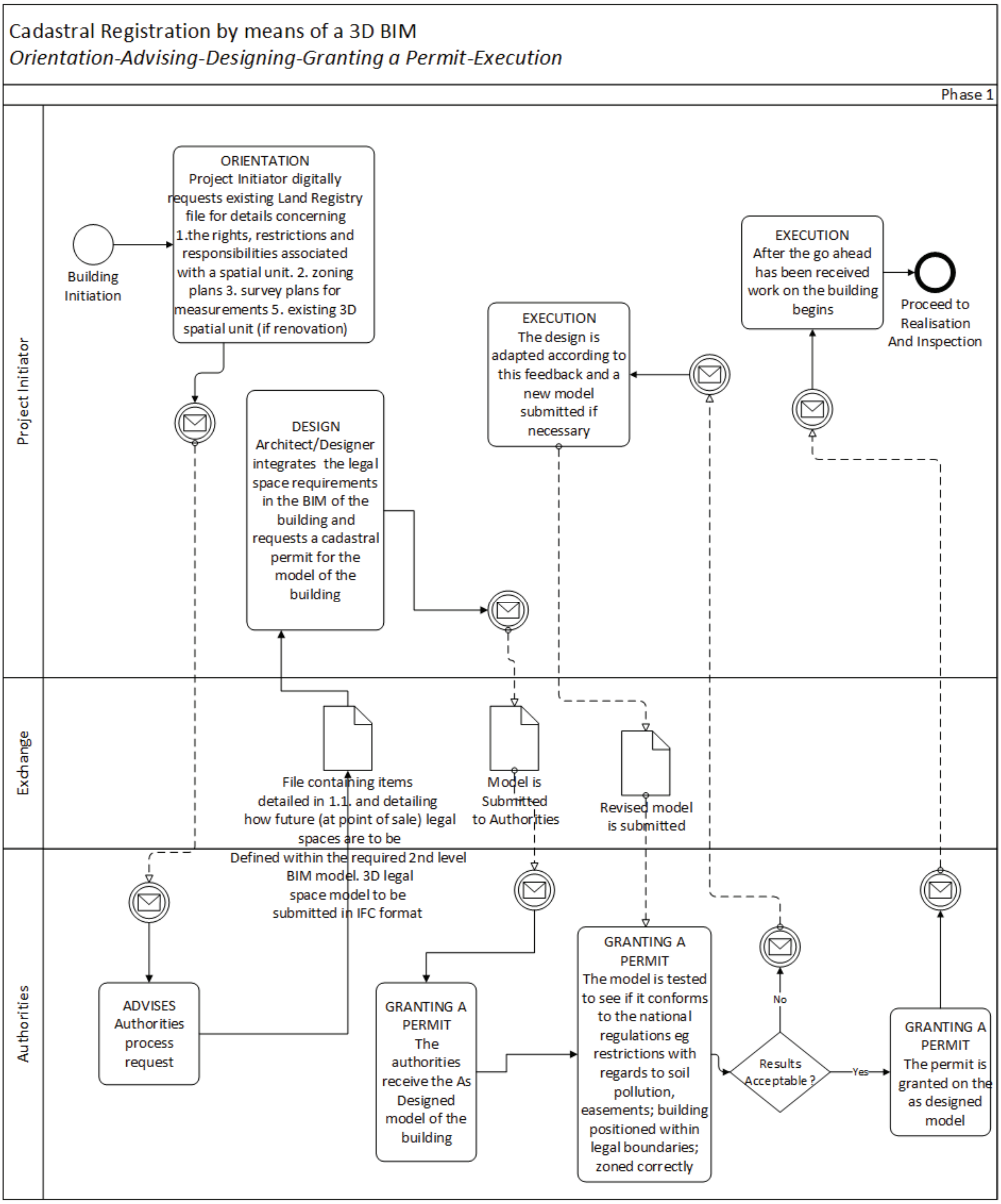

Figure 10 IDM Workflow: Cadastral Registration by means of a 3D BIM Phase 1

A further issue is that the building may subdivided and put up for sale in a different manner than was initially communicated. Thus the cadastral data base needs to have an 'as sold' data set for its records. Underpinning the entire process is the use of open BIM standards which ensure that the data can be used by many, for a variety of purposes and for a long time.

This workflow has been given in the manner of a BIM open standard (the IDM) in order to illustrate how different actors should collaborate. Communicating it in this manner could also be helpful when detailing cadastral requirements to a building project. This workflow has been modelled on a similar workflow proposed in the Netherlands for obtaining BIM data for building registrations (Pijpker et al 2015).

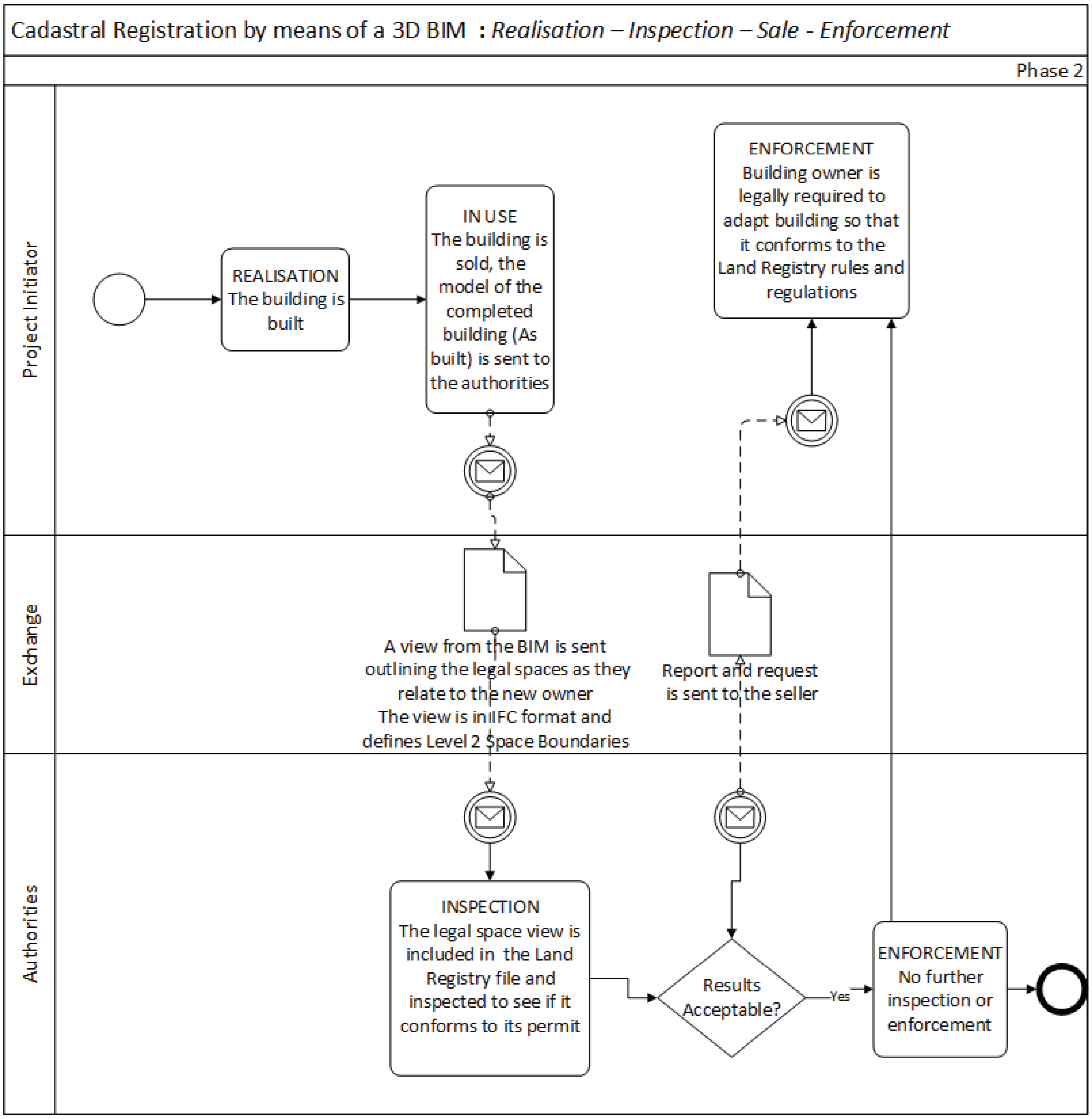

Figure 11. IDM Workflow: Cadastral Registration by means of a 3D BIM Phase 2

6. CONCLUSION

This paper has looked at how data can obtained from BIMs for input into a 3D Cadastre, first from the perspective of a use case 'The Lake Restaurant' and secondly by means of a workflow illustrated using an open BIM standard, the Information Delivery Manual.

Use of the IFC's virtual spaces and zones, designed for energy analyses could be a way for virtual cadastral legal spaces to be defined within BIMs. The spaces are able to be grouped into zones and can be number of non-adjacent, aggregate or intersecting volumes. This capability could prove very attractive to the complex shapes of modern buildings, but could also be used to encompass spatial units spread over different rooms in the same building.

The spaces defined within zones and thus forming a virtual legal space would need to have level 2 space boundaries in order to ensure a topological volume. This topological volume could in turn be used as data in a topological database and thus be used to generate an overview of legal spaces within the Netherlands. The IFC also includes a topological half space solid, which would allow the inclusion of 2D volumes, either separately or as a space within a zone.

The Lake Restaurant use case demonstrates the right of superficies and therefore is an ideal volume for showing why a 3D Cadastre is needed. While the idea of extracting topological spaces from the existing BIM was initially explored, the fact that many of the spaces were open made this impossible. Instead a new topological volume was built and the outdoor terrace was given its own volume above the water.

The fact that the Lake Restaurant was such a difficult space to register highlighted the need for a new topic and thus new semantics to be created within the IFC in order to define legal spaces. This means that a step further than simply achieving interoperability between the IFC and cadastral legal spaces by using the same semantics would need to be taken. The review and expansion of the IFC is an ongoing process which this proposed new topic would become a part of.

The workflow which forms the second half of the paper is based, in part, on the difficulties experienced in creating a legal space for the Lake Restaurant. Communicating cadastral requirements early in the design process would facilitate the process of obtaining legal spaces from BIM. While in many cases spaces can simply be extracted from BIMs at the end of the design process, legal spaces could also be defined at the beginning of the design process. Requiring that a conceptual mass of the plan of the building be sent to the cadastre for testing early on would ensure the presence of topological legal spaces for use by the cadastre. It is also a way to check that the building is being designed and built within cadastral regulations – the rights, restrictions and responsibilities associated with the spatial unit.

Future work will look further into the automated extraction of legal spaces in the form of *IfcZones* from other BIM models and at what new semantics might be required in order to do so. Furthermore, a central principle of a traditional 2D land registry system is that of an owner owning the volume above the 2D spatial unit up to infinity and below to the Earth's core. In the Lakeside Restaurant use case, the volume extends only to the water's surface. While it is possible to model the area above the terrace up to infinity using *IfcHalfSpaceSolid,* and to group this virtual space into a zone together the *IfcSpace* of the restaurant, it would form on odd spatial unit and the choice has been made in this case not to do so. However, being able to model partially unbounded spaces (using *IfcHalfSpaceSolid)* could be important in a 3D Cadastre and could form the topic for further future work.

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BIOGRAPHICAL NOTES

Jennifer Oldfield teaches teenagers and adults **(**Teaching English to Speakers of Other Languages –TESOL) and is an examiner for Cambridge ESOL. She first became involved in geographical information in 2008. She has worked as translator for Geonovum on two projects, firstly the City GML domain application for the Netherlands and then the Dutch data dictionary for construction – the CB-NL. This article is part of a Master's in Geographic Information Management Applications completed at Utrecht University.

Peter van Oosterom obtained an MSc in Technical Computer Science in 1985 from Delft University of Technology, the Netherlands. In 1990 he received a PhD from Leiden University. From 1985 until 1995 he worked at the TNO-FEL laboratory in The Hague. From 1995 until 2000 he was senior information manager at the Dutch Cadastre, where he was involved in the renewal of the Cadastral (Geographic) database. Since 2000, he is professor at the Delft University of Technology, and head of the 'GIS Technology' Section, Department OTB, Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands. He is the current chair of the FIG Working Group on '3D Cadastres'.

Wilko Quak has an MSc in computer science from Utrecht University, The Netherlands (UU). He worked for several years (1993-2001) as a researcher at the Dutch research center for mathematics and computer science (CWI) and University of Amsterdam (UvA) on Spatial DBMS performance. Since 2001 he has been a researcher at the Section GIS Technology, OTB, Delft University of Technology. At Delft University his research focus is moving towards spatial data modeling, data interoperability and standardization. Since 2007 he has been working part-time for Geonovum (the National Spatial Data Infrastructure (NSDI) executive committee in the Netherlands).

Jeroen van der Veen has an MSc in urban design from Delft University of Technology, the Netherlands. He has worked since 2001 as project manager for several Dutch government departments. Currently he works for Ministry of Internal Affairs and the Cadastre as project manager for the information-houses Legal Space and Building, within the framework of the new Environs Act. He was involved in the management of a number of nationwide projects in the field of geographical infrastructures. Notably the National portal of spatial plans (RO-Online/RP.nl), the Registry Large-scale Topography (BGT).. He is especially keen on building bridges between the worlds of geo-, building- and legal information and management of projects in complex multi-organization networks.

Jakob Beetz works as an assistant professor at the Department of the Built Environment of the Eindhoven University of Technology in the Netherlands. He has been involved in research, development and standardization of technologies and data models for Building Information Modelling for more than 10 years. He is the co-founder of the Open Source model server platform 'bimserver.org', and currently serves as co-chair of the Linked Building Data standardization group within the international buildingSMART organization.

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