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BIM/IFC as input for registering apartment rights in a 3D Land Administration Systems – A prototype webservice☆

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A R T I C L E I N F O

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A B S T R A C T

The need for 3D Land Administration Systems (LAS) is growing. In this respect, research is carried out in the field of 3D LAS with respect to data sources, registration of 3D Rights, Restrictions and Responsibilities and dissemination services. Within this context, BIM/IFC models are considered promising sources for 3D LAS, even though the reuse of such models from practice has not yet been examined adequately. Evaluating BIM/IFC-models from practice is crucial, since they are created for different purposes, fulfilling various design criteria. This paper investigates the technical challenges encountered when using real-world BIM/IFC-models for apartment rights' registration in a 3D LAS. It addresses the validation of five Dutch real-world BIM/IFC-models against four technical criteria, namely: existence of IfcSpace; geometric validity; no overlap and georeferencing. The results of the validation show that the collected BIM/IFC-models lack georeference, IfcSpace and a reference to attributes related to the respective legal units in the Dutch 3D LAS. After validation the models are stored in a 3D LAS Database management system (DBMS), in which the legal spaces are enriched with information of the Rights, Restrictions and Responsibilities (RRR's) in line with the Land Administration Domain Model (LADM - ISO 19152:2012). The contents of the 3D LAS DBMS are visualised in a web viewer. Additionally, the design for a webservice is introduced, aiming to automate the process of validation, conversion and visualisation. The paper concludes with recommendations and guidelines for creators of BIM/IFC-models based on the outcome of the validation, as well as challenges and recommendations for implementing a validation webservice.

1. Introduction

In the last couple of decades, the escalating population density has led to a marked intensification of land use, which is characterised by a growing prevalence of multi-dimensional infrastructure. As traditional cadastral systems, relying on 2D maps, lack the efficiency needed to accurately represent the overlapping property rights in such complex urban areas, the need for 3D Land Administration Systems (LAS) is growing. Concurrently, technological advancements rapidly improve methods to collect, create, visualise, register, store and disseminate 3D data. The relationships between people and land in vertical space can no longer be unambiguously represented in 2D, while a representation of spatial units in 3D could provide a clearer insight. Specifically, 2D representations regarding ownership rights within complex apartments might be insufficient for complete delineations and registration of these rights (Atazadeh et al., 2017b). Therefore, LAS are seeking to adopt 3D digital approaches for managing, storing and representing complex ownership rights and restrictions (Alattas et al., 2021).

In this context, much research is carried out on data used as input in 3D LAS, where 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

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environment for 3D lifecycle management of buildings. This is because not only does BIM provide highly detailed semantic and physical information belonging to buildings and facilities, but in parallel, there is a growing global adoption for BIM (Guler et al., 2022a).

Previous research has shown promising results using BIMs as input for 3D LAS (Andrianesi and Dimopoulou, 2020; Meulmeester, 2019; Oldfield et al., 2017, etc.), as briefly presented in sub-Section 2.4. Specifically, the investigation of the link between two international standards, IFC (ISO 16739–1:2024) and the ISO 19152 Land Administration Domain Model (LADM - ISO 19152:2012) for land administration purposes show promising results, as reusing existing models is cost-effective and in line with the Spatial Development Lifecycle, which is further enhanced with the use of standards (Kalogianni et al., 2020a).

Although the research carried out in this field, there is little knowledge on the use of real-world BIMs. Noardo et. al. (2020) researched the usefulness of BIM/IFC-models from practice in the city of Rotterdam, the Netherlands, for which a prototype tool was developed to check building regulations concerning parking units, overlaps, overhang distances, height-related aspects and georeference. It is concluded that a validation tool for semantics and geometry of BIM/IFC-models would be useful, while the curriculum of professionals in the industry shall be enriched in order to be able to model and handle BIM/IFC-models as input for a 3D LAS.

However, the BIM/IFC-models used in other research have been designed or altered with the purpose of being used in a 3D LAS, while BIM/IFC-models from practice are created with a variety of purposes. For the real-world implementation of a 3D LAS it is expected that the BIM/IFC-models that can potentially be used as input for 3D LAS are not created with that purpose in mind. It is therefore relevant to investigate issues that arise when using BIM/IFC-models created with different purposes from practice.

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. The scope of this research is the Dutch LAS and BIM/IFC-models from Dutch practice. It addresses the validation of BIM/IFC-models on known technical issues, places the BIM/IFC-models in a conceptual 3D LAS Database management system (DBMS), in which the legal spaces are enriched with information of the Rights, Restrictions and Responsibilities (RRR's) in line with the Land Administration Domain Model (ISO 19152:2012). The rest of the paper is structured as follows: The necessary background information about the Dutch Kadaster, BIM/ IFC models, LADM and the use of BIM for LAS is presented in Section 2. Following, the methodology of the research is presented and the steps followed are analysed. Results are presented in Section 4, while the webservice design to automate the process of validation, conversion and visualisation, follows. Finally, the paper concludes with recommendations and guidelines for designers based on the outcome of the validation, as well as challenges and recommendations for implementing a validation webservice are addressed at the last two sections. The Annexes contain an overview of the technical development, including the development of a preliminary prototype 3D LAS with visualisation and a link to a github repository where the code is stored.

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). LAS is the combination of both land administration and land registration: a system that both measures the parcels 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). This research focuses on the application of 3D LAS in the Netherlands, taking into account the international trends and the research on the implementation of a 3D LAS internationally. Namely, Croatia (Mader et al., 2018), Australia (Atazadeh et al., 2017a), Saudi Arabia (Alattas et al., 2021), Turkey (Guler and Yomralioglu, 2021; Çoruhlu et.al., 2016), Malaysia (Hassan et al., 2008), China (Ying et al., 2018) and Israel (Adi, Shnaidman, and Barazani, 2018) are some of the countries that actively work towards the development of 3D LAS for their country, from the research.

With the increasing exploitation of the international standard Land Administration Domain Model (LADM, ISO 19152:2012) from academia and industry, LADM-based country profiles are being developed for several countries (Kalogianni et al., 2021; Kara et al., 2024; Kalogianni et al., 2018; Zamzuri et. al, 2023), while research is also targeted to linking the legal and physical counterparts of 3D cadastral objects, through the technical models such as CityGML, IndoorGML, BIM/IFC, LandXML, InfraGML, INTERLIS, etc. (Thompson et al., 2016; Atazadeh et al., 2018; Alattas et al., 2018; Jenny et al., 2018, Shahidinejad et al., 2024).

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), the LADM (2.3) and the use of BIM as input for 3D LAS (2.4).

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. The right of ownership being the most apparent. A parcel can contain split property, for example an apartment building split one a single parcel can be split up into multiple rights. 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 (Fig. 1; Stoter et al., 2013). Next to exclusive right to an area, a deed of division contain agreements on shared property and maintenance responsibilities. For example, a wall between two apartments can be owned by both adjacent apartment owners, and constructional walls and (gevels) can be owned by all parties with an apartment right. The agreements on this are textual, and not represented in the division drawing.

The representation of parcels in 2D maps in case of multi-level property which overlap, is managed 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 (Fig. 2).

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

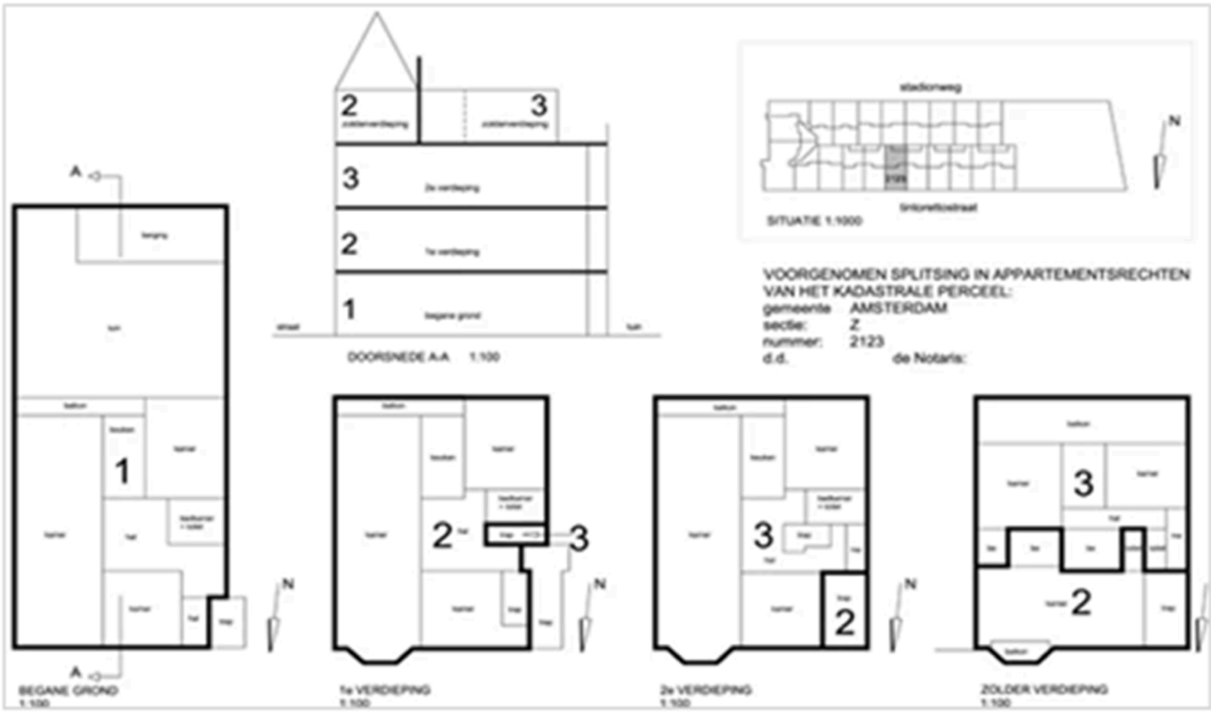


Fig. 1. A splitsingstekening (division drawing) (Max Architectuur BV, 2021).

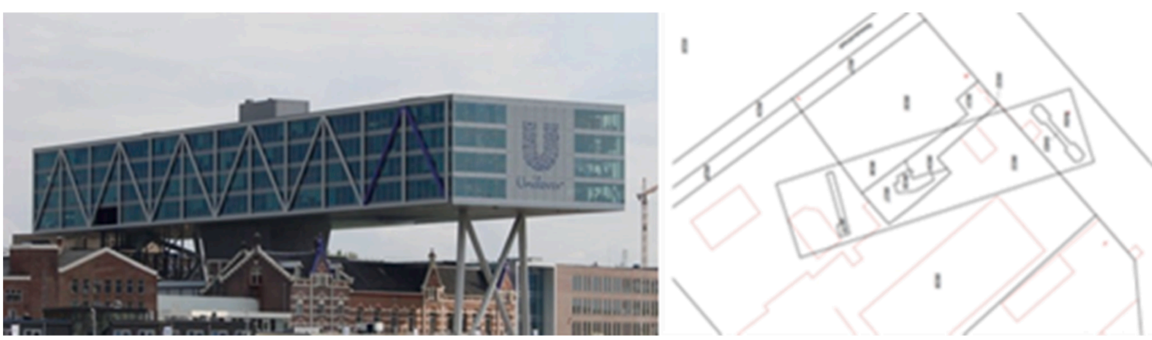


Fig. 2. The Unilever building and its representation on a 2D parcel map (Stoter et. al, 2013).

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. Additionally initial mappings of the LADM to the Dutch LAS have been made (Annex D LADM, Soffers & Hagemans, 2017), and in current years a program for geometrically improving the cadastral map inspired by the LADM is executed (Hagemans et al., 2022).

2.2. BIM/IFC-models

The concept of BIM is storing and maintaining data in the form of a 3D model through the entire lifecycle of a building. For this purpose BIMs 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, for example 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 issuing building permits, as well as register 3D spatial units with related RRR's in a 3D LAS.

BIMs are created with a variety of purposes. A BIM can be created in the design stage of a building. For this, there is a variety in detail, as some BIM modellers only use BIM for creating a 3D Architectural design, whilst others create several BIMs of the entire building, including the construction, utilities, rooms etc. In some cases, even the planning of the building (4D BIM, source) and the furniture is included. Initiatives to create BIM of existing buildings is also upcoming. For example using Lidar scans to acquire 3D scans of a building, and constructing a BIM from that source. Use cases for this include asset management, heritage protection and indoor route finding. Additionally BIM and the IFC file format are being used to model other objects such as bridges, road structures and utilities.

The variety of purposes in creating BIM results in a variety of structure in BIM/IFC-models. For example, BIM/IFC-models created for architectural design may contain little to no information about the constructional assets of a building. BIMs created for construction are often lacking administrative or abstract objects, such as rooms or spaces, as those are not objects to be built.

Additionally the initial design of a BIM (as-designed), is not always updated to a BIM which reflects how a building is actually built (as-built). BIMs created for existing buildings often lack not visible objects, such as isolation or utilities located inside walls.

Next to the variety of purposes, there is also a variety in the way a BIM is semantically modelled. Even though the IFC format dictates an ontology, there is freedom in which properties and attributes can be named.

2.3. ISO 19152 Land Administration Domain Model (LADM)

The LADM is an international 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).

Although the LADM Edition I is extensively used (Kalogianni et al., 2021) and is applicable for various use cases and purposes, ISO rules prescribe periodic review, and therefore, its revision is currently ongoing. The second edition of the standard has extended the scope of the first Edition, including land value, use and development, supporting the development and refinement of LA functions, based on requirements used to design the model, as presented by Kara et al., 2024).

The second edition of LADM is organised as multipart, in the following six (6) parts:

- Part 1 – Generic conceptual model
- Part 2 – Land registration
- Part 3 – Marine georegulation
- Part 4 – Valuation information
- Part 5 – Spatial plan information
- Part 6 – Implementation aspects

Fig. 3 presents the five (5) out of six (6) parts that are currently under development and under the revision process, whilst the development of Part 6 has not yet started.

Part 1 is a high-level umbrella standard that supports all the other parts of the new edition of the LADM and provides an overview of all parts. The "Party", "Administrative" and "SpatialUnit" packages are common packages in Part 1, as well as, in Part 2. For the common packages, in Part 1 the fundamental notions are introduced, while the detailed description of these packages is included in Part 2 (attributes, multiplicities of relationships and attributes).

Part 2 focuses on Land Registration and is largely based on the first edition of LADM, with refinement and extension at the survey model, the 3D spatial profiles and semantically enriched code lists.

Part 3 on Marine Georegulation harmonises the description of RRRs in the marine domain, aligned with land concepts in order to provide seamless land/ marine LA. Furthermore, in Part 4 the Valuation Information Package introduces valuation information used and produced in the context of LA, while in Part 5 the Spatial Plan Information Package deals with spatial planning information and includes the planned land use (zoning).

Lastly, Part 6 concerns the implementation of the standard, including a methodology for developing a LADM-based country profile, an abstract framework for representing LA workflows (processes), a metamodel for structuring and managing semantically enriched code list values, as well as support for different encodings, including, among others, the OGC API family of standards-compliant recommendations for the development of interoperable LADM schema-based information systems (Lemmen et al., 2023).

2.4. BIM as input for 3D LAS

The use of BIM as a basis for establishing RRRs in LA has been explored in many initiatives the last decade, some of those are briefly listed below. Most of the studies carried out focus on the technical aspects, while research on the legal aspects and stakeholder support is limited.

Combining BIM/IFC with LADM creates a correlation that enhances the understanding of the legal space in condominium ownership (Guler et al., 2022a; Ying et al., 2021). Atazadeh et al. (2021) explored the

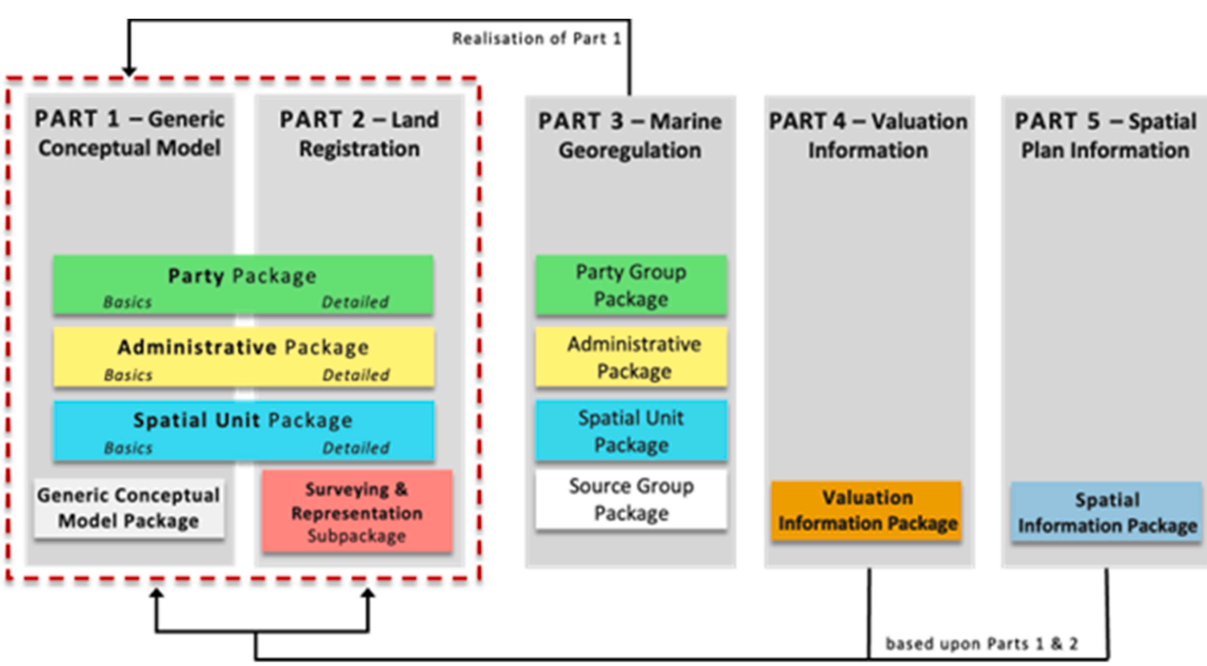


Fig. 3. Packages of LADM Edition II Parts (Kalogianni et al., 2023).

feasibility of the 3D digital management of legal interests in multi-storey building developments in Australia by extending the IFC standard with LADM concepts. In the same direction, Liu et al. (2023) proposed mapping LADM to IFC, in order to extend it with legal information. The proposed model is tested using a 3D building ownership model presented in a case study of China by subdividing ownership boundaries based on clarifying the internal structure of condominium ownership, embedding the apportionment mechanism, and integrating the semantics, attributes, and geometry associated with the physical and legal entity of the condominium.

Similarly, Alattas et al. (2021) addressed the most recent regulations regarding the use and ownership of multi-unit complexes in Saudi Arabia to map the concepts at class level from IFC to LADM, while extracting rules for treating the spaces of various types of walls, slabs, roofs, and constructive elements, such as foundation and pillars. Three main types of spaces are examined in this study: private part, common part, and exclusive common part and the approach is tested with a real-world example IFC file. In China, Zhou et al. (2021) propose a 3D real estate data model (based on an extended IFC model) used to query and define basic topological relationships in GIS for urban construction and management purposes.

Guler et al. (2022b) compare the cases of the Netherlands, Saudi Arabia, and Turkey by revealing the similarities and discrepancies with respect to the registration of apartment rights using BIM/ IFC in terms of legislative basis and current practice. What is more, Barzegar et al. (2021) present an IFC-based database schema for urban land administration purposes, focusing on the spatial analysis requirements in Victoria, Australia. Recently, the Dutch Kadaster, aiming to use BIM for rights and responsibilities to register multi-level building complexes, explores the option that each subdivision submission can optionally be accompanied by a single BIM legal model (BLM), to improve legal certainty. In this scene, a platform "BIM Legal" has been developed, so that Kadaster investigates possible implementations of BIM in the process of the registration of apartment rights with the land registry (Stoter et al., 2023).

3. Methodology

The main objective of this paper is to identify the requirements of BIM/IFC-models in order to be able to effectively be reused as input for 3D LAS and implemented within a system. Focus is given on the validation of the models. This can be further sub-categorised to the following research sub-questions: 1. What are the preliminary interests and benefits of user groups when using BIM/IFC-models as input for 3D LAS?; 2. Which data quality issues are encountered when testing real-life BIM/IFC-models as input for the Dutch LAS, and how can they be resolved? 3. How can the process of validating, converting and visualising BIM/IFC-models be made available for larger user groups?

Based on the Design Science Research approach the following methodological steps are executed (Fig. 4): First research preparation is conducted by identifying user groups and collecting real-world BIM/ IFC-models. Two suppliers of BIM/IFC-models are interviewed about their use of BIM/IFC-models. Based on them, preliminary insights for user groups are provided (Subsection 3.1). In parallel, literature review is conducted to identify and assess known complications and previous work on using BIM/IFC-models as input for 3D LAS (Chapter 2). As a next step, the collected BIM/IFC-models are validated (Subsection 3.2). A 3D LAS DBMS prototype is built (Annex H). Finally, the results, consisting of the outcome of the validation, a prototype and a design for a webservice are presented in chapter 4.

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).

3.1.1. Case studies

The Central Park and Westflank BIM/IFC-models (Fig. 5) are both part of a development 'cu2030' in the station area of Utrecht. The area is of interest since it is a mixed functions-area with multiple property rights. The Westflank model contains an apartment building and the

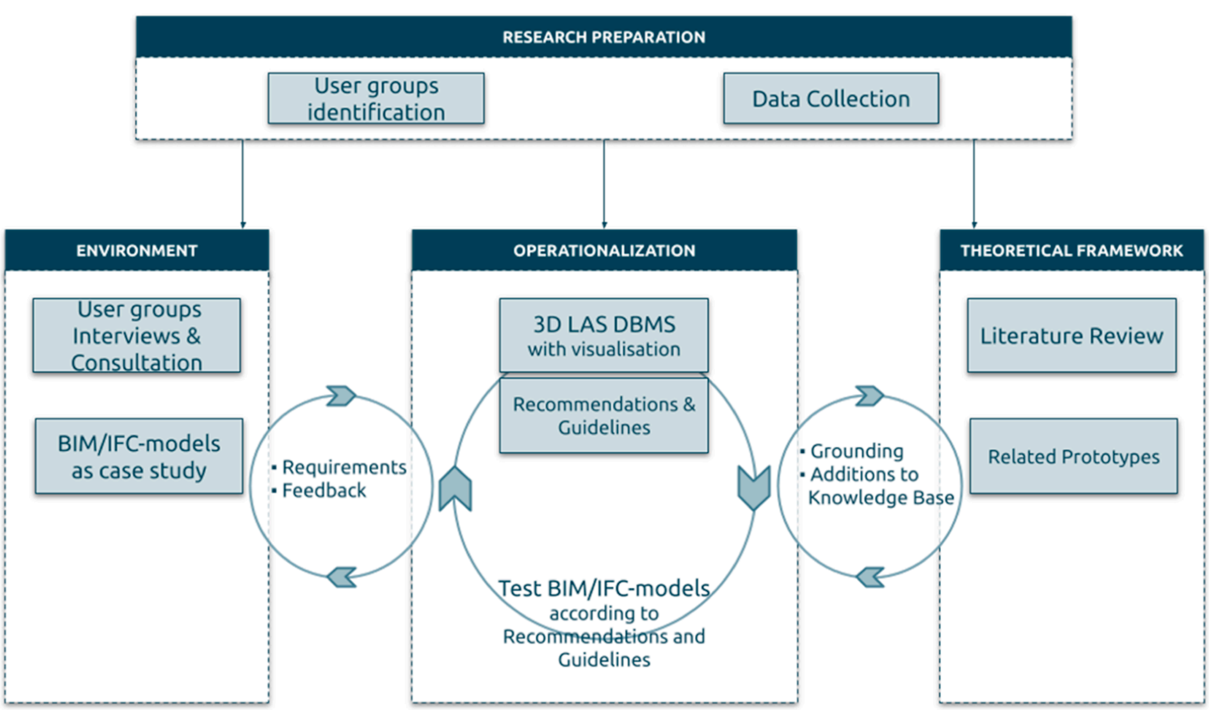


Fig. 4. Methodological Steps.

Table 1
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

Central Park model contains an office to be built (Figs. 5, 6). The Pontsteiger building has a complex geometry: it contains two towers which are connected through a bridge. The Central Library BIM/IFC-model represents the Central Library in Rotterdam. The Schependomlaan BIM/IFC-model represents an apartment building in Nijmegen.

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 organisation, but the workflow of that organisation 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. Wind flow and sun studies are made, and these could benefit from the use of accurate 3D models.

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 undesired for a digital twin, due to amongst others processing capabilities of browsers. 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

The relevance of the technical requirements and methods to validate the requirements are given in the following paragraphs. 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 must have no overlaps or gaps, as spaces should be mutually exclusive (3.2.3).
- The BIM/IFC-mode shall be georeferenced, 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/

Fig. 6. Central Park building (middle) under construction (own photo, March 31, 2021).

Fig. 5. The Westflank (left) and Central Park (right) BIM (BIMvision, 2021).

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 IfcSpace objects 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 index numbers 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 IfcSpace objects.

It should be noted that next to spaces, building elements including walls, facades and utilities can also be assigned RRR's, however building elements are not assigned RRR's in the scope of this research. Stoter et. al. (2023) does propose the possibilities of assigning RRR's to building elements in the Dutch LAS, however it is also acknowledged that the first step towards a 3D LAS is assigning RRR's to spaces. Moreover building elements in BIM/IFC-models are often modelled for construction, not regarding separate units. Therefore, in order to assign RRRs to building elements in BIM/IFC-models, these elements have to be subdivided. Alattas et al. (2021) give an example of this by describing the process of subdividing a building with its building elements into private, common, and exclusively common spaces.

3.2.2. *Valid geometries*

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). In this validation it was assessed whether the features of the BIM/IFC-model are compliant with OGC 1.2.0. This ensures that geometries within the IFC/IFC-model adhere to specified standards, including geometry types, geometry structure and topological relationships. Additionally a check is made for non-planar surfaces and correct orientation of surfaces. Checking this is important for further geometric analysis and visualisation. For efficiency, often geometric analyses assume planar surfaces and a right-handed orientation. If this is not the case the analysis can give false results. Additionally by default in 3D rendering only the outside surfaces are rendered, which are assumed to be defined by a right-hand orientation. Incorrect orientation leads to holes in the 3D rendering (Ledoux, 2013). After the validation of geometries, an attempt is made to repair the found issues: 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. 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.

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 vol) are excluded and not counted as overlap. The geometries are compared to each other using a materialised view (Appendix G). The query does not utilise a spatial index, which has a negative impact on the execution time. Concurrently only geometries which have a distance of less than 10 m are compared. The outcome of the materialised view is analysed within FME (Appendix B).

3.2.4. *Georeferencing*

BIM/IFC-models usually 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 2×3 and do not support these attributes.

The BIM/IFC-models are validated by investigating the existence and contents of the attributes stated by (Clemen and Görne, 2019; Table 2). The tool IfcGeoRef (Clemen and 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 is assessed if it complies with LoGeoRef10-LoGeoRef50, and if so the contents of the attributes are exposed.

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.

4. Results

4.1. Results of validation

4.1.1. Legal spaces

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. Valid Geometries

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.

4.1.3. Spatial relations

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 carried out 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 2×3.

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. Modelling guidelines for data quality for BIM/IFC-models

The data quality issues encountered in the validation of the BIM/IFC-models as input for a 3D LAS are:

- the lack of 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,
- invalid geometries,
- overlapping geometries and
- the lack of georeference.

For effectively designing BIM/IFC-models to reuse as input for a 3D LAS regarding the found data quality issues, recommendations and guidelines are formulated as follows:

- rooms have to be included in the BIM/IFC-model and modelled as IfcSpace,
- IfcSpace should contain a property set including the apartment index number, the cadastral parcel number, the complex number, the space type and the respective Municipality.
- IfcSpaces can be grouped, but these groups should not be included as a (duplicate) IfsSpace volume. IfcZone can be used to group spaces.
- 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 2×3 models it is necessary to enrich the IFC files with attributes complying to LoGeoRef30 and/or LeGeoRef40.

Table 3
Results of validation.

		a) Legal Spaces					b) Valid Geometries				c) Overlaps	d) Georeferencing				
BIM/IFC-model	IFC version	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

5. Designing a validation webservice

The developed prototype consists of a series of FME workspaces combined with storage and queries in PostgreSQL. Even though through this development the validations are automated, it still requires manual labour to run the FME workspaces and upload the Cesium Tilesets to a web viewer, which is too complicated for an architect or project developer. Concurrently if this process was to be implemented for an organisation or even wider at a National level, it would require manual labour to send and receive the BIM/IFC-models, and send the results of the validation to the designer of the BIM/IFC-model. A design for a webservice is made to minimise manual actions and automate the process of validating BIM/IFC files to be reused for 3D Land Administration purposes. Challenges that arise for building and implementing the webservice are addressed.

In recent years other efforts to set up a validation webservice have been made. The international BuildingSMART foundation introduced an IFC validation service and the IDS standard to respectively check an IFC file against the IFC schema, and a semantic check defined in a Information Delivery Standard. These developments are promising. However, they only validate based on semantics, not on other issues such as geometry.

5.1. Context of the webservice

The workflow and the webservice can be placed inside current building permit processes, in which project managers have to request a building permit before the building process. Next to requirements for BIM/IFC-models as highlighted in this research, the validation service could be extended to validate other requirements of the building as stated in the Dutch law 'Bouwbesluit 2012' (Building Law 2012 - Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022) in which requirements are stated for buildings regarding amongst others the size of the building, safety and environmental laws. In order to better prepare the BIM/IFC-models also for the future 3D Land Administration, it should also be validated at this stage and check if the 3D Spatial Units are properly defined.

5.2. Design of the webservice

The design of the webservice (Fig. 7) describes the process and information flow of the proposed webservice. First the actors of the workflow are clarified, thereafter the stages of the workflow are described.

The workflow describes two main actors: the project manager and the civil servant. The exact interpretation and name of the roles may vary per use case. Additionally the roles can represent one person or group of persons, i.e. a government department. In the workflow the project manager is responsible for the building project. At its core, the role represents the actor with responsibility to deliver the BIM/IFC-model and ensure the BIM/IFC-model is successfully validated. The civil servant role represents the governing body responsible for overseeing and assessing building projects. The civil servant is tasked with maintaining the 3D LAS DBMS, and it that regard review and approve BIM/IFC-models. Concurrently the civil servant is responsible for maintaining the validation software, and making decisions about the validation criteria which should be implemented. To form the validation criteria, the civil servant is aware of relevant laws and business requirements.

Stage 1 - In this stage the project manager uploads a BIM/IFC-model to the webservice. If the BIM/IFC-model does not meet the stated requirements no interference of a Civil Servant is needed. The Project Manager will alter or instruct to alter the BIM/IFC-models to meet the requirements. A FAQ-section on the website can address commonly occurring errors. The Civil Servant can be contacted for questions. This stage is followed multiple times and at different moments. Firstly, the As-designed BIM/IFC-model is validated, approved and stored. After the building phase the As-built BIM/IFC-model is validated, with additional validations to compare the As-built model with the As-designed model, to remark significant changes.

Stage 2 - When a BIM/IFC-model is successfully validated, the Civil Servant is notified. The Civil Servant is tasked with approving or denying the BIM/IFC-model. This action is still desired, as a manual check can highlight errors which are not included in the validation. Concurrently the involvement of a Civil Servant is needed to monitor the building site and see if the BIM/IFC-model is congruent with reality. The Civil Servant is also tasked with decision making an automated process is not able to do, e.g. is a difference in the As-built and As-designed model justified. However the Civil Servant is now aided by the validation report.

Stage 3 - The last stage requires no manual action. The BIM/IFC-model is stored both on a file server and converted to a 3D LAS DBMS. The former is done to aid the process of comparing the As-designed and As-built model, and to keep an original copy which can be used for other

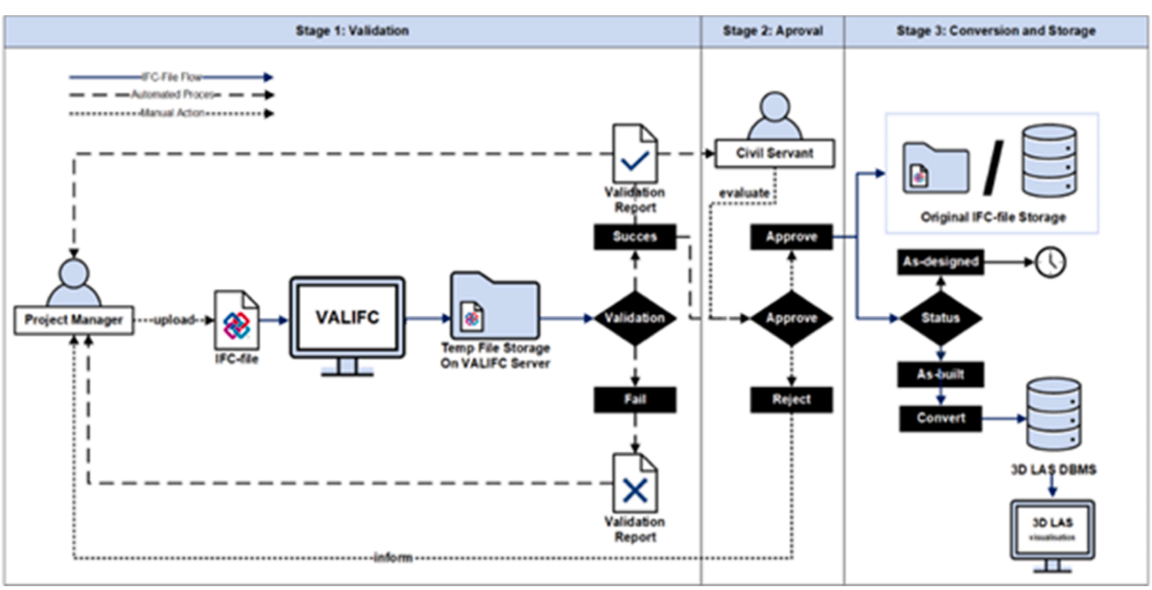


Fig. 7. Workflow of the webservice.

purposes. Lastly, the visualisation of the 3D LAS DBMS is updated. The 3D LAS DBMS has the purpose of storing information about the Spatial Units and corresponding Land Administration properties. Additionally the DBMS could be used for other purposes, in which 3D data of buildings can be relevant, i.e. a Digital Twin, utility management, wind-, sun- or air quality research, indoor navigation and information for emergency services.

5.3. Technical design choices and challenges for the webservice

For the prototype development and methodology (3.2) BIM/IFC-models were validated and converted into a PostgreSQL database with FME workspaces. Workspaces stored on a local computer do not allow to be run automatically. FME Server is able to integrate workspaces into an automated workflow, and create an User Interface. However, FME is proprietary software. In order to reduce costs and create an open source solution the aim is to develop the webservice, VALIFC, using non-proprietary software.

A website is built and deployed on a local server using Flask (Grinberg, 2018), a web development kit. Using the Ifcopenshell python library. A frame is built in which a user can upload a BIM/IFC-model with the *.ifc file extension. The BIM/IFC-model is stored on the server. The BIM/IFC-model is validated, currently only the existence of IfcSpace is validated. A report in the *.json file format is generated and shown to the user.

Technical challenges to implement the remaining validation criteria are the implementation of extracting geometries from the BIM/IFC-model using the Ifcopenshell library or other open source software. This is needed to validate the geometric validity, spatial relations, and convert and store the geometries in a DBMS. Attributes regarding georeferencing capabilities can be extracted and checked. However there are challenges in determining whether the values are congruent with reality.

6. Discussion

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 organisational challenges have to be addressed as well. Efforts from the Dutch LAS itself to move towards a 3D LAS, for example Stoter et. al (2023), can aid this process. A legal mandate, combined with standards, have the possibility to direct user groups when designing and exchanging BIM/IFC-models.

Next to the given guidelines more standardisation regarding the contents of a BIM/IFC-model is desirable, as it promotes the reuse of BIM/IFC-models not only as input for 3D LAS, but also for other purposes such as automated permit checking, use in digital twins and asset management. The need for standardisation is recently gaining attention, for example with initiatives in countries to come to unified standards (Kirahub, 2023, CCIC, 2023). The use of standards is aided by technological developments to validate if the standards are being adhered to. In this light the development of BuildingSmart to develop an IFCValidator and the introduction of the IDS standard to store and check semantic properties of a BIM/IFC-model are interesting to further look into.

New technologies have to support users in such a way that they can eradicate chorefull tasks and can focus on their expertise. In this regard the method of buying and selling can change to be more efficient as shown by Coruhlu & Toludan, T. (2019) who proposed a data model based on the LADM to efficiently transact property via e-Turkey. Which part of an apartment belongs to whom, might become more clear in a 3D visualisation. Some mistakes made by trying to understand complex situations by interpreting 2D floor plans can be avoided, as unambiguous 3D representations are used. Notaries as legal entities play an important role for the Dutch cadastre. This work is merely technical, and involves more work with legal and human side. They will benefit from better technical systems, again eradicating chorefull tasks and giving more time to focus on their expertise. Supporting notaries with technical solutions hence is important, but therefore not only software, but also BIM/IFC-model guidelines and/or standards have to be made and followed. A move towards this is seen in the Netherlands, in which it should be noted that in the Netherlands, notaries themselves are involved and willing, since their current process with 2D maps can be tedious.

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.

The built prototype consists of a series of FME workspaces, a PostgreSQL DBMS and a web viewer. This differs from the design for the webservice, which is based on open source software. The difference occurred from amongst others technical limitations due to software availability. When further implementing a webservice a design choice has to be made to use proprietary or open source software.

6.1. 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/IFC-models 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 2×3, 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.

A design of a webservice is introduced, however the implementation is not fully realised. Future work is needed to further develop and build a webservice, which is capable of validating and converting BIM/IFC-models in a 3D LAS DBMS. The design of a webservice can also be used for other purposes, such as automated permit checking. A lack of standards, both in content of BIM/IFC-models, exchanging BIM/IFC-models and offering checking services hinders this development. However the current Horizon project ACCORD (2024) is investigating on a European scale the automation of permit checking using BIM/IFC-models, and proposes an API-based microservice checking architecture, which could be of interest. Next to a first registration in a 3D LAS, RRR's can change, and ownership can be transacted. Coruhlu & Toludan, T. (2019) have proposed a data model based on the LADM to efficiently transact property via e-Turkey. It is useful to investigate transactions for the Dutch LAS as well.

7. Conclusions

For this research 5 BIM/IFC-models are collected, validated and used as input for a prototype 3D LAS. A design of a webservice to validate and process BIM/IFC-models is introduced. Expected user groups 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. The preliminary interests of user groups were presented by consulting architect and a civil servant. They underline the importance of being able to extract information from, and process and convert BIM/IFC-models in a standardised way, and implement methods to reuse BIM/IFC-models.

Multiple data quality issues are encountered when testing the real-world 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. Guidelines are created to address these issues.

A design for a webservice is presented, aiming to introduce an automated workflow to validate, approve and convert BIM/IFC-models into a 3D LAS DBMS. The webservice has the potential to facilitate both project managers and civil servants in validating, approving and converting BIM/IFC-models. However there are still technical challenges to be addressed.

The research gives insight into how BIM/IFC-models should be designed to effectively be reused as input for 3D LAS, getting input from both theory and practice. The use of real-world BIM/IFC-models adds value, since it gives insight into the reusability which can be expected when implementing the use of real BIM/IFC-models for a 3D LAS. The awareness that these outcomes may differ in the case of BIM/IFC-models with different purposes can add to a successful preparation for a 3D LAS.

CRediT authorship contribution statement

Eftychia Kalogianni: Writing – review & editing, Writing – original draft. **Marjan Anje Broekhuizen:** Writing – original draft. **Peter van Oosterom:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

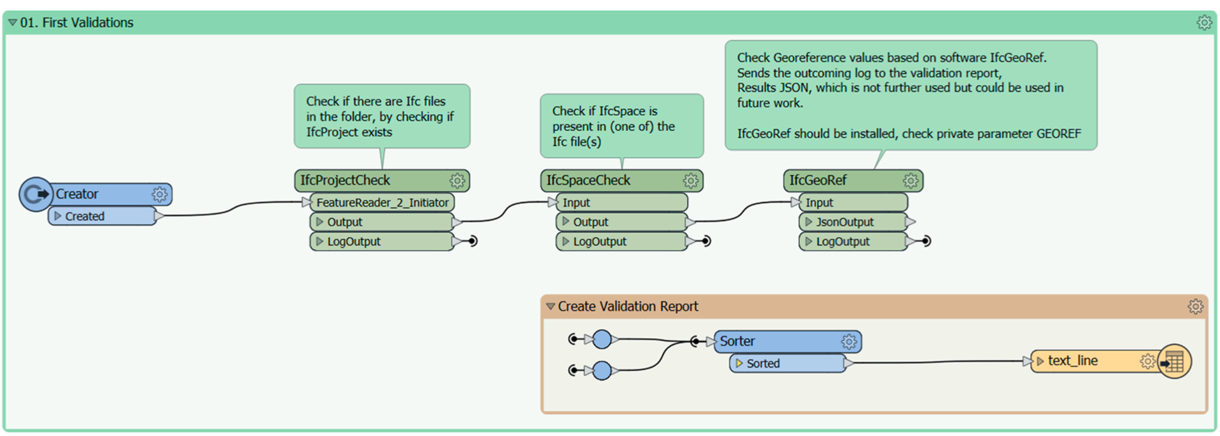
Data Availability

Code is available through github, but data files cannot be shared because of IP.

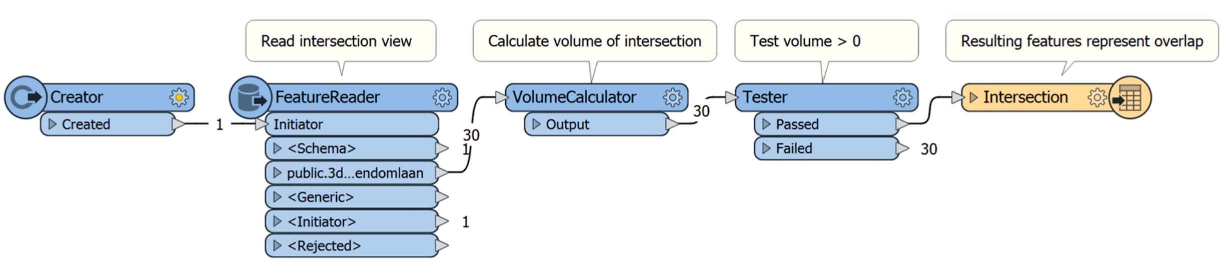
Apendices

The developments as presented in the appendices can also be downloaded from the github repository: https://github.com/superjumpylion/BIMIFCto3DLAS.git

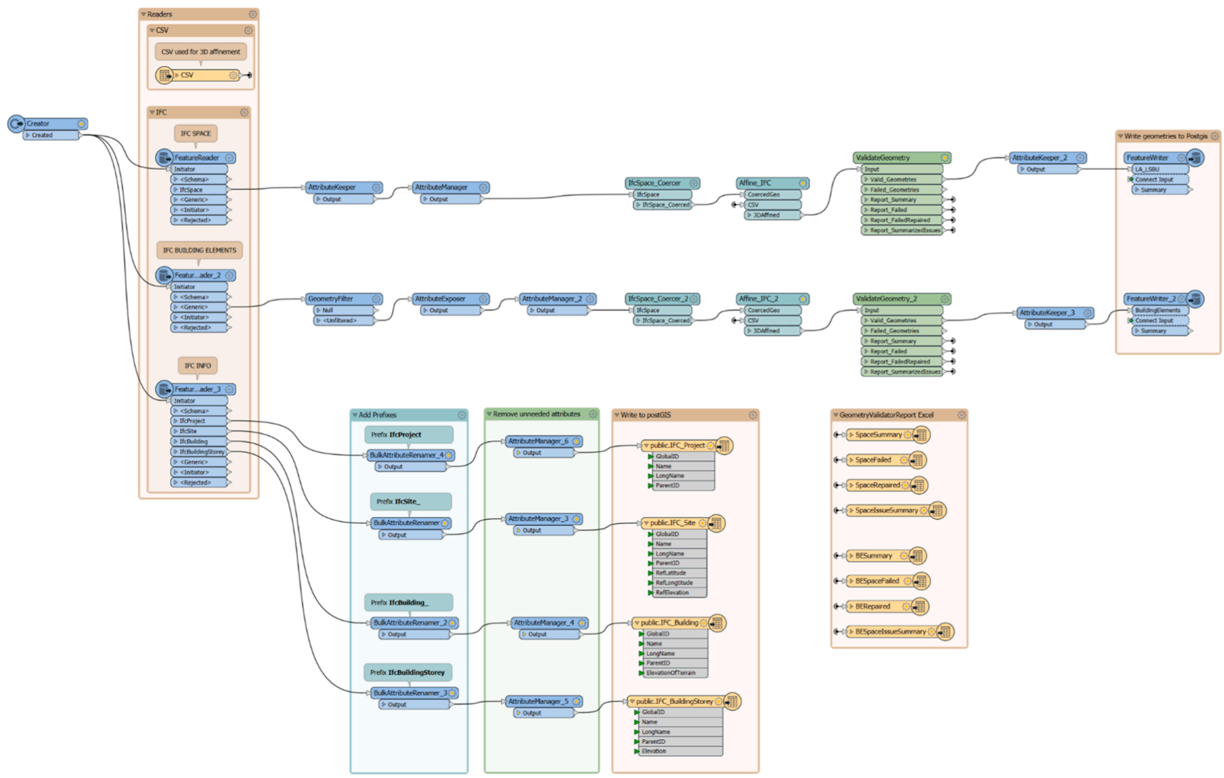
A - 1_IFCspaceAndGeoRefCheck - Validates if IfcSpace is present and generates a IfcGeoRef report containing information about georeferencing capabilities.



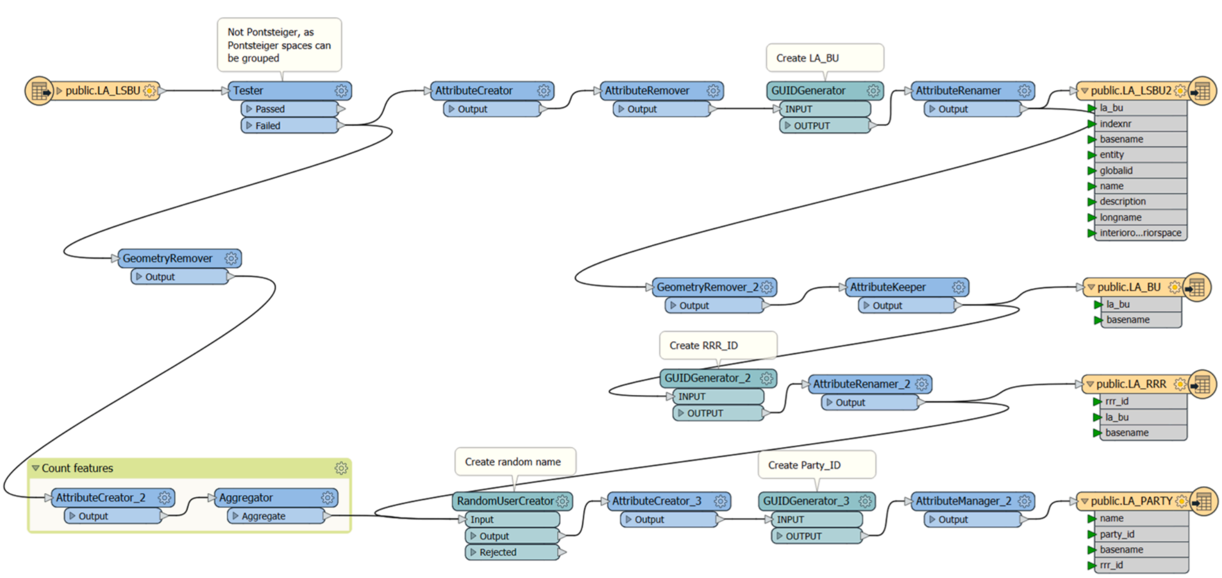
B - 3_Intersection - Reads the 3D intersection view from the DBMS, calculates volumes and results volumes > 0 as overlap.



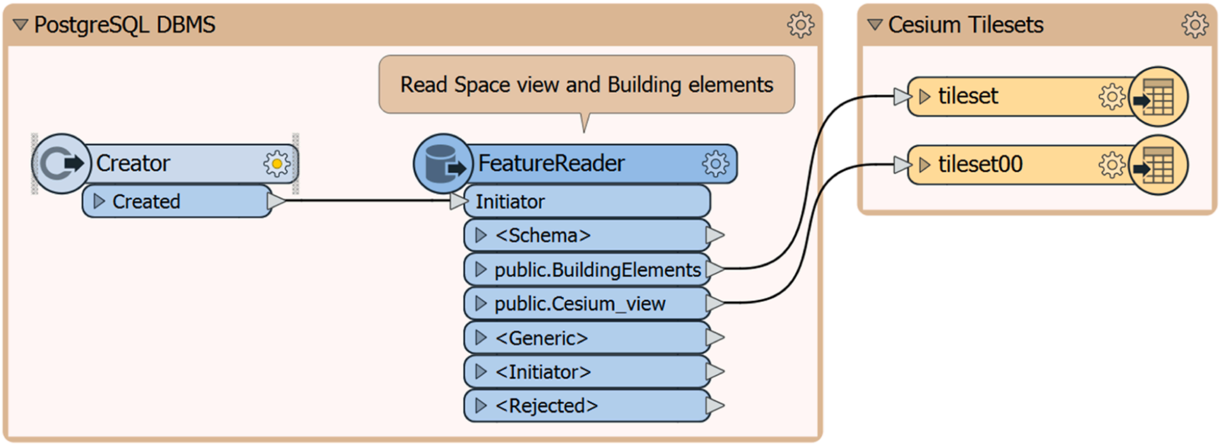
C - 2_BIMIFCtoDBMS - Coerces geometry, validates geometry, and inputs valid geometries in DBMS



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
```

H - Description of the 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.

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:

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