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BIM Models as Input for 3D Land Administration Systems for Apartment Registration

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Key words: 3D Land Administration System, Building Information Model, Industry Foundation Classes, Land Administration Domain Model, Rights, Restrictions and Responsibilities

SUMMARY

The growth of cities and the pressure on land worldwide leads to more complex and multilevel structures with different space interrelations. For the registration of complex spaces mostly 2D Land Administration Systems (LAS) are used, while a representation of space in 3D could provide a clearer insight. Concurrently, technological advancements rapidly improve methods to collect, create, visualise, register, store and disseminate 3D data. In this context, much research is now being carried out at the sources and data used as input in 3D LAS and the various methods for their collection. In this scene, the approach to reuse data from the design phase is gaining ground. Specifically existing Building Information Models (BIMs), usually encoded in the non-proprietary Industry Foundation Classes (IFC) format (EN ISO 16739:2018) are considered a promising source for 3D LAS.

Previous research has shown promising results using BIMs as input for 3D LAS. However, the use of BIM/IFC-models from practice has not yet been tested adequately. This paper investigates the technical issues that are encountered when using real-world BIM/IFC-models as input for the registration of apartment rights in a 3D LAS and how that process can be improved. In the context of this paper, BIM/IFC-models are iteratively being validating against technical requirements. Five real-world BIM/IFC-models are collected. They are tested on the existence of IfcSpace, geometric validity, overlap and the ability to georeference the BIM/IFC-models.

The results of these validation show that the collected BIM/IFC-models lack the ability to be georeferenced. Additionally most BIM/IFC-models did not contain IFCSpace, or reference to essential attributes for identifying legal units in the Dutch 3D LAS. Recommendations and guidelines are formulated to address these issues. The BIM/IFC-models are placed in a 3D LAS at conceptual level, in which the legal spaces are enriched with information of the Rights, Restrictions and Responsibilities (RRR's) to those spaces in line with the LADM.

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1. INTRODUCTION

The growth of cities and the pressure on land worldwide leads to more complex and multilevel structures with different space interrelations. For the registration of complex spaces mostly 2D Land Administration Systems (LAS) are used, while land administration is challenged by an unprecedented demand to utilise space above and below earth's surface. The relationships between people and land in vertical space can no longer be unambiguously represented in 2D, while a representation of space in 3D could provide a clearer insight. Concurrently, technological advancements rapidly improve methods to collect, create, visualise, register, store and disseminate 3D data.

In this context, much research is now being carried out at the sources and data used as input in 3D LAS and the various methods for their collection. In this scene, the approach to reuse data from the design phase is gaining ground. Specifically existing Building Information Models (BIMs), usually encoded in the non-proprietary Industry Foundation Classes (IFC) format (EN ISO 16739:2018) are considered a promising source for 3D LAS. BIM is widely recognised as a common data environment for 3D lifecycle management of buildings. The IFC format (ISO 16739-1:2018) and the ISO 19152 Land Administration Domain Model (LADM - ISO 19152:2012) both are international open standards that have a significant impact in their own domain. Reusing existing models is cost-effective and in line with the Spatial Development Lifecycle (Kalogianni et al., 2020a). Previous research has shown promising results using BIMs as input for 3D LAS (Andrianesi & Dimopoulou, 2020; Meulmeester, 2019; Oldfield et al., 2017). However, the use of BIM/IFC-models from practice has not yet been tested adequately, as there are various aspects that need to be addressed.

This paper investigates the technical issues that are encountered when using real-world BIM/IFC-models as input for the registration of apartment rights in a 3D LAS and how that process can be improved. In the context of this paper, BIM/IFC-models are iteratively being validating against technical requirements and placed in a 3D LAS at conceptual level, in which the legal spaces are enriched with information of the Rights, Restrictions and Responsibilities (RRR's) to those spaces in line with the LADM.

2. BACKGROUND

Land administration consists of land registration and cadastres, where the former concerns the registration of Rights, Restrictions and/or Responsibilities (RRR) of land, whereas cadastres register and map parcels. Concurrently land registration is defined as "*the process of recording legally recognized interests [...] in land*" and a cadastre is defined as "*an official* *record of information about land parcels, including details of their bounds, tenure, use, and value*" (Zevenbergen, 2002). A Land Administration System (LAS) is the combination of both land administration and land registration: a system that both measures the parcels of land and registers the relation in terms of RRR's of parties to the land. LAS is the definition that will be used since the proposed 3D LAS consists of both the registration of RRR's as well as the 3D representation of parcels. The growth of cities and concurrently complex 3D properties, as well as technological developments, have led to an interest and research of 3D LAS the past two decades (Dimopoulou & van Oosterom, 2019). The following sections describe the background of this research and give an overview of current rights in the Dutch LAS (2.1), BIM/IFC models (2.2) and the LADM (2.3).

2.1 The Dutch LAS "Het Kadaster"

The Dutch LAS, "het Kadaster", consists of both land registration and a cadastre. Formally the Dutch LAS is tasked to acquire, geometrically register, maintain and cartographically visualise public registries. The Dutch LAS has different RRR's which can be registered. First the right of ownership (eigendomsrecht). This ownership includes in theory not only the land itself, but also the space upwards and downwards from the parcel according to the principle of the rule of accession (superficies solo cedit). Next to complete ownership, there are forms of limited ownership rights. The right of superficies (opstalrecht) allows to own or place immovable property in, on, or under property of another party. The right of long lease (erfpacht) is a right to use the land, i.e. a municipality provides long lease to a party, which owns the building on the land, in exchange for a one time or reoccuring fee. The right of easement (erfdienstbaarheid) is a right of which the owner has the responsibility to allow access to his land to serve another party. The apartment right (appartementsrecht) is a right to part of a split parcel. This right is used for multi-level apartments. Since 2D parcels do not define exclusive ownership of apartments, the ownership of a residence in an apartment building is required to have the boundaries of properties in a deed of division (splitsingsakte), part of this deed is a 2D drawing with a graphical representation of the boundaries (Figure 1; Stoter et al., 2013).

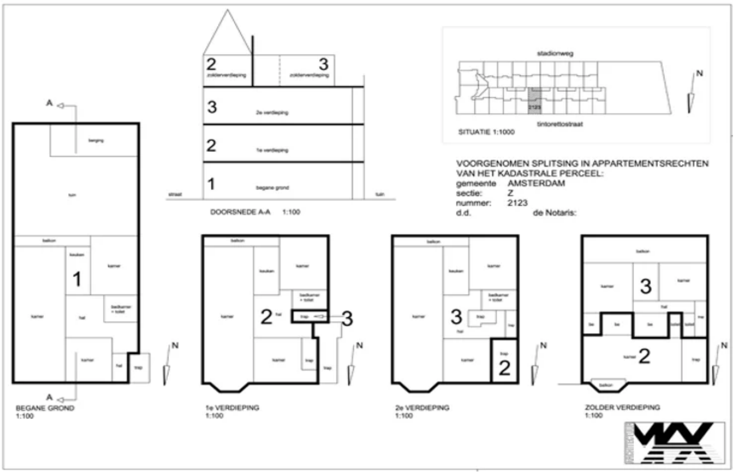

Figure 1: A splitsingstekening (division drawing) (Max Architectuur BV, 2021)

Even though rights are not registered in 3D, some of the limited rights allow for a division of rights in 3D situations. The apartment right being the most apparent, as it deals with vertical split property. Next to the apartment right, the principles of vertical and horizontal accession (vertikale en horizontale natrekking) apply in the Dutch LAS. This principle defines the ownership of a property when it is part of, and cannot be divided, even though it may be on, go over or under the ownership of someone else. Examples of horizontal and vertical accession are tunnels, bridges and underground infrastructure.

The representation of parcels in 2D maps in case of multi-level property which overlap, is handled by dividing the map into multiple parcels. For each parcel the multiple rights are represented. This representation might be clear for the people who are involved in registering the property, however it is hard for people who are not familiar with the real-life situation to interpret these maps. An example of a complex 3D situation represented on a 2D map is the Unilever building as shown in (Figure 2).

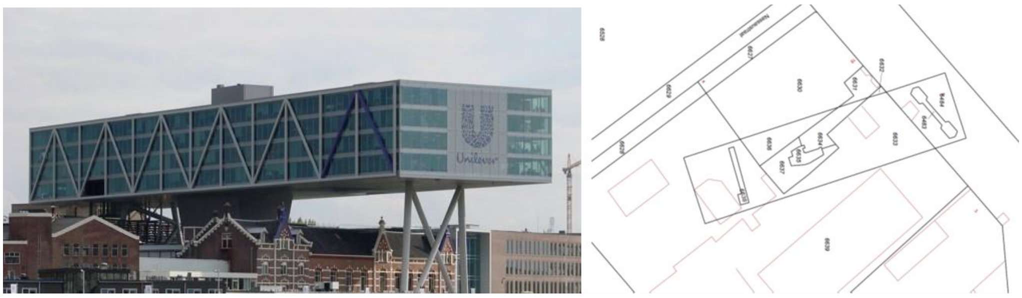

Figure 2: The Unilever building and its representation on a 2D parcel map (Stoter et. al, 2013)

In the Netherlands, research has been conducted on the possible layout of a LAS in which 3D representations can be incorporated. Stoter et al. (2016) implicated a 3D model of the train station in Delft to be registered in the Dutch LAS. A 3D pdf is added as a division drawing, instead of a 2D drawing. The 3D representation is added in the existing LAS and legal framework. The use of a 3D representation allowed for a better presentation of a 3D complex situation, however, the 3D representation cannot be linked to surrounding parcels. Cemellini (2018) developed a system architecture prototype for a 3D LAS, which focused on 3D data storage, dissemination and visualisation through a web-viewer. It is extended by Meulmeester (2019), who researched the possibility of BIM/IFC models as input in a 3D LAS, enriched with legal information required by the Dutch LAS. However this has not been tested with real-world BIM/IFC-models.

2.2 BIM/IFC models

The concept of BIM is about storing and maintaining data in the form of a 3D model through the entire lifecycle of a building. For this purpose BIM models contain both 3D spatial information (geometry), as well as semantic information about the building (Kalogianni et al., 2020a). It fits with the principle of Life Cycle Thinking (LCT), which focuses on the collaboration between parties and the reuse of sources. The collaboration of different parties in the design stage of a BIM can prevent building mistakes by using clash detection, hence combining models of different disciplines and notice if there are overlaps between objects which cannot exist in real-life. Detecting these clashes in the design phase prevents the costs that occur when these mistakes would be noticed in the building phase.

However the circular approach does not stop after the designing phase, BIM can also be used during maintenance, renovation and demolition. Hence BIM can be used from the design, through maintenance, through possible renovation, until the demolition phase. Concurrently there is potential in using BIM for permitting buildings, as well as register 3D spatial units with related RRR's in a LAS.

2.3 ISO 19152 Land Administration Domain Model (LADM)

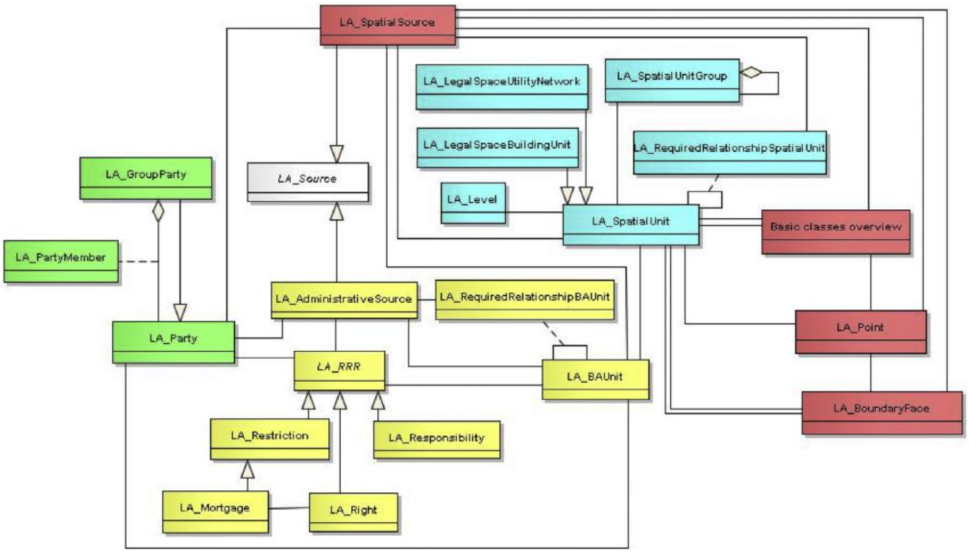

Figure 3: Land Administration Domain Model (Lemmen et. al., 2015)

The LADM is an international knowledge domain specific standard capturing the semantics of the Land Administration Domain. It provides a common, standardised, global vocabulary, ontology and semantics aiming to stimulate the development of software applications and accelerate the implementation of land administration systems that support sustainability objectives (van Oosterom & Lemmen, 2015). The LADM is a conceptual model and one of the first spatial domain standards within ISO TC211, aiming to support "*an extensible basis for efficient and effective Land Administration Systems*" (Kalogianni et al., 2020b). The LADM has a wide use and interest, with several countries investigating and/or applying LADM in their LAS (Kalogianni et al., 2018). For example Croatia (Mader et al., 2018), China (Ying et al., 2018) and Israel (Adi et al., 2018). Currently the development points for the LADM are modelling, storing, visualising, and maintaining spatial units.

Figure 3 shows the UML model of LADM, which consists of three main packages. The party package (green) consists of classes which represent a party, which can be a person or organization such as a municipality or a company. This can also be a group of parties. The administrative package (yellow) stores the RRR's to a basic administration unit (LA_BAUnit) and is linked to the parties and building units. The basic administration unit is linked to the spatial unit package (blue) which contains classes to store spatial information of the basic administration unit. This can be a verbal description, a 2D map, and also a 3D model, among others. To support the spatial unit package for storing geographical information, the representation and survey package (red) contain classes to store surveying and other geographical data.

3. METHODOLOGY

The research objective of this paper is formulated as follows: *How should BIM/IFC-models be designed to effectively be reused as input for 3D LAS?* This can be further sub-categorised to the following research sub-questions: 1. Which technical complications are encountered when using BIM/IFC-models as input for 3D LAS?; 2. Which solutions are recommended for those complications?; 3. What are the different interests and benefits of user groups when using BIM/IFC-models as input for 3D LAS? 4. Which of the technical complications are encountered when testing real-life BIM/IFC-models as input for the Dutch LAS, and how can they be resolved?

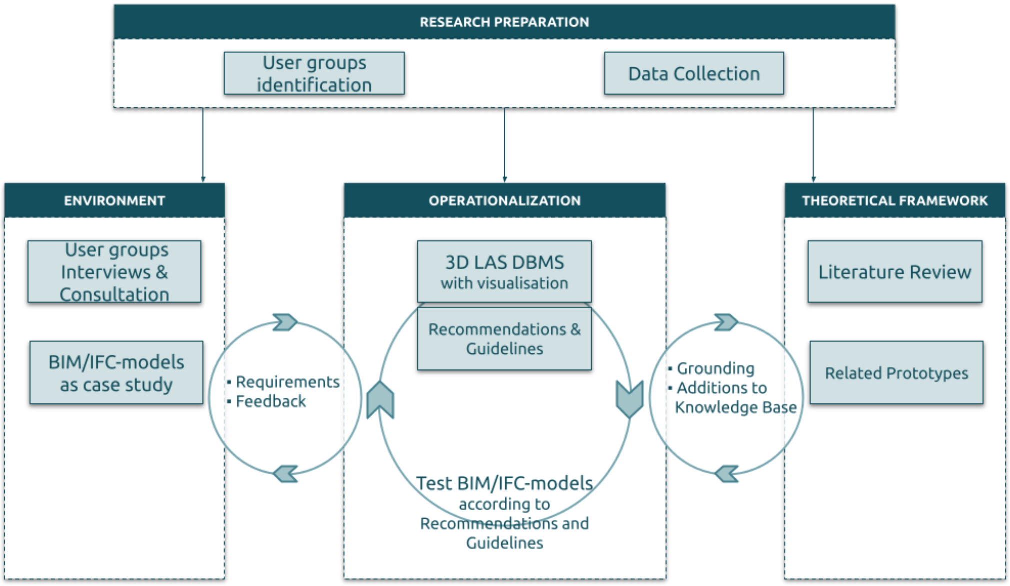

Figure 4: Methodological Steps

Based on the Design Science Research approach the following methodological steps are executed (Figure 4): First research preparation is conducted by identifying user groups and collecting real-world BIM/IFC models (3.1.1). Secondly user groups are consulted to give input for the 3D LAS DBMS and give insight in their use of BIM (3.1.2). A literature review is conducted to assess known complications and previous work on using BIM as input for 3D LAS (Chapter 2). Lastly the BIM/IFC models are validated (3.2), and a 3D LAS DBMS prototype is built (3.3).

3.1 Data Collection and user group identification

The BIM/IFC-models are collected for the purpose of this paper with the following criteria: the BIM/IFC-model concerns a building; concerns a real-world model; is located in the Netherlands; has multiple property rights. Hence, five IFC-models are obtained (Table 1).

Table1: Collected BIM/ IFC-models

Name	Supplier	Location
1. Central Park	Municipality of Utrecht	Utrecht
2. Westflank	Municipality of Utrecht	Utrecht
3. Pontsteiger	Menno Mekes	Amsterdam
4. Schependomlaan	Virtual Systems	Nijmegen
5. Central Library	Virtual Systems	Rotterdam

3.1.1 Case Studies

The Central Park and Westflank models (Figure 7) are both part of a development 'cu2030' in the station area of Utrecht. This area is an area of mixed functions as well as different owners. At its core is the Central Station of Utrecht, a large transfer hub. Next to a transport function, other functions include retail, offices, residential as well as leisure. The largest stakeholders in the area are the municipality of Utrecht, the Dutch railways (Nederlandse Spoorwegen) and Prorail, the railway manager in the Netherlands, but other parties own ground as well. The area is of interest because of the variety in function and owners, as well as the complex 3D structures that are joined with this project.

Figure 5: Central Park building (middle) under construction (own photo, 2021)

The Westflank model contains an apartment building to be built. Central Park contains offices which can be rented. A remarkable feature of this building is the park in the middle of the building, which is to be used as a shared space. The Central Park BIM/IFC-model (Figure 5) consists of an aspect model of the inside and the frontage. Other BIM/IFC-models containing stairs to the station area and a parking garage are also collected. They are included for context but are not validated in this research. The Pontsteiger building (Figure 6) has a complex geometry: it contains two towers which are connected through a bridge. It is located in Amsterdam and built in 2015. The building has multiple functions. Apartments are located in the building, as well as a hotel. The Central Library BIM/IFC-model represents the Central Library in Rotterdam. The Schependomlaan BIM/IFC-model represents an apartment building in Nijmegen.

Figure 6: Pontsteiger building (wikimedia creative commons)

3.1.2 User groups

The expected users of a 3D LAS include the public, land registries, land surveyors, notaries, AEC industry, urban planners, local government, real estate agents, contractors, banks, valuators, engineers who issue permits and architects among others (Kalogianni et al., 2020a). Experience from practice is discussed with the architect of the Pontsteiger and an employee of the municipality of Utrecht who is contributing to a digital twin of the municipality of Utrecht.

The architect experiences hurdles in the reuse of BIM/IFC-models leading to data loss after the building was built. For example a BIM is supplied to a municipality or other organization, but the workflow of that organization is based on 2D data. Concurrently, the BIM is transposed to 2D data, and the original 3D data is not maintained. The architect stated that in his work field 3D models of surrounding buildings are often used in the designing phase of new buildings, especially when designing high-rise in urban environments. Windflow and sun studies are made, and these could benefit from the use of accurate 3D models.

Figure 7: The Westflank (left) and Central Park (right) BIM

The employee of the municipality of Utrecht mentions that even though he sees an added value of adding BIM/IFC models to the digital twin, a conversion is required to simplify the model. This is needed to decrease the file size, but also to reduce the level of detail, as the level of detail in BIM/IFC-models is often not wanted for a digital twin. However conversion, i.e. simplifying BIM/IFC-models is time-consuming, as hardly any model is built the same and thus requires manual labour to adjust to make the model suitable for a digital twin. Hence he would benefit from designers adhering to standards to be able to automate the process of simplifying BIM/IFC-models for input in a digital twin.

3.2 Data Validation

Important technical requirements based on the literature review include:

- The availability of uniquely identifiable volumes, including the representation of rooms as IfcSpace, to define legal units which can be linked to the RRR's of the legal unit (3.2.1).
- The geometries to be valid (3.2.2).
- The IfcSpace volumes to contain no overlaps or gaps, as spaces should be mutually exclusive (3.2.3).
- The ability to georeference the BIM/IFC-model, as the geographic location of a building is necessary in the context of a LAS (Cemellini, 2018; 3.2.4).

3.2.1 Legal spaces

The BIM/IFC-model contains uniquely identifiable IfcSpace entities which represent rooms. These rooms can be grouped to form a unit, this definition is stored in the BIM/IFC-model. Rooms can be defined in BIM/IFC-models as IfcSpace, yet IfcSpace is not always included in a model. The first step in the validation of legal spaces is to check if IfcSpace entities are present. The outcome does not inform whether the IfcSpace is a complete set of all rooms. This is validated through the overlap/gap analysis (3.2.3). Concurrently, the IfcSpaces are uniquely identifiable so that they can be linked to legal building units, additionally they can be grouped into legal units, i.e. an apartment which consists of multiple rooms. The former is checked by validating the existence of a IfcGloballyUniqueId (GlobalId). For the grouping of rooms there are no mandated standards. Meulmeester (2019) proposed the addition of a propertyset to IfcSpace to include the Dutch LAS indexnumbers etc., however this proposal has not been implemented in standards. Additionally groups of rooms can be defined by groups in the model, such as IfcZone. Lastly a relation between rooms can be implied by the name of spaces, i.e. spaces which belong to the same apartment have the same prefix.

Concludingly checks are made on the presence of IfcSpace and unique GlobalId's, these are integrated in a FME workspace (Appendix A). Thereafter it is validated by inspecting the BIM/IFC-model whether: IfcSpace contains a propertyset which contains attributes required by the Dutch LAS; groups of rooms are defined in the model; a relation between rooms is implied in the name of IfcSpaces.

It should be noted that next to the rooms, a legal unit contains the interior building elements, and often the exterior elements adjacent to the rooms. Current practice in the Ducth LAS do not model the boundaries, such as walls and floors, as property. The reason for this is that the graphical representation, a 2D drawing of the building, is not legally binding. Rather it is a graphical representation of the building and where the building is located. Therefore the modelling of building elements such as walls and floors is not possible for the Dutch LAS, and only the rooms are defined as legal units (Meulmeester, 2019).

If a LAS does allow building elements to be modelled as property, it should be defined in the BIM/IFC-model to which legal unit they belong. When these links are not integrated in the BIM/IFC-model, some links can be calculated by adjacency to a legal unit. Interior elements, such as walls dividing two legal units, however result in a conflict. Hence to define the ownership of building elements manual adjustments might be needed. Alattas et al. (2021) describe the process of subdividing a building with its building elements into private, common, and exclusively common spaces.

3.2.2 Valid Geometries

It was assessed whether the features of the BIM/IFC-model are compliant with OGC 1.2.0. When calculating spatial relations between objects, invalid geometries may result in errors or an incorrect calculation. Therefore the geometry of features is validated using a FME Workspace (Appendix C). Additionally a check is made for non-planar surfaces and correct orientation of surfaces. If non-planar surfaces are found they are triangulated. Incorrect oriented surfaces are realigned.

3.2.3 Spatial relations

It was assessed whether the IfcSpace volumes do not overlap. For the Dutch LAS, parcels have to be mutually exclusive. Hence overlap between parcels is not allowed. The touching of geometries is expected, as two adjacent spaces can touch on the bounding surface. Figure 8 shows possible DE-9IM relations for 3D geometries. For the Dutch LAS spaces have to be mutually exclusive, hence geometries may not equal or overlap each other, since that contradicts the premise of legal units being mutually exclusive.

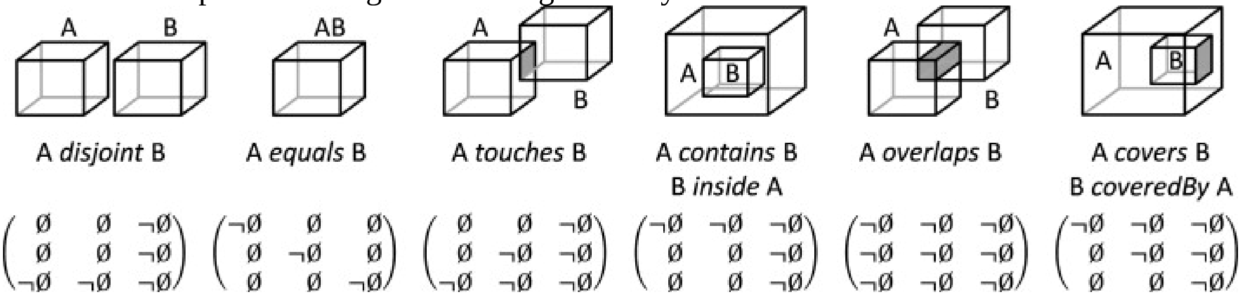

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Figure 8: Eight predicates defining the possible topological relationships between two solids in 3D (Daum & Borrmann, 2014)

Defining spatial relations between 2D geometries is well integrated in the used software. FME Desktop and PostgreSQL with the extension of PostGIS have tooling to create a DE-9IM matrix which represents the spatial relation between 2 geometries. However this tooling is not yet able to deal with 3D geometries. Collection of polygons, i.e. a geometrycollection or multi-polygon, can be used as input, however the outcome still represents the 2D relations, not taking into account a Z-coordinate.

For validating whether there is overlap a method is used which utilises the ST_3Dintersection function of the SFCGAL PostgreSQL extension (Postgis, 2021). This method extracts the shared portions between 2 3D geometries. However touching surfaces are also extruded. To exclude these false positive results, surfaces (geometries with a 0 volume) are excluded and not counted as overlap. The geometries are compared to each other using a materialized view (Appendix G). The query does not utilize a spatial index, which has a negative impact on the execution time. Concurrently only geometries which have a distance of less than 10 meters are compared. The outcome of the materialized view is analyzed within FME (Appendix B).

3.2.4 Georeferencing

BIM/IFC-models are designed in local coordinate systems (LCS), rather than coordinate reference systems (CRS). Hence, to georeference a model to the correct location a transformation has to be made and stored in the model. Clemen and Görne (2019) give an overview of the different ways to store attributes, which facilitate the georeferencing a BIM/IFC-model. It should be noted that the existence of these attributes are dependent on whether or not the designer included them in the model. Additionally, the latter LoGeoRef50 is based on attributes which are introduced in IFC 4, whereas older models, including the ones validated in this research, are IFC 2x3 and do not support these attributes.

Table 2: Synthesis of LoGeoRefs as defined by Clemen and Görne (2019)
Adjusted from Noardo et al., (2021)

LoGeoRef	Supported CRS	Storing Entities
LoGeoref10	No CRS, approximate location by means of the address	'IfcPostalAddress' referenced by either 'IfcSite' or 'IfcBuilding'.
LoGeoRef20	WGS84 EPSG:4326	'RefLatitude', 'RefLongitude', 'RefElevation' attribute of 'IfcSite'.
LoGeoref30	Any Cartesian CRS, including projected coordinates (CRS not specified in the file)	'IfcCartesianPoint' referenced within 'IfcSite' (defining the projected coordinates of the model reference point); 'IfcDirection' attribute of 'IfcSite'.
LoGeoref40	Any Cartesian CRS, including projected coordinates (CRS not specified in the file)	'WorldCoordinateSystem' storing the coordinates of the reference point in any Cartesian CRS and direction TrueNorth.
LoGeoref50	Specific projected CRS, specified by means of the EPSG code	IFC v.4 - Coordinates of the reference point stored in 'IfcMapConversion' using the attributes 'Eastings', 'Northings' and 'OrthogonalHeight' for global elevation. Rotation for the XY-plane stored using 'XAxisAbscissa' and 'XAxisOrdinate'. The CRS used is specified by 'IfcProjectedCRS' in the attribute 'Name' by means of the proper EPSG code.

The BIM/IFC-models are validated by investigating the existence and contents of the attributes stated by Clemens and Görne (2019; Table 2). The tool IfcGeoRef (Clemens & Görne, 2019) is integrated into the FME workspace (Appendix A), and is used to assess the georeferencing capabilities of the BIM/IFC-models. Each model it is assessed if it complies with LoGeoRef10-LoGeoRef50, and if so the contents of the attributes are exposed.

3.3 Development of prototype

The prototype consists of the validation workflow to validate the BIM/IFC-models, a PostgreSQL database which stores the BIM/IFC-models in a LADM compliant DBMS, and a Cesium webviewer. After the validation of the BIM/IFC-models, the BIM/IFC-models are put in a DBMS through an FME workspace (Appendix D). The IfcSpace entity is represented as LA_LegalSpaceBuildingUnit. For the BIM/IFC-models where a grouping of IfcSpace is present, the groups are defined as LA_BAUnit. For models where the grouping is not present, single LA_LegalSpaceBuildingUnits are also defined as LA_BAUnit. The BIM/IFC-models do not contain information about the RRR's to the legal units. For the purpose of building a prototype 3D LAS, fictitious parties and RRR's are put in the DBMS as LA_RRR and

LA_Party. The contents of the 3D LAS DBMS are converted into cesium tiles with FME Desktop (Appendix E) and uploaded to an online cesium viewer.

4. RESULTS

4.1 Results of validation

4.1.1 <u>Legal spaces</u>

In 2 out of 5 BIM/IFC-models IfcSpace is present (Table 3 - a). The Central Park, Westflank and Central Library model do not contain IfcSpace. Revit is used to automatically generate rooms in the BIM/IFC-models with no IfcSpace. However not every room is recognized, and some building elements such as columns, or incorrectly defined as room. The Central Park, Westflank and Central Library models contain no information required for the Dutch LAS. The Schependomlaan model contains names of rooms which imply a relation. The Ponsteiger model contains no information such as a LAS index number either, but groups are defined which represent legal units, such as ‘bnr. 100’. Concludingly the lack of IfcSpace in some models, and lack of Dutch LAS information are insufficient for placement in a Dutch LAS.

4.1.2 <u>Valid Geometries</u>

All geometries in the BIM/IFC-models are compliant with OGC 1.2.0. (Table 3 - b) In mainly the IfcWindow, IfcDoor and IfcBeam elements multiple non-planar surfaces and incorrect oriented geometries were detected, these are triangulated and repaired.

Table 2: Results of validation

BIM/IFC-model	**IFC version**	**a) Legal Spaces**					**b) Valid Geometries**				**c) Overlaps**	**d) Georeferencing**				
		Contains IfcSpace	Unique GlobalId's	LAS propertyset	Groups	Implied relation in name	OGC pass	Passed	Repaired	Failed	Overlaps	LoGeoRef10	LoGeoRef20	LoGeoRef30	LoGeoRef40	LoGeoRef50
1. Central Park	2x3	No	Yes	No	No	No	100%	97%	3%	> 1%	-	False	True	True	False	False
2. Westflank	2x3	No	Yes	No	No	No	100%	80%	20%	> 1%	No	True/False	True	False	False	False
3. Pontsteiger	2x3	Yes	Yes	No	Yes	Yes	100%	96%	4%	> 1%	Yes	True/False	True	False	False	False
4. Schependomlaan	2x3	Yes	Yes	No	No	Yes	100%	84%	16%	> 1%	No	True/False	True	False	False	False
5. Central Library	2x3	No	Yes	No	No	No	100%	97%	2%	1%	No	True/False	True	False	False	False

4.1.3 <u>Spatial relations</u>

For the Pontsteiger model, overlap is present. This is due to the grouping of spaces, in which the group of spaces is also defined as a space, which overlap with the containing spaces. In the Westflank model the 3D intersection function resulted in a collection of geometries, however none of them contained any volume, i.e. they represent surfaces, which indicates a touching relation between two adjacent geometries. No overlap is found in the Central Park of Central Library model, however none to only a few rooms are present in those models. The Schependomlaan model contained no overlap either, although it should be noted that not all IfcSpace geometries could be correctly extracted.

4.1.4 Georeferencing

An analysis is done through IfcGeoRef to assess which georeferencing attributes the BIM/IFC-models contain (Table 3 - d). LoGeoRef10 information is present in 4 out of 5 models, however in these attributes, IfcPostallAdress, incomplete or incorrect adresses are stated. All models contain Reference points according to LoGeoRef20. These include RefLatitude, RefLontitude and RefElevation which reflect a single reference point in the WGS84 (EPSG:4326) CRS. However these points do not reflect the actual location of the buildings. For example, the Ponsteiger reference point is in Canada. The Central Park, Westflank and Central Library models all contain a reference point close to, but not exactly at the real location of the building.

The Central Park model contains a reference to a cartesian point (LoGeoRef30). However, it is not clear which CRS is referenced. The remaining 4 models do not contain attributes according to LoGeoRef30. Concurrently, all models do not contain attributes concurring with LoGeoRef40, i.e. they do not contain other coordinate reference points. As expected attributes for LoGeoRef50 are missing in all models, since those attributes are incorporated in IFC 4, while all validated models are IFC 2x3.

In conclusion, none of the BIM/IFC-models contain sufficient attributes for georeferencing. Even though manually affining the BIM/IFC-models is not the optimal solution, the 5 BIM/IFC-models are placed on their approximate position by affining using a 3D Affiner in a FME workspace (Appendix B).

4.2 Prototype and its visualisation

The BIM/IFC-models are put in a DBMS. Additionally tables are created for LA_BuildingUnit, LA_RRR and LA_Party. For the visualisation of the DBMS, the contents of the DBMS are converted to a Cesium Tileset, and uploaded to a web viewer[1](Figure 9).

63bf6c0a-a755-47ba-95a8-a04f288ef6aa

LA_BuildingUnit	{53ecc6e2-75ab-405a-9521-fa3a00a73df5}
LA_RRR	{26f5373f-4496-4252-9cab-9a4b639b9701}
LA_Party	{b992e243-5be9-4548-abde-2dcca41b369e}
Party Name	Mathilda Rohr
LA_LegalSpaceBuildingUnit	UtrechtA2173
Space Name	Room

Figure 9: Online 3D LAS viewer

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[1] http://broekhuizen.link/ces/3dlas.html, http://broekhuizen.link/ces/3dlasspace.html

5. DISCUSSION AND CONCLUSIONS

5.1 Discussion and Conclusion

For this research 5 BIM/IFC-models were collected, validated and used as input for a prototype 3D LAS. The built 3D LAS prototype includes LADM components, however LADM is not fully integrated. Furthermore the BIM/IFC-models used as input are mainly as designed BIM/IFC-models. In a 3D LAS the used BIM/IFC-models should be as-built, as this reflects the real-world situation. In the prototype 3D LAS only IfcSpace entities are modelled as legal units, as the Dutch law does not allow walls and other building elements to be included as legal units. However, with the technological developments, and further research into a 3D LAS, it should be reconsidered if building elements could be included as legal units.

Multiple technical complications are encountered as result of the validation of the BIM/IFC-models. The most important are the lack of rooms in the form of IfcSpace, the lack of identification for linking the legal units with the Dutch LAS and the lack of attributes to georeference the models. For effectively designing BIM/IFC-models to reuse as input for a 3D LAS, recommendations and guidelines are formulated as:

- Rooms have to be included in the BIM/IFC-model as IfcSpace
- IfcSpace should contain a propertyset which include the apartment index number, cadastral parcel number, complex number, space type and municipality.
- Concurrently IfcSpace can be grouped, but these groups should not be included as a (duplicate) IfsSpace volume.
- Attributes for georeferencing should be included in the BIM/IFC-model. It is recommended that IFC4 files with attributes for georeferencing are preferred above the IFC2x3 files. For existing IFC 2x3 models it is necessary to enrich the IFC files with attributes complying to LoGeoRef30 and/or LeGeoRef40 (Table 2).

5.2 Future Work

For this research 5 BIM/IFC-models were collected. A larger dataset of more BIM/IFC-models, with a wider variety in designers, would give a better insight in the ability of real-world BIM/IFC-models as input for 3D LAS. The availability of open BIM/IFCmodels however is low, it should be assessed which incentives can be used for designers to share their BIM/IFC-models for research. Concurrently BIM/IFC-models of other countries could also be tested against the used validations.

All collected models are IFC 2 x 3, which have known issues with georeferencing. For the validation FME Desktop and PostgreSQL were used. Spatial relations are defined by executing an intersection function. A DE-9IM matrix could give better insight in spatial relations, and also define the type of relation. It should be further assessed which software tools allow for this analysis. In addition, for 3D LAS boundaries, and the direction of boundaries are important. Future research could focus on the validation of topology and boundaries.

The focus of this research was on the technical challenges that arise when using BIM/IFC-models as input for 3D LAS. However to implement the given recommendations and guidelines legal and organizational challenges should be addressed. A legal mandate, combined with standards, have the possibility to direct user groups when designing and exchanging BIM/IFC-models.

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BIOGRAPHICAL NOTES

Marjan Broekhuizen is a MSc student in Geographical Information Management and Applications, a joint masters programme of the Delft University of Technology and three other Dutch universities. She is currently working on her Thesis under guidance of Eftychia Kalogianni and Peter van Oosterom, the research topic being ‘BIM/IFC files as input for 3D Land Administration Systems’. The contents in this paper are based on this Thesis research. She works at a consulting company as a GEO-ICT consultant, focusing on the development of applications with FME.

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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’ group at the Digital Technologies Section, Department Architectural Engineering and Technology, 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’. He is co-editor of the International Standard for the Land Administration Domain, ISO 19152.

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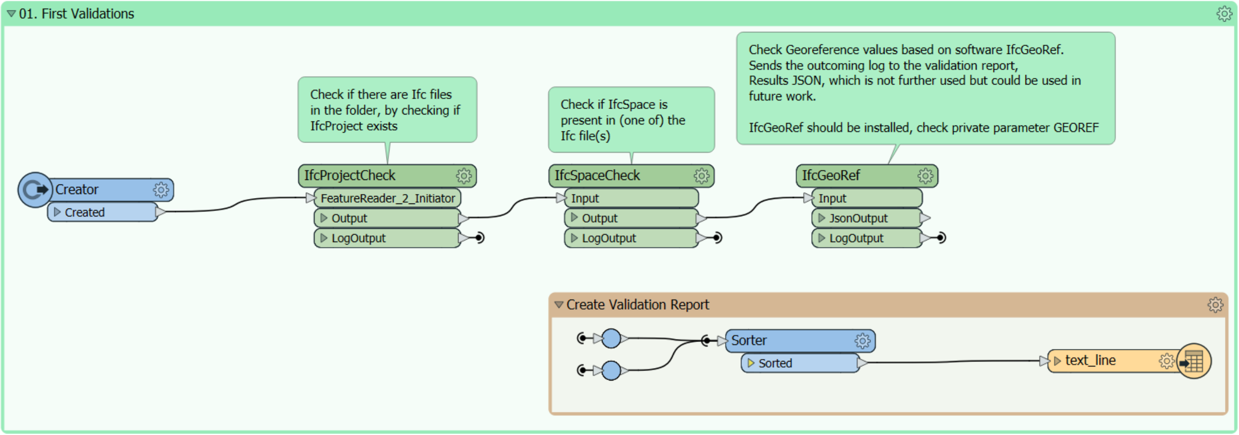
APENDICES

The FME workspaces, PostgreSQL dll, HTML-code and Cesium.js code are available at: https://github.com/superjumpylion/BIMIFCto3DLAS

A - 1_IFCspaceAndGeoRefCheck - Validates if IfcSpace is present and generates a IfcGeoRef report containing information about georeferencing capabilities.



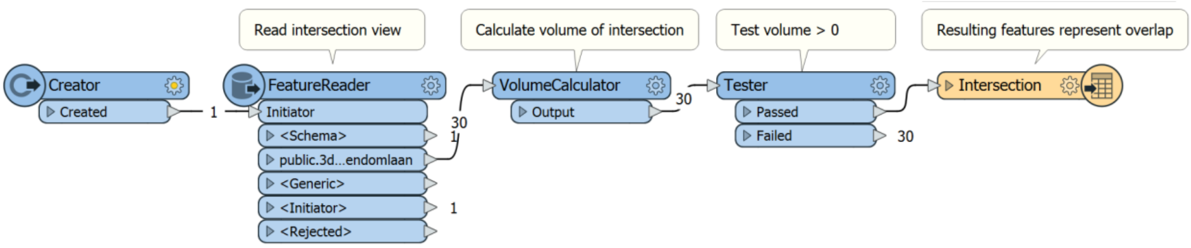
Check if there are Ifc files in the folder, by checking if IfcProject exists

Check if IfcSpace is present in (one of) the Ifc file(s)

Check Georeference values based on software IfcGeoRef. Sends the outcoming log to the validation report, Results JSON, which is not further used but could be used in future work.

IfcGeoRef should be installed, check private parameter GEOREF

B - 3_Intersection - Reads the 3D intersection view from the DBMS, calculates volumes and results volumes > 0 as overlap.



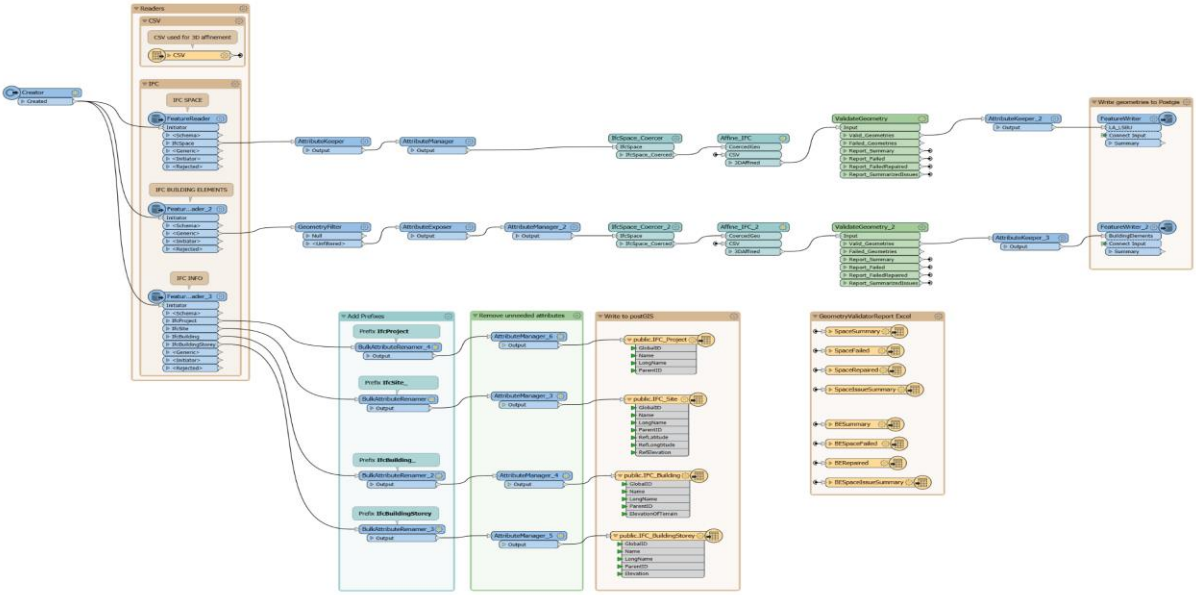
Read intersection view

Calculate volume of intersection

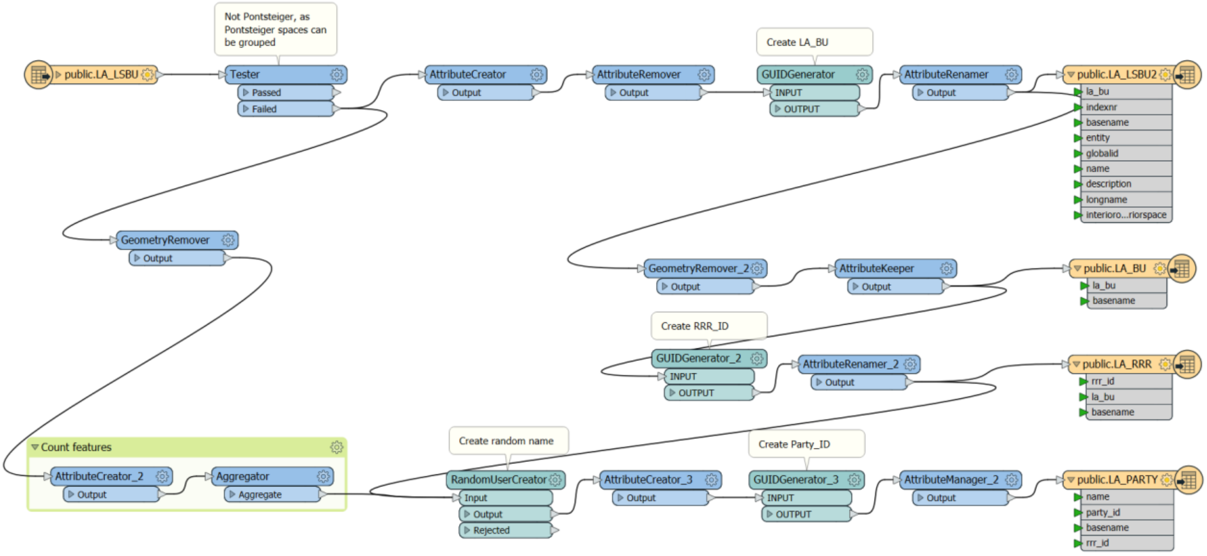
Test volume > 0

Resulting features represent overlap

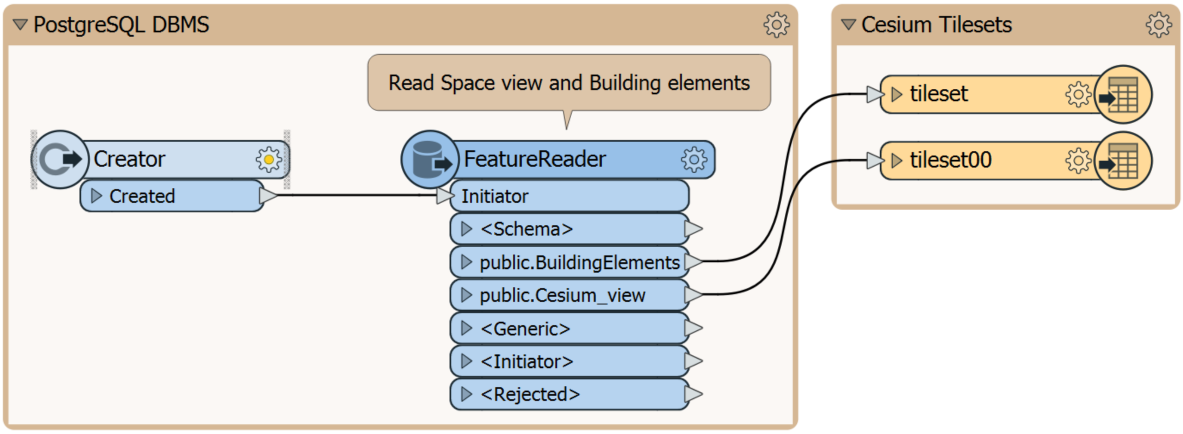
C - 2_BIMIFCtoDBMS - Coerces geometry, validates geometry, and inputs valid geometries in DBMS



D - 4_FictiveLADMa - Reads LA_LegalSpaceBuildingUnits and generate fictive parties and relations



E - 5_DBMStoCesiumtiles - Read Cesium_View from DBMS and write to Cesium Tiles



F - Adresses to find the BIM/IFC models in the viewer

1. Central Park - 5.104487, 6.112662 (this model was not affined correctly)
2. Westflank - Soerabayastraat, Utrecht, Netherlands
3. Pontsteiger - Pontsteiger, Amsterdam, Netherlands
4. Schependomlaan - Houtlaan, Leusden, Netherlands
5. Central Library - Centrale Bibliotheek, Rotterdam, Netherlands

G - 3D intersection query

```
SELECT concat(t1.globalid, t2.globalid) AS id_comb,
   t1.globalid AS gid_1,
   t2.globalid AS gid_2,
   t1.basename,
   st_3dintersection(t1.geom, t2.geom) AS intersectgeom
FROM "LA_LSBU" t1
   CROSS JOIN "LA_LSBU" t2
WHERE t1.globalid <> t2.globalid
  AND t1.basename::text = t2.basename::text
  AND st_3ddistance(t1.geom, t2.geom) < 10::double precision
  AND geometrytype(t1.geom) IS NOT NULL
  AND geometrytype(t2.geom) IS NOT NULL
```