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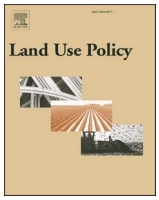

A BIM-based approach to design a lifecycle 3D property formation process: A Swedish case study

Jing Sun [a,*], Jesper M. Paasch [b], Jenny Paulsson [a], Väino Tarandi [a], Lars Harrie [c]

[a] KTH Royal Institute of Technology, Department of Real Estate and Construction Management, Teknikringen, 10B, SE-100 44 Stockholm, Sweden
[b] University of Gävle, Department of Computer and Geospatial Sciences, SE-801 76 Gävle, Sweden
[c] Lund University, Department of Physical Geography and Ecosystems Science / GIS Centre, Sölvegatan 12, SE-223 62 Lund, Sweden

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ABSTRACT

3D property formation has become an important solution to provide a more comprehensive and accurate representation of the property's physical characteristics than traditional 2D property formation. Despite the numerous benefits of the 3D property formation, there is a need for more detailed descriptions of 3D cadastral data delivery between the involved actors to ensure efficient and effective collaboration. In particular, the practical difficulties are when/what related 3D cadastral information and models should be exchanged and stored from/to whom. Therefore, to address these issues, we propose a lifecycle 3D property formation process with four phases by designing an IDM process, which is an international open BIM process standard. In the purpose of forming a Swedish lifecycle 3D property formation process, the IDM process has been applied through organizational, legal and technical aspects, including identifying actors and their roles and values, gathering 3D property formation requirements, defining the data exchange requirements and designing the process map. Moreover, a case study was used to specify the Swedish lifecycle 3D property formation process and information delivery between stakeholders in the IDM. The aim is to facilitate a standardized and unambiguous digital 3D property formation procedure on a national level in order to improve and enhance the digital Swedish Cadastral and Land Administration Systems, but the process is quite generic and could also be applied in other countries.

1. Introduction

With the increased interest and demand in 3D property, 3D property formation has shown significance (Choon and Hussion, 2012; Larsson et al., 2020) and it has been shown that 3D property formation is an effective method for subdividing and separating the ownership of different activities in densely built areas, e.g. in cities (van Oosterom et al., 2018). The 3D property formation process requires involved actors to share and exchange 3D cadastral information and models between each other. However, much of this information sharing and exchanging is still using textual description and non-machine readable data formats in practice. During recent years, there have been several studies of technical solutions for the cadastral process both from a technical perspective (Oldfield et al., 2017; Stoter et al., 2017; Sun et al., 2019a) and a legal perspective (Swensson and Juulsager, 2014; Andrée et al., 2018).

In Sweden, one of the biggest challenges is the lack of a detailed and efficient process that could describe the 3D cadastral data delivery between multiple actors as well as actions from the actors to obtain an unbroken digital flow of data in practice. Most documents used in the 3D property formation process are still recorded and registered in paper format or frozen digital images (Andrée et al., 2018). The Swedish cadastral authorities use 3D CAD drawings specifying the 3D real property boundaries in the cadastral formation process, but these drawings are not formally archived in the national real property register (Larsson et al., 2020). Moreover, the organizations and different stakeholders involved in the 3D property formation process reveals it as an unclear and ambiguous process. There are recommendations, standard guidelines and requirements for cadastral formation at national level, but no formal instructions for the cadastral authorities on how to use digital data, e.g. BIM models, in the 3D property formation process. The digital building models used in the 3D property formation process are stored in different ways locally, but it does not exist a formal national process for storing the digital models in the national real property register.

To address these issues, we propose a BIM-based approach to design

* Corresponding author.
E-mail addresses: jingsun419@gmail.com, jingsun@kth.se (J. Sun), jesper.paasch@hig.se (J.M. Paasch), jenny.paulsson@abe.kth.se (J. Paulsson), vaino.tarandi@abe.kth.se (V. Tarandi), lars.harrie@nateko.lu.se (L. Harrie).

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a Swedish lifecycle 3D property formation process that covers the organizational, legal and technical perspectives. The IDM (Information Delivery Manual) is an international process standard of BIM that is used in the paper to design and develop a Swedish lifecycle 3D real property formation process, as well as to illustrate the cadastral requirements sharing and exchanging between different actors. The main purpose is to facilitate a general, standardized and unambiguous digital 3D property formation procedure on a national level in order to improve and enhance the digital Swedish cadastral and land administration systems. To achieve this, the IDM is applied in the procedure through four steps: identifying the main actors, gathering the 3D property formation requirements, defining the data exchange requirements and designing the process map. A case study based on the property Organellen in Stockholm, Sweden, is performed to illustrate how data will be exchanged between different actors in the lifecycle phases when forming 3D property. Specifically, compared with the properties Organellen created in the current procedure, we investigate how the property formation procedure would work in the new proposed IDM that defines the cadastral information requirements for each actor and specifies how the information should be delivered, when it should be delivered, and in what format.

The structure of the paper is as follows: Section 2 provides brief backgrounds of 3D property formation, BIM including IFC and IDM. Moreover, the current status of 3D property formation process in Sweden and challenges with it are described. In Section 3, the process schema is designed and presented as a BIM process standard IDM with description of actors' role and value, as well as four detailed phases. Each step by actors and data delivery of this process are described. Then the process schema is implemented in a Swedish case study in Section 4. Section 5 discusses and provides suggestions from organizational, legal and technical aspects for promoting the 3D property formation procedure. The paper summarizes the conclusions in Section 6 with the main findings of this research and further work.

2. Related work

2.1. 3D property formation

Property formation is a complex domain including real property subdivision, amalgamation, re-allotment, partition, and other processes (Hjelmblom et al., 2019). Several countries have introduced 3D property units (van Oosterom, 2018) as a complement to the 2D property units. The interest of 3D property has increased during the last decade and many research activities have been conducted. For example, Paulsson and Paasch (2013) divided 3D property research into four categories for classification: legal, technical, registration and organizational. 3D properties clarify the ownership and rights between several actors. Stoter et al. (2017) developed a workflow to create a 3D PDF visualizing a multi-level property situation to be registered as a legal document in the land registers. van Oosterom et al. (2019) explored the challenges of 3D cadastre visualization and presented the main results of the public usability testing of a web-based 3d cadastral visualization system. The 3D property formation process is complex and must comply with various legal and regulatory requirements varying across different jurisdictions. Moreover, multiple actors are involved when forming 3D property, which makes the process challenging in order to develop a streamlined and efficient process to satisfy the needs of the actors.

2.2. BIM

Building Information Model (BIM) is not only a model or tool but also a process and technology of creating, maintaining, using and exchanging building information (Sacks et al., 2018; Neuville et al., 2019). In the AEC sector, BIM is a digital representation of a building in the life cycle phases, containing rich details of building properties such as structures, elements, spaces, schedules, and other aspects of a construction project (Sun et al., 2019b). When integrating with cadastre, BIM models provide detailed spatial information about physical components of buildings, which could address the problems with good capabilities as physical model to generate a 3D cadastral model (Sun, 2019). However, in the 3D property formation phases, many organizations and cadastral surveyors may not have enough BIM expertise to use, check, validate, register, manage and update the integrated 3D cadastral models. Therefore, the gap is how to utilize a BIM method for 3D property formation effectively and efficiently.

BuildingSMART has developed international open standards (Fig. 1) for the building industry worldwide: Industry Foundation Classes (IFC) enable digital storage for interoperability; International Framework for Dictionaries (IFD) to specify the terminology; and Information Delivery Manual (IDM) / Model View Definitions (MVD) identify the process (buildingSMART, 2019).

2.2.1. IFC

IFC is the most spread open international standard in the BIM domain, which is designed to exchange and share information among software applications by many different stakeholders (Borrmann et al., 2018) and supports definition of building elements and the spatial relationship between the elements. In view of the fact that IFC has powerful capabilities to model detailed physical information and represent 3D property boundaries accurately, BIM/IFC has attracted a wide attention and started to integrate with 3D cadastre (Sun et al., 2019a). For instance, Atazadeh et al. (2017) performed a case study to explore the feasibility of BIM to model the boundaries of ownership spaces inside buildings and identified relevant geometric and semantic IFC entities. Thus by using IFC, different organizations and software applications can work together seamlessly, which is essential for the successful implementation of a standardized 3D property formation process.

2.2.2. IDM

ISO 29481–1:2016 defines the Information Delivery Manual (IDM) as a standardized document that captures the business process and gives detailed specifications of the information that a user fulfilling a particular role would need to provide at a particular point within a project (ISO, 2016). It is a BIM methodology that describes an interaction framework and specifies processes and information flow during the lifecycle of a facility by bringing many different stakeholders together in a project-specific organization as stated in ISO 29481–2:2012 (ISO, 2012). The standard clarifies a detailed process, helps all actors' communication, harmonizes different product data models delivered and stored, identifies the results of that activity, as well as improves the management more efficiently and collaboratively. IDM can specify information requirements for specific information use cases in a structured manner and is mainly composed of three parts: a process map (PM), exchange requirements, and a model view definition (MVD) (Sacks et al., 2018). The PM is normally created in the Business Process Model and Notation (BPMN), which is a standardized graphical specification

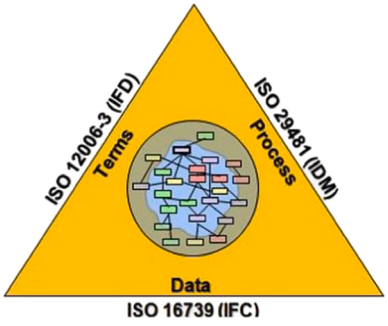

Fig. 1. Open BIM standards: IFD, IFC, IDM (BuildingSMART, 2019).

language for modeling business processes and workflows developed by the Object Management Group (OMG, 2011). BPMN is used for the formalization processes in BIM and provides various features e.g. pools, swim lanes, flow objects (a set of activities, events, gateways), connecting objects and artifacts (Borrmann et al., 2018).

In general, IDM supports issues such as:

- Which kinds of information is required and delivered in what order?
- How should the information be exchanged and stored?
- Who should take responsibility to produce the 3D models for existing buildings?
- How to regulate information flow and improve information quality within processes?

Recently, some studies have utilized the IDM process to describe how cadastral information is shared and exchanged between stakeholders following international standards in the 3D property formation procedure (Oldfield et al., 2017; Sladić et al., 2020). Oldfield et al. (2017) proposed an IDM workflow for the Dutch cadastral registration where two actors were involved in the registration workflow during different phases: project initiator and authorities. One issue with the proposed workflow is that it did not mention the details of the 3D property formation process with more related actors. Sladić et al. (2020) identified user needs in IDM to model business processes.

2.3. The Swedish property formation process

2.3.1. Current status

The Swedish mapping, cadastral and land registration authority (Lantmäteriet) is a public authority and has the overall responsibility for the formation of real property including making decisions on new property units, making changes to existing boundaries, and making decisions concerning joint properties, easements and rights of way. That being said, 40 large municipalities have by the government been authorized to make cadastral formation, etc. within their domains, for example Stockholm municipality. All properties and cadastral changes are registered in the national Swedish cadastre at Lantmäteriet.

Each municipality is its own property formation cadastral and land registration authority, being authorized by the Government after fulfilling certain preconditions. The municipal cadastral authorities are responsible for and in charge of the entire formation process to form real property locally. Lantmäteriet has recommended the Swedish Government to modernize the legal statutes for real property registration to facilitate a smooth transfer from today's handling of information to an information infrastructure of tomorrow (Sun and Paulsson, 2020).

A property is formed through decision by a cadastral surveyor employed by Lantmäteriet or a municipality, depending on where in Sweden the property is planned to be formed. The cadastral authorities use 3D CAD drawings containing the 3D real property boundaries in the cadastral formation process, but the digital drawings are not archived in the national real property register (Larsson et al., 2020). In order to form real property in 3D, the issue is that 3D physical models with 3D property boundaries must be registered with 2D legal documents (Sun et al., 2019a), since there is not digital 3D storage solutions in the reap property register. This poses challenges for different actors to access unified cadastral data and cooperate with unambiguous documentation.

Recently, the increased interest in 3D property formation in Sweden requires an effective formation process. Swensson and Juulsager (2014) illustrated the Swedish property formation process: application, investigations/consultations, field survey map, meeting decisions, conclusions of procedure, invoice sent and registration. Andrée et al. (2018) developed a vision of a future process model where different actors cooperate in conjunction with BIM and geographic information (Fig. 2). They did, however, not provide a detailed description of each phase and the data exchange between the actors in the formation process.

Sun et al. (2019a) formulated general basic requirements for 3D cadastral formation and proposed a general framework to integrate 3D cadastre and 3D digital models, both BIM and 3D city models, that supported the requirements above. Especially, they defined links and transformations between cadastral data (stored in LADM and a cadastral

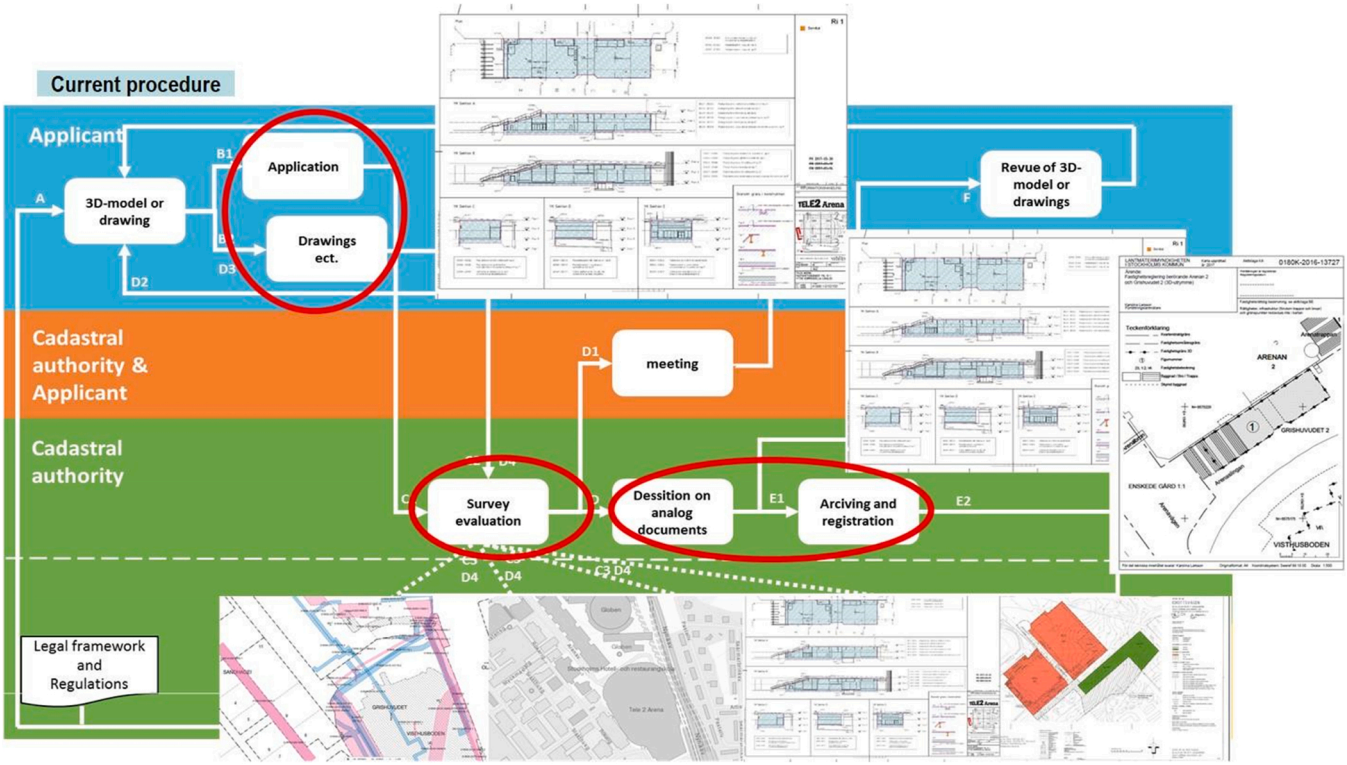

Fig. 2. Current process of Swedish 3D real property formation (Andrée et al., 2018).

unit), BIM-model (stored in IFC at an Architecture, Engineering and Construction (AEC) company) and 3D city models (stored in CityGML at a surveying unit) (Fig. 3). However, Sun et al. (2019a) did not describe the digital data delivery between the related actors to obtain an unbroken digital flow of data in the 3D cadastre process.

2.3.2. *Challenges of the Swedish 3D property formation process*

There are some problems associated with today's process. From the applicant's perspective, it is a challenge to illustrate the desired boundaries, rights and desired common facilities for a future 3D property in a manageable and sustainable way. It is difficult to correctly report a 3D volume only in paper drawings and read a cadastral index map in 2D with properties and rights decided in 3D (Kitsakis et al., 2018). This is clarified not least when the application is submitted with requests to make changes to existing 3D boundaries. Then the cadastral surveyor first needs to go through the paper documents to understand where the 3D spaces and boundaries are located, assess the suitability of the desired new demarcation and then in the decision documents clearly state how these change. There is a need for the applicant to receive guidance on how to best specify the application so that the material submitted to the authority is as functional and complete as possible. By using materials that are produced in the design of a new building, materials are used in a more efficient way.

Furthermore, additional parts of the administrative process that need improvement are that the cadastral index map (register map) needs to be clearer, previous decisions need to be easier to understand, more uniform and unambiguous administrative documents are needed, access to uniform data throughout the process is needed, reusable information is needed, and uniform visualization is needed. If data is produced in a very different design and quality, it can be difficult to obtain a coherent basis for decisions and registers, which can complicate interpretation and future handling, which in turn leads to costly processes for change of cadastral management. Today, 3D property formation decisions are sometimes made based on older building permit drawings with boundaries drawn by hand.

3. Formalization of a Swedish lifecycle 3D real property formation process with IDM

The 3D real property formation process is divided into four basic phases: initiation, preparation, decision and registration (Fig. 4).

As introduced in Section 2.2.2, IDM can be applied in 3D cadastre to describe how cadastral information is shared and exchanged between stakeholders. In this study, we use the IDM approach to design and develop a Swedish lifecycle 3D real property formation process, as well as to illustrate the cadastral requirements exchanging between different actors. The proposed method aims to facilitate a general, standardized and unambiguous digital 3D property formation procedure on a national level in order to improve and enhance the digital Swedish Cadastral and Land Administration Systems. The IDM method applied to design a Swedish lifecycle 3D property formation process covering the organizational, legal and technical aspects is presented as the following steps:

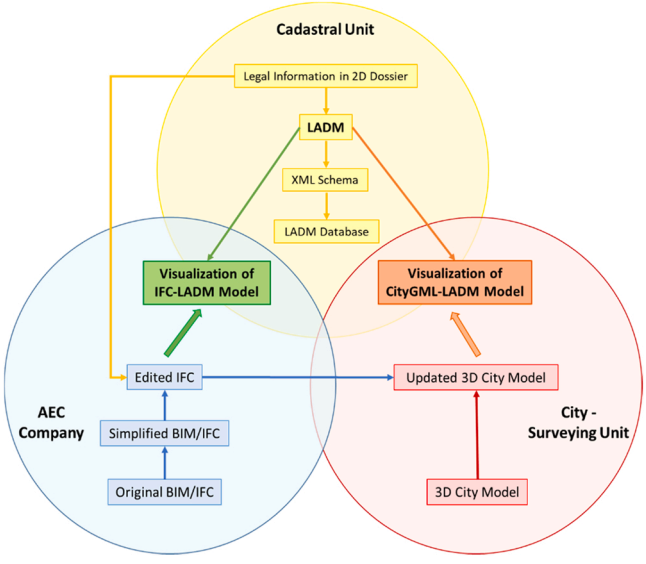

Fig. 3. The framework for integrating 3D cadastre with BIM and GIS (Sun et al., 2019a).

Fig. 4. The four phases in the lifecycle 3D real property formation process.

1) Identify the actors: The first step is to identify the actors who will be involved in the whole lifecycle phases including persons/companies and organizations e.g. authorities. The actors' roles and values are described as well.
2) Gather the 3D property formation requirements: The second step is to gather the 3D property formation requirements, such as actors/stakeholders needs and requirements, which information/data/model needs to be exchanged, the types of those information/data/model, legal and regulations requirements etc.
3) Define the data exchange requirements: Once the 3D property formation requirements are gathered, the next step is to define the data exchange requirements including e.g. identifying the input and output data, describing detailed data requirements, and specifying responsible actors.
4) Design the process map: In this study, we use BPMN to design the IDM process map for the Swedish lifecycle 3D property formation. This involves identifying the phases, actors, data/models, events, activities and gateways that illustrate the relationship diagrams.

Step 1 is introduced in Section 3.1, and Step 2 to Step 4 are described in each phase in Section 3.2. A precondition for the proposed property formation process is that structured 3D digital information is archived and available. It should be noted that administrative routines not related to the property formation process itself, such as the acknowledgement to the applicant that the cadastral authority has reviewed the application, are not described. This paper does not discuss the possible future digitalization and automation of administrative routines, such as digital signatures. See e.g. Hjelmblom et al. (2019).

3.1. *Actors*

Actors involved in the property formation vary in organizations, municipalities and countries. In this paper, we identify five main actors according to the Swedish current cadastral procedure when forming a 3D property: applicants, the cadastral authorities, land and environment court, local municipalities, and the national cadastral authorities. Each of these actors and their activities are represented by a lane in the IDM model (see details in Fig. 5).

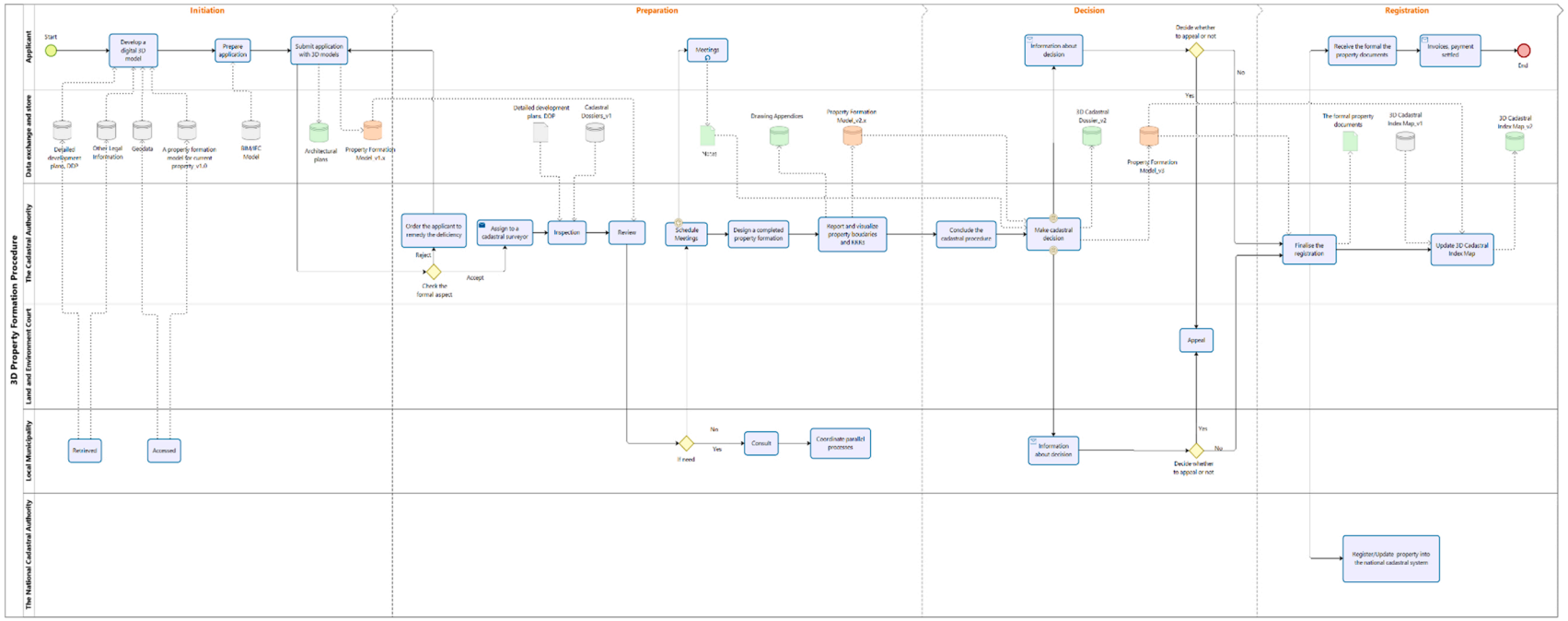

Fig. 5. A Swedish lifecycle 3D real property formation process with IDM (the input data is shown in grey color and the output data is highlighted in orange and green colors). Fig. 5 has been divided into three enlarged figures (see details below: Fig. 6 for the initiation phase, Fig. 7 for the preparation phase, and Fig. 8 for the decision phase and registration phase).

The role of main actors and their value are shown in Table 1. The cadastral authorities include cadastral surveyors that play an essential role during the 3D property formation process. The appointed cadastral surveyor by the cadastral authorities is in charge of the entire formation process that includes surveying cadastral boundaries (where applicable), making legal decisions for forming new property, changing a completed and registered property formation, rearranging related property rights and creating new rights (such as easement or right of way).

3.2. IDM process

An IDM process is proposed to generally illustrate how the main actors cooperate, form and register 3D properties during the lifecycle phases. The proposed IDM process is a developed 3D property formation process as a hybrid way of transition from 2D to full 3D that will improve the effect of registration process and optimize the registration compared with the current cadastral formation process. It embodies the digital cadastral management from the organizational aspect.

Fig. 5 shows a developed process of the Swedish lifecycle 3D property formation process in IDM. There is also one additional lane named "*Data exchange and store*" to illustrate the details of information flow that relative 3D cadastral data and models share, exchange and store through activities between actors. The input data is in grey color and the output data highlights in orange and green colors.

3.2.1. Initiation phase

The initiation phase of a 3D property formation process is where the applicant, typically a property developer, prepares and submits an application to the cadastral authority.

3.2.1.1. Process. The initiation phase starts prior to the application for property development. The property developers or owners prepare and develop their digital 3D models by obtaining information via the local municipality, which can be accessed online and from other sources for built environment data to build the 3D model, supplemented with the applicant's own building information for the new construction. This proposed process for 3D property formation presupposes that the current cadastral index map is updated to a 3D version. There is a more or less fully automated process for converting to the applicant's register model, which creates standard volumes for rights and 3D spaces. In order to get a more accurate account of each object, a review of decision documents etc. is required.

In connection with the application, the applicant produces supplementary documentation. The application is prepared by the applicant, possibly with the assistance of someone engaged by the applicant, sent to the cadastral authority and supplemented early in the process with a digital property formation model. This proposed property formation model is provided by the applicant according to guidelines / requirements by the cadastral authority for which objects are to be attached, some objects are always included, some never and others may depend on what the investigation of facilities etc. results in. The submitted model is a suggestion for property formation and has no legal force (shown in Fig. 6).

Table 1
The role and value of main actors.

Actors	Actors role and value
Applicants	Prepare a proposed 3D property model, submit an application and meet with the cadastral surveyors until sufficient documentation has been produced.
The cadastral authorities (including cadastral surveyors)	Responsible to check the application and assign cadastral surveyors that are in charge of the entire formation process including e.g. inspection and review of property units and property boundaries, making legal decisions, registration and update of 3D cadastral index map.
Land and environment court	If needed, both the applicant and local municipality can decide whether to appeal or not to the Land and Environment Court after receiving the decision information.
Local municipalities	Provide the access of relevant data, and coordinate ongoing parallel processes through consultation.
The national cadastral authorities	Responsible for registering and updating the 3D property into the national cadastral system.

3.2.1.2. Data. The input cadastral documents, geodata and models for applicants to develop a digital 3D model can be accessed from the cadastral authorities and the municipalities (Fig. 6). The input data may be various depending on different purposes and situation of projects. The detailed development plan (DDP, zoning plans) regulates the buildings in the area. Since 2022, all DDPs have to be in machine-readable form following the national specifications. The legal information of national and local regulations and geodata of relevant area are necessary to use to design and develop a BIM/IFC model of the 3D property units in order to meet all the cadastral legal requirements. An extract for the area can be submitted from the register model via the common platform if available. Copies of existing relevant property formation models and other decision documents can be obtained from the archive, which shows snapshots of constructions, property boundaries and rights, etc. from when the decision in each case was made. The extracts together with their own information and comparison with e.g. current planning regulations and building permits via the common platform can form the basis for a 3D model.

The BIM/IFC model could be an as-designed model (before construction begins) or an as-built (after construction has been completed) / as-is model (existing building), depending on which stage the project is on. To avoid redundant data storage, the BIM/IFC models are better to be simplified and only kept necessary building elements to meet the cadastral legal requirements when creating 3D property formation models. If there are existing CAD 2D plans or 3D geometry models, the CAD data could also be used to create a BIM/IFC model as the proposed 3D property formation model. Table 2 lists some input data (grey) and output data (orange) that may be required, basic requirements of the data/model and responsible actors / authorities in the initiation phase.

The output data is a proposed property formation model without legal force in BIM/IFC format provided by the applicant. The 3D property units are defined as closed 3D volumes and modelled as spaces and zones (or *IFCSpace*) in the BIM/IFC model. It is important that property formation models state both existing and proposed changed, revoked and new boundaries and rights, respectively. If there are general requirements formulated by the cadastral authorities, the applicant must be followed to generate 3D property units as well as property boundaries. Otherwise, the property boundaries need to be suggested and stated clearly and accurately by the applicant in the proposed property formation model. Combined with version management (Eriksson et al., 2021), the proposed 3D property formation model is exported with spaces and recorded as version 1.x in order to see in retrospect what changes took place with the cadastral procedure. In the case that applicants are unable to generate a qualified 3D property formation model, external experts or firms can be consulted or hired by the applicant to generate the model. Architectural plans created from the property formation model are necessary to illustrate the new property boundaries for each 3D property unit.

3.2.2. Preparation phase

3.2.2.1. Process. The preparation phase starts with the cadastral agency checking the application, which is returned to the applicant if incomplete or containing errors (Fig. 7). After checking and further preparing

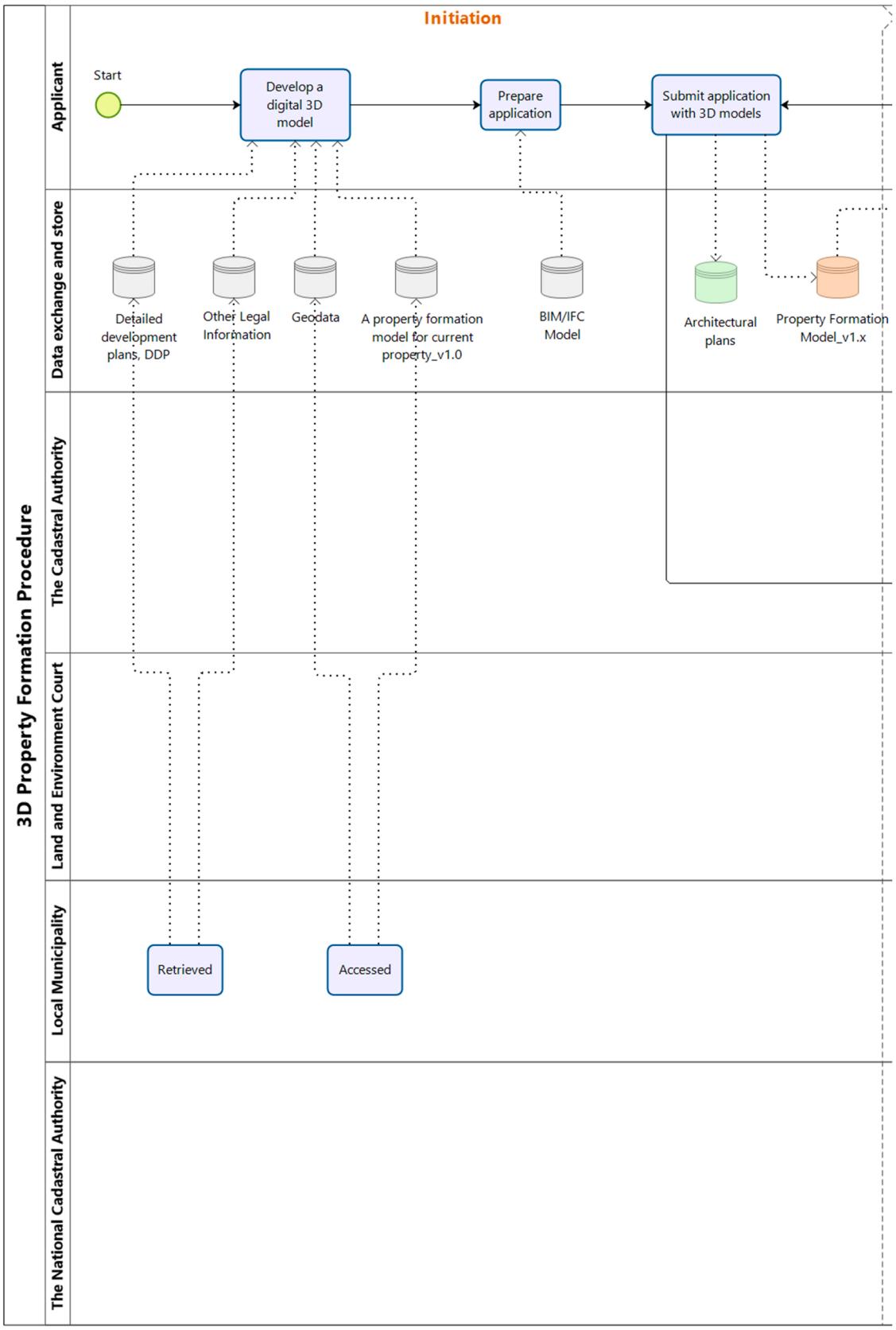

Fig. 6. Initiation phase, enlarged from Fig. 5.

Table 2
The input and output data, basic data requirements and responsible authorities in the initiation phase (input data shows in grey and output data shows in orange).

Input/output data	Data requirements	Responsible actors
Detailed development plans	Necessary. The detailed development plan (DDP, zoning plans) regulates the buildings in the area. Since 2022 all DDP has to be in machine-readable form following the national specifications.	Local municipality
Other legal Information	Necessary. Other planning regulations (apart from DDP), including national building rules and building permits (if the applicant has already obtained that).	Local municipality and the National Board of Housing, Building and Planning (and other national agencies)
Geodata	Necessary. 2D or 3D geodata is accessed from local municipality to design a BIM/IFC model. Currently (2022) work is performed to standardize these as part of *National Specifications for geodata*.	Local municipality
A property formation model_v1.0 for the current properties	If available. If there are existing relevant property formation models, an extract for the area can be utilized.	Local municipality
BIM/IFC model	Necessary. The BIM model could be as-designed model or as-built / as-is model,	Applicant
	depending on which stage is the project on.	
A proposed property formation model_v1.x	Necessary. No legal force. Combined with version management, the BIM/IFC model is generated to state both existing and proposed changed, revoked and new boundaries and rights.	Applicant (external experts or firms can be consulted or hired by the applicant)
Architectural plans	Necessary. Illustrations of the new property boundaries for each 3D property unit. Created from the property formation model_v1.x.	Applicant

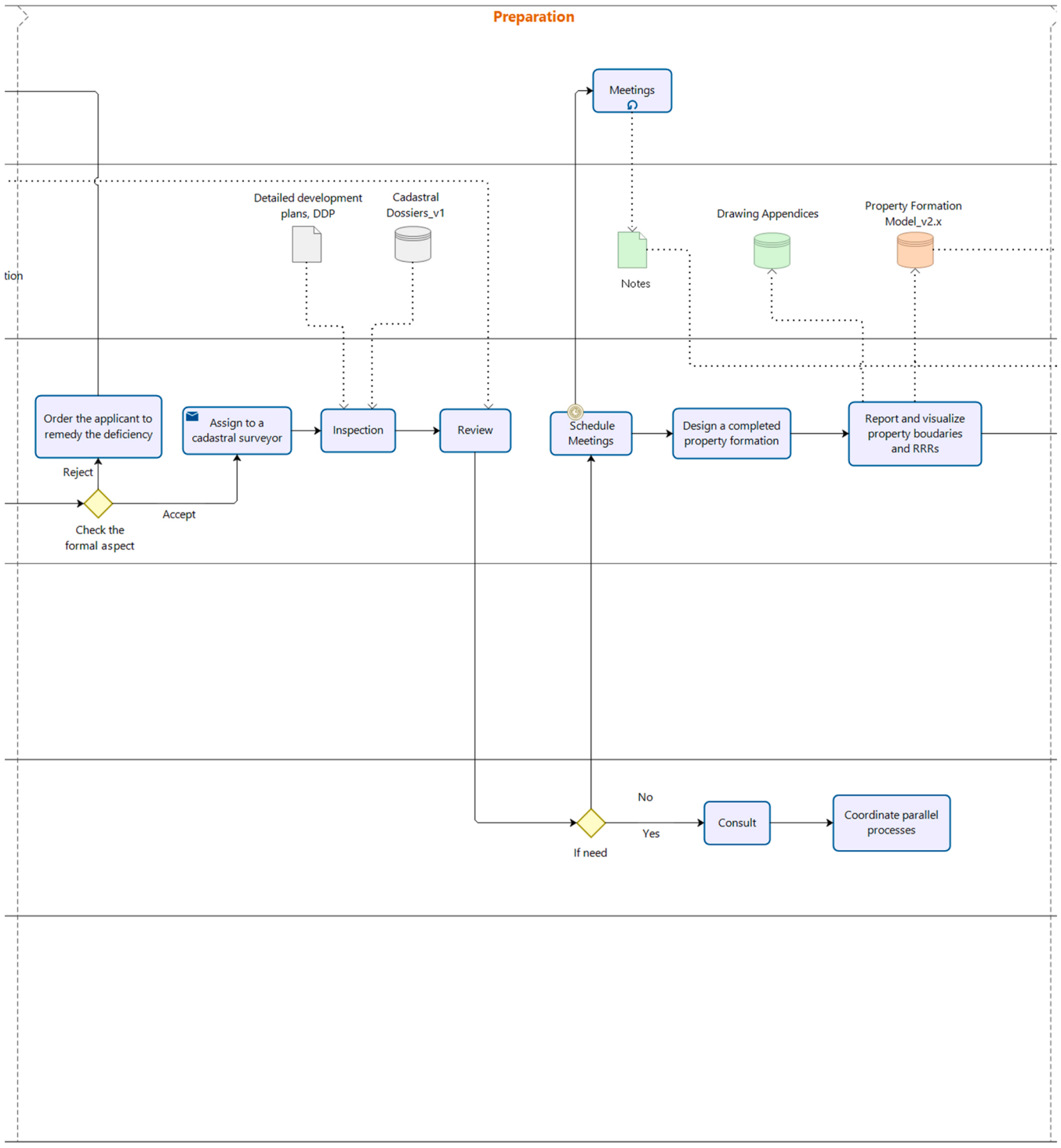

Fig. 7. Preparation phase, enlarged from Fig. 5.

the application, a cadastral surveyor is assigned to the case. The cadastral surveyor examines the suggested property formation against current legislation (mainly the Property Formation Act, FBL) as well as other applicable planning regulations and given building permits for the area concerned. When testing suitability, etc., the need for changed and / or additional rights and demarcations may arise.

The cadastral surveyor inspects the proposed property formation model, architectural plans and the necessary cadastral map on footprint level, for example property boundaries and easements, against current regulations in 3D. The DDP is used to regulate the buildings in the area. The cadastral surveyor reviews the suggested property boundaries of the 3D property units and the need for RRRs. It is important to check that the 3D property formation models_v1.x does not violate any rules in the detailed development plan, e.g. that a 3D property is proposed for a purpose that is not allowed in the area.

Complete documentation needed for the property formation is generally not ready in connection with the application and one or more meetings are held with the applicant(s) until sufficient documentation

Table 3
The input and output data, basic data requirements and responsible authorities in the preparation phase (input data is shown in grey and output data is shown in orange).

Input/output data	Data requirements	Responsible actors
The proposed property formation model_v1.x	Necessary. See Table 2.	Applicant
Cadastral dossiers_v1	If there are existing cadastral dossiers, 2D or 3D.	The cadastral surveyors
Detailed development plans	Necessary. See Table 2.	Local municipality
Notes	Necessary. The notes and records of meetings.	The cadastral surveyors
The drawing appendices	Necessary. The description of a draft decision, states existing, changed, revoked and new boundaries and RRRs.	The cadastral surveyors
3D property formation models_v2.x	Necessary. Updated version of the property formation version model_v1.x. The model will be kept up to date and state existing, changed, revoked and new boundaries and RRRs.	Applicant and cadastral surveyors

has been produced. If needed, the cadastral surveyor will consult with the local municipality (typically regarding water supply, sewerage, and/or development plan issues) and/or regional or governmental agencies, such as the national Road Authority (typically regarding road access). The version of property formation model_v1.x may be changed and updated to new versions – property formation model_v2.x – in cooperation with the applicant by the cadastral surveyor during the preparation phase. Ongoing parallel processes for building permits and detailed plans are coordinated through consultation and/or other contact with the relevant stakeholders. During this process, the cadastral surveyor prepares drawing appendices of a draft decision based on the documentation received from the applicant. These documents consist

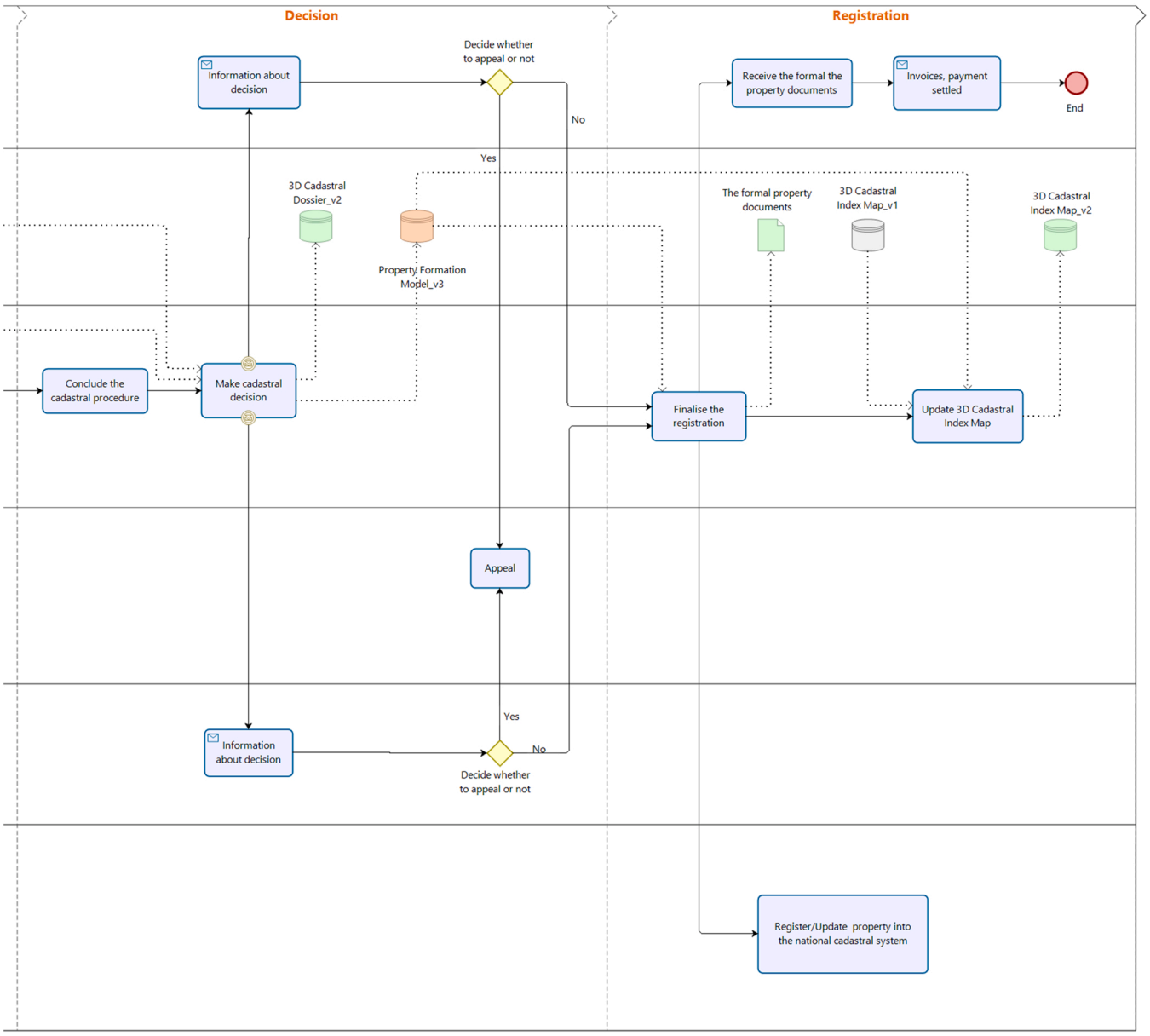

Fig. 8. Decision phase and registration phase, enlarged from Fig. 5.

typically of an administrative (cadastral) map, description and minutes.

3.2.2.2. Data. The input data is application documents, including 2D/3D cadastral dossiers (if there are existing cadastral dossiers) and other information such as e.g. DDP and the proposed property formation model (version 1.x, provided by applicant in the initiation phase).

The output data is a 3D property formation model (updated version 2.x), notes and the drawing appendices (Table 3). The description of a draft decision normally refers to drawing appendices that report details about 3D spaces and relevant rights. Analogue or digital construction drawings showing the maximum extent of the 3D space in horizontal and/or vertical planes are usually produced by the applicant, in consultation with the cadastral authority. The notes are used to record details of every meeting. The 3D property formation models_v2.x is necessary for keeping the model up to date and resolving potential conflicts as preparation progresses.

3.2.3. Decision phase

3.2.3.1. Process. The cadastral surveyor will conclude the cadastral procedure and make a final decision (Fig. 8). The actual cadastral decision is central for forming a new property unit for e.g. housing purposes, legalizing the existence of the newly formed property (FBL, 1970, 4 chap. 25 a §). A final version of 3D property formation models_v3 is exported based on the previous version and stored after the final decision has been made, which can be used to update the 3D cadastral index map in the registration phase. Both the applicant and municipality will receive the decision information and decide whether to appeal or not to the Land and Environment Court. The cadastral decision is confirmed by the cadastral surveyor. The decisions include, most importantly, the assessment of whether the intended real property unit is enduringly suited to its purpose, which is a legal requirement for its creation (FBL, 1970, 3 chap. 1 §). In addition to this, information from the property register and the digital index map (which serves as an overview basis) is used.

Table 4
The input and output data, basic data requirements and responsible authorities in the decision phase (input data is shown in grey and output data is shown in orange).

Input/output data	Data requirements	Responsible actors
3D property formation models_v2.x	Necessary. See Table 3.	Applicant and cadastral surveyors
Notes	Necessary. See Table 3.	The cadastral surveyors
Cadastral dossiers_v2	Necessary. The 3D cadastral dossier is created or updated, and includes the property formation model_v3.	The cadastral surveyors
3D property formation models_v3	Necessary. Updated version of the property formation version model_v2.x. The final version will be used to update the 3D cadastral index map later.	The cadastral surveyors

3.2.3.2. Data. The 3D property formation models_v2.x and notes are used as input data. The output data is 3D cadastral dossier, including map, description, minutes, notes, 3D property formation model (updated version 3), and appendices. The 3D cadastral dossier is created / updated (if there are existing cadastral dossiers) and includes the property formation model_v3 (see Table 4). Currently, the decision documents are in paper format, and this also applies to previous cadastral decisions as well as current planning regulations and decided building permits that are used as a basis. A legal change is required to make the decision documents archived in digital format (e.g. 3D PDF) to have a legal status.

3.2.4. Registration phase

3.2.4.1. Process. The cadastral surveyor finalizes the registration of the new real property in the Real Property Register national cadastre after the mandatory appeal period has ended and no appeals have been made (Fig. 8). Finally, the applicant receives the formal property documents and the property formation process ends after the payment is settled. Meanwhile, the cadastral dossier is stored in the agency's digital archive. The new or altered 2D and 3D real properties are registered in the agency's archive and shown in the 3D cadastral index map. The cadastral surveyor updates the property register and the 3D cadastral index map when a cadastral decision has gained legal force. Archive files are archived separately, and can be accessed via a link in the property register. The cadastral surveyor will update new 3D property units in 3D city models after registration.

3.2.4.2. Data. The input data is the 3D property formation models_v3 that is utilized to finalize the registration, as well as to create a 3D cadastral index map or to update the 3D cadastral index map (if there is an existing 3D cadastral index map). After finalizing the registration, all the cadastral information should be stored in the formal property documents, shown in Table 5.

The different versions of 3D property formation models could be similar if the applicant designs against the current legislation and regulations. The property boundaries of those models may be changed slightly to meet all the cadastral legal requirements.

4. Case study

In this paper, we perform a case study based on the property Organellen in Stockholm, as mentioned earlier, to illustrate the 3D property formation process from legal, organizational and technical perspectives. Organellen is located in Hagastaden, between Dalagatan and Norra Stationsgatan. The project is under construction (2022) and lead by Besqab Projekt & Fastigheter limited company where the BIM model is created by Lindberg Stenberg Arkitekter limited company. The property Organellen includes two buildings with 195 apartments, both condominiums and owner-occupied apartments, as well as a parking lot.

The properties in Organellen were created by the City of Stockholm, using their current procedures (described in 4.1). In our study, we investigate how the property formation procedure for Organellen would work in the new proposed IDM process (Section 4.2). In the case study, we only use the property Organellen 100 (parts of one of the buildings),

Table 5
The input and output data, basic data requirements and responsible authorities in the registration phase (input data is shown in grey and output data is shown in orange).

Input/output data	Data requirements	Responsible actors
3D property formation models_v3	Necessary. See Table 4.	Applicant and cadastral surveyors
3D cadastral index map_v1	If available. If there is an existing 3D cadastral index map.	The cadastral authority
The formal property documents	Necessary.	The cadastral surveyors
3D cadastral index map_v2	Update the 3D cadastral index map_v1 with the property formation model_v3.	The cadastral surveyors

which consists of three areas (Organellen \100\1, \100\2 and \100\3) that are situated at different storeys.

4.1. The property Organellen

This section is a description of Organellen based on the cadastral dossiers created by the City of Stockholm. The property unit Organellen 100 consisting of three areas are registered in 3D. In spite of this, the property units and property boundaries are still using textual description and 2D drawings.

In the current 3D property formation process, the property boundaries are firstly proposed by the applicant and then inspected by the cadastral surveyors. If the proposed boundaries are legal and reasonable following the current legal regulations, the cadastral surveyors will make a decision and register property units in the system. The property unit areas Organellen \100\1 and \100\2 are at the story named Plan 10 and the other property unit area Organellen \100\3 is at Plan 9. Table 6 illustrates the property boundaries of the 3D property unit Organellen 100 registered in the cadastral dossier (translated from Swedish).

In the cadastral dossier, only the drawing appendices of Organellen \100\1 are recorded with figures to illustrate different heights of vertical property boundaries, shown in Fig. 9. Fig. 10 shows the current cadastral index map (in 2D), in which the black dots in the red rectangular represent that the footprints of the 3D property unit of Organellen.

4.2. What could be a Swedish lifecycle 3D property formation process

In the study, we only use Organellen 100 with three property unit areas to illustrate how the data and model could be created, exchanged and stored among the actors following the proposed IDM process. As mentioned in Section 2.2, the Stockholm municipality has obtained permission from the Swedish Government, thereby being the cadastral authority responsible to form the 3D real property of Organellen and in charge of the entire formation process.

4.2.1. Initiation phase

Before submitting the application, the applicant prepares and designs an architectural BIM model of Organellen. The preparation can be made by the applicants themselves or with the assistance from some other actor engaged by the applicant. The BIM model used for case study is an as-design model that has been designed in Revit (Fig. 11).

In the process of creating this BIM model, the architect company has used 2D/3D geodata from the municipality (in form of a construction map; swe. *nybyggnadskarta*) against legal regulations. It is important for the applicant to check that the requirements from the DDP and/or the building permit are fulfilled for the proposed new 3D properties. In this case study, this check was done manually by studying documents.

As mentioned in Section 3.2.1, to avoid redundant data storage, the new 3D property units are created in a simplified version of the original BIM model that has only kept necessary building elements to meet the cadastral legal requirements and model 3D property units spaces and boundaries. The 3D property units are modelled as closed 3D volumes in the BIM model using Revit. In the case study, the property boundaries are generated following the suggested property boundaries in Table 6. To create horizontal property boundaries, *space separator* is used to identify central, interior or exterior line of different building elements as boundaries, e.g. the central line of the inner walls, the interior line of external walls and the exterior line of windows. For different heights of vertical property boundaries, extra *sections* need to be manually added firstly. Then in each section view, *levels* corresponding to the suggested heights are created and if needed the heights of spaces can be adjusted (an example is shown in Fig. 12).

Table 6
The property boundaries of 3D property unit Organellen 100 (translated from Swedish).

3D Property Unit area	Heights in RH2000	Requirements of 3D Property Boundaries
\100\1 *Plan 10*	Lowest height: + 17.3 m Highest Height: + 21.7 m	**Up** 1) At windows: at the top of windows, which corresponds to about + 21.3 m in RH2000; 2) Otherwise: in the middle of the floor, which corresponds to about + 21.6 m and 21.7 m in RH2000. **Down** 1) At window: at the bottom of window, which corresponds to about + 17.7 m in RH2000; 2) Otherwise: in the middle of the floor, which corresponds to about + 17.3 m in RH2000. **Sideways** 1) At the outer wall: inside the wall (the wall is not included in the 3D space); 2) By window: • towards the street (parallel to the street): in the 2D boundary (which mainly corresponds to the outside window section); • otherwise: (side window section) in outside window section (window is included in its entirety in the 3D space); 1) Inside the building: in the middle of the wall.
\100\2 *Plan 10*	Lowest height: + 16.5 m Highest Height: + 21.7 m	**Up** 1) At windows: at the top of windows, which corresponds to about + 20.7 m in RH2000; 2) Otherwise: in the middle of the floor, which corresponds to about + 21.7 m in RH2000. **Down** 1) At window: at the bottom of window, which corresponds to about + 16.7 m in RH2000; 2) Otherwise: in the middle of the floor, which corresponds to about + 16.5 m in RH2000. **Sideways** 1) At the outer wall: inside the wall (the wall is not included in the 3D space); 2) By window: • towards the street (parallel to the street): in the 2D boundary (which mainly corresponds to the outside window section); • otherwise: (side window section) in outside window section (window is included in its entirety in the 3D space); 1) Inside the building: in the middle of the wall (which partly corresponds to the 3D limit for Organellen 1).
\100\3 *Plan 9*	Lowest height: 14.0 m Highest Height: 18.1 m	**Up** 1) At windows: at the top of windows, which corresponds to about 17.5 m in RH2000; 2) Otherwise: in the middle of the floor, which corresponds to about 18.1 m in RH2000. **Down** 1) At window: at the bottom of window, which corresponds to about 14.5 m in RH2000; 2) Otherwise: in the middle of the floor, which corresponds to about 14.0 m in RH2000. **Sideways** 1) At the outer wall: inside the wall (the wall is not included in the 3D space); 1) By window: • towards the street (parallel to the street): in the 2D boundary (which mainly corresponds to the outside window section); • otherwise: (side window section) in outside window section (window is included in its entirety in the 3D space); 1) Inside the building: in the middle of the wall.

Spaces are created separately due to the spaces are bounded by different building elements in Revit. Fig. 13 shows those spaces in the three property unit areas without building elements, visualized in Solibri. Red volumes represent main spaces, while green volumes for spaces of windows and blue for spaces of floors. Then separated spaces are grouped into *zones* (named Organellen \100\1, \100\2 and \100\3 respectively) to represent the legal property unit areas.

The proposed property formation model is thus generated with spaces as 3D property units and spaces boundaries as property boundaries, recorded as the property formation model_v1. Fig. 14 shows the property formation model_v1 with created spaces and spaces boundaries for the three property unit areas of Organellen 100, which left is with all building elements and the right is without external walls.

The application should also include the architectural plans that illustrate the new 3D properties, similar to the ones shown in Fig. 9. These floor plans are generated from the 3D property formation model, which are shown in Fig. 15 and Fig. 16.

Finally, the applicant submits a 3D property formation application of Organellen including the proposed property formation model (version 1) (in IFC format) and the architectural plan illustrations to the Stockholm municipality (in PDF format).

4.2.2. Preparation phase

The cadastral authority in the Stockholm municipality checks the

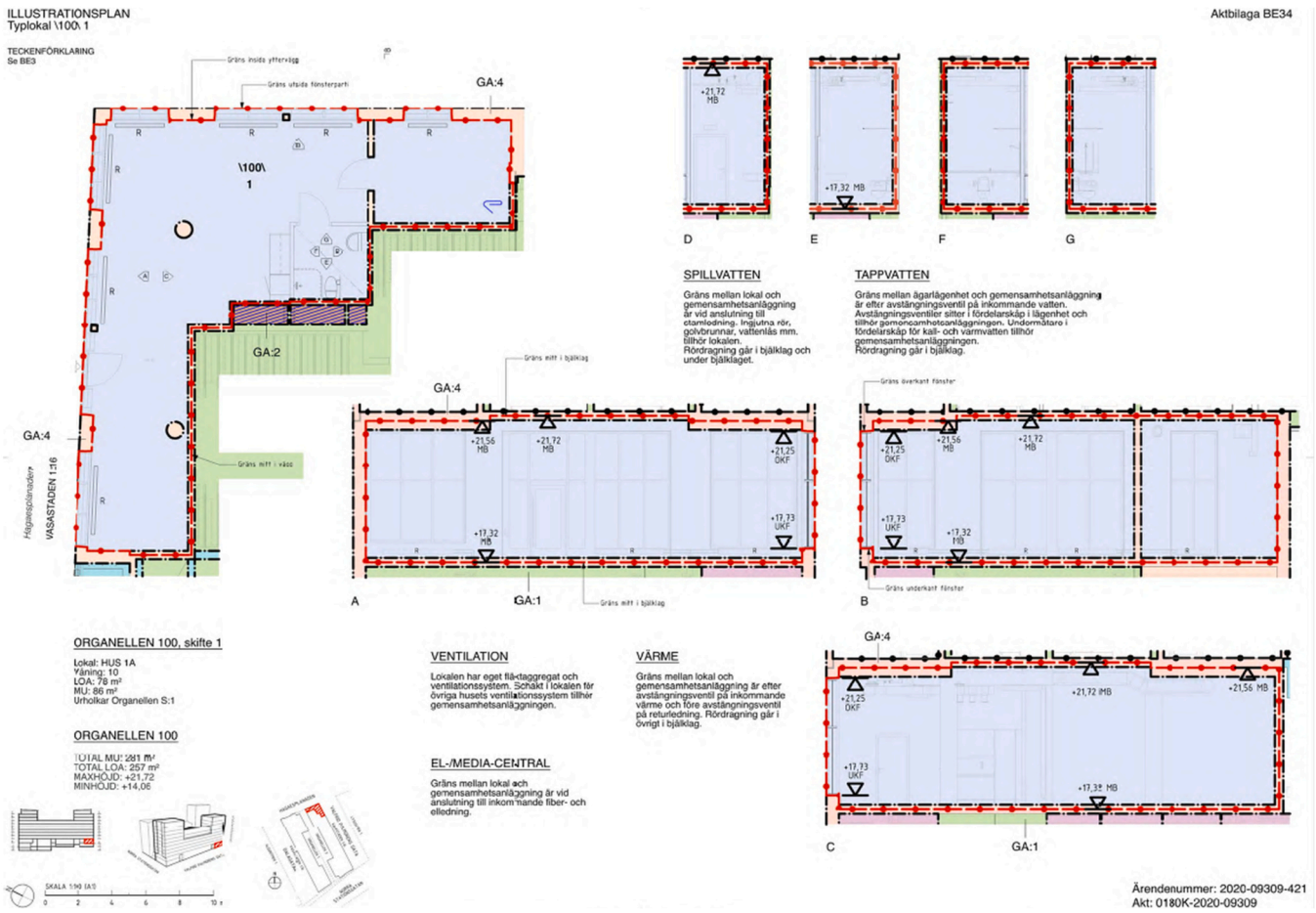

Fig. 9. Architectural plans of Organellen \100\1.

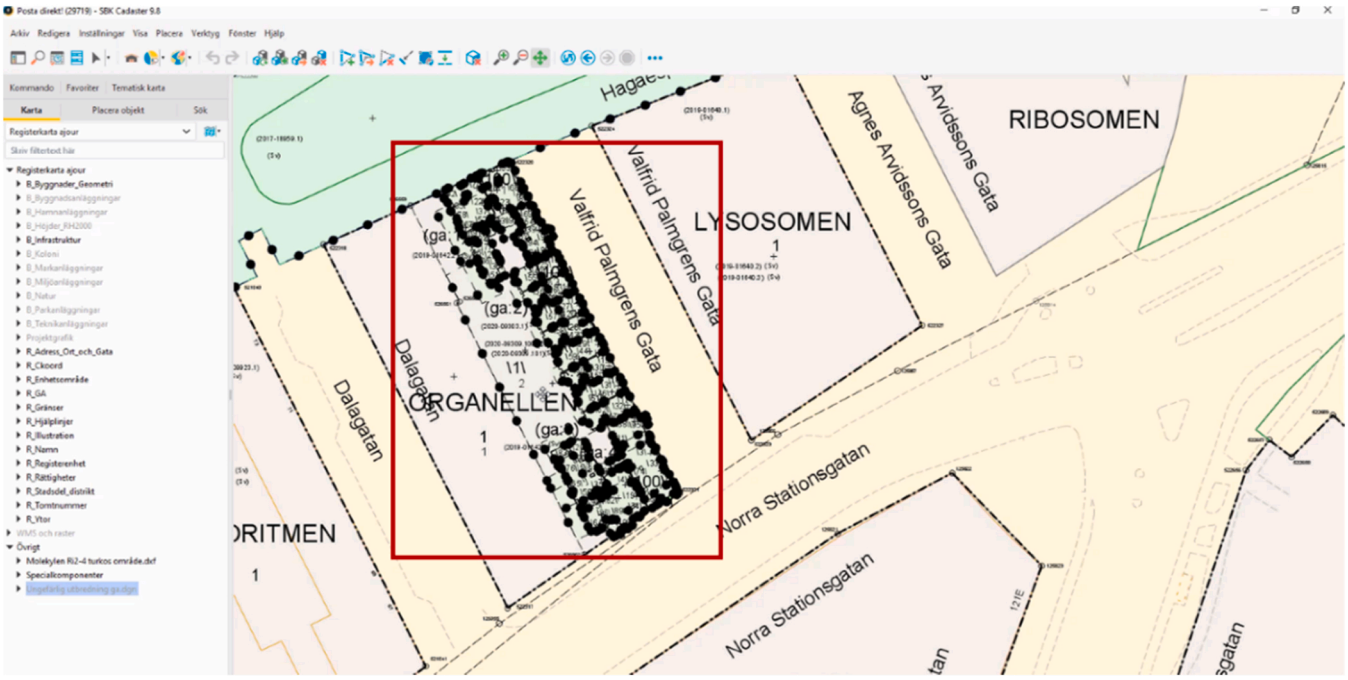

Fig. 10. Current cadastral index map where 3D properties are marked with black dots. In the red rectangular, the black dots represent that property units of Organellen have been registered in 3D.

Fig. 11. The original BIM model of Organellen, Stockholm, Sweden.

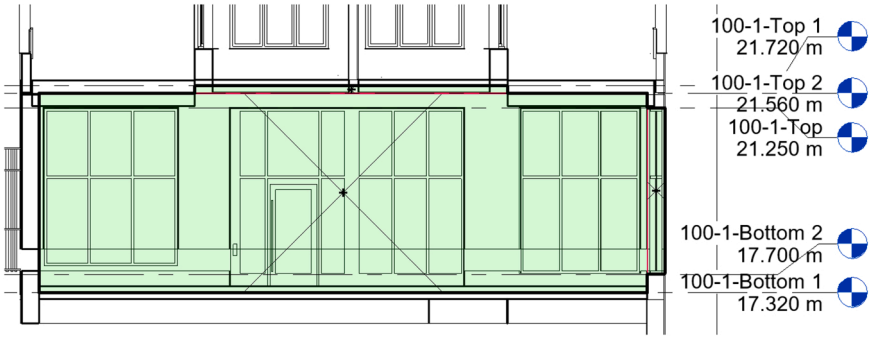

Fig. 12. Example of creating different heights of vertical property boundaries, view of Section A.

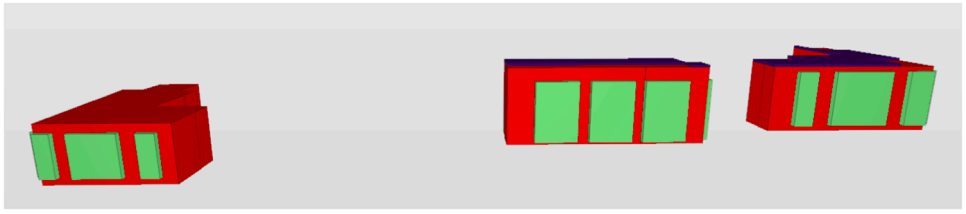

Fig. 13. Three property units of Organellen 100, visualized in Solibri without building elements (Red volumes represent main spaces, green volumes for spaces of windows and blue for spaces of floors).

formal aspects of the submitted application. After acceptance, the cadastral authority assigns a cadastral surveyor that is in charge of forming and registering 3D properties. The cadastral surveyor inspects the property formation model_v1 (Fig. 14), architectural plans (Fig. 15 for Organellen \100\1 and \100\2, and Fig. 16 for Organellen \100\3) with DDP. Then the cadastral surveyor reviews the property boundaries (visualized in Fig. 17).

Fig. 18 shows an example of how the 3D property unit and property boundaries of Organellen \100\1 are inspected and reviewed in Solibri, as well as checked the relationships of IFC spaces and building elements in Fig. 19. In addition, a relation between the outer wall and the main space volume 3 is indicated with an arrow, which can have information about the kind of ownership that is defined. e.g. surface to surface, 50% of the thickness of the wall etc.

Work meetings with the applicant and other contacts are held continuously. During the procedure, the property formation model will be kept up to date (recorded as 3D property formation model_v2.x) and state any existing, changed, revoked and new boundaries and RRRs of the proposed property units.

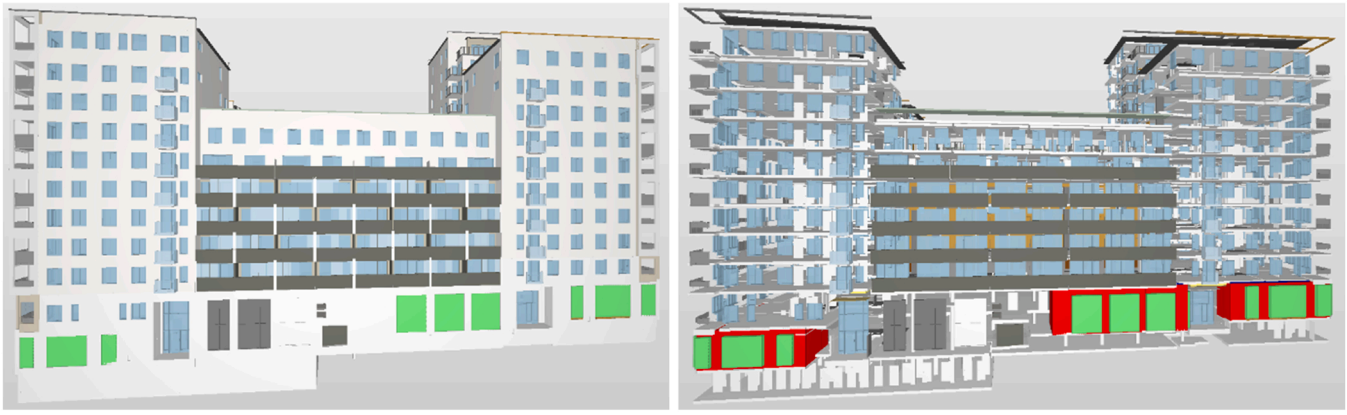

Fig. 14. Left: the property formation model_v1, with created spaces and spaces boundaries for the three property unit areas of Organellen 100. To the right, the model is shown without external walls.

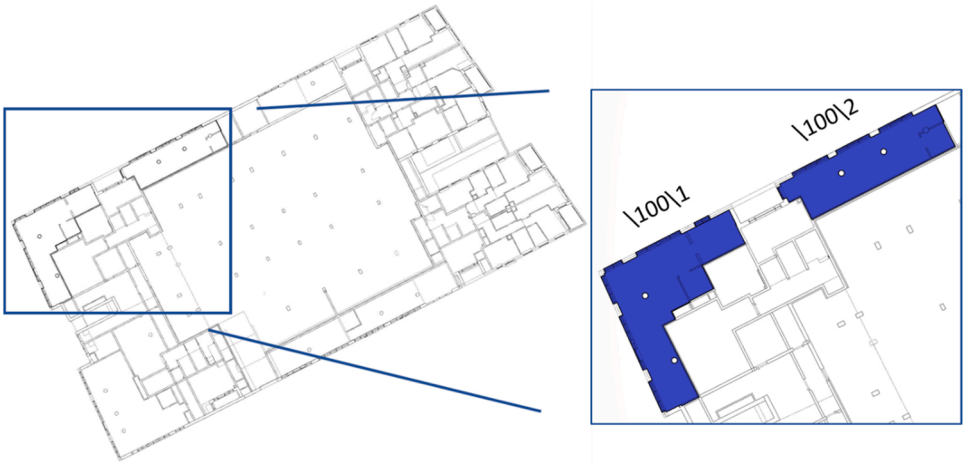

Fig. 15. Architectural plan that illustrates Organellen \100\1 and \100\2, at Plan 10. The floor plan is generated from the property formation model in Fig. 12.

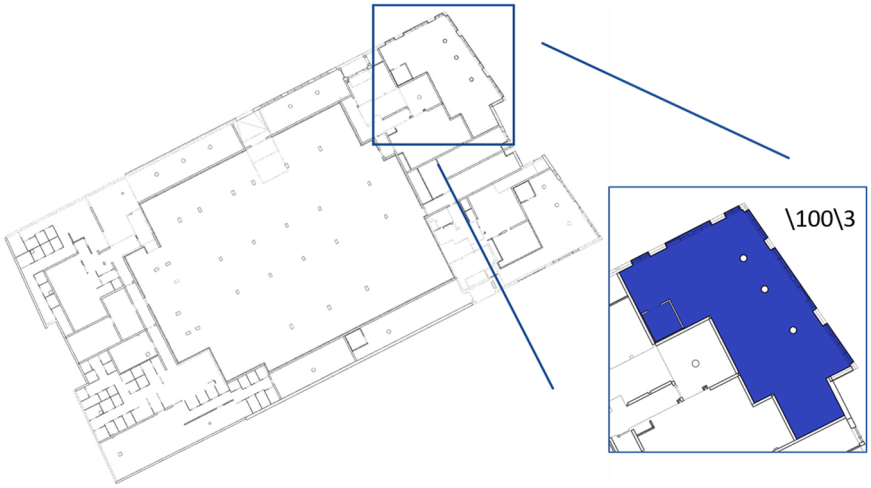

Fig. 16. Architectural plan that illustrates Organellen \100\3, at Plan 9. The floor plan is generated from the property formation model in Fig. 14.

4.2.3. Decision phase

In this phase, the cadastral surveyor concludes the cadastral procedure and makes a final decision. The final decision includes a property formation model in IFC format (3D property formation model_v3) as well as description, 3D visualization of the property formation model in 3D PDF (shown in Fig. 20), architectural plans, minutes, and appendices which are stored in the 3D cadastral dossier. In the case study, the different versions of 3D property formation models are similar since the applicant designs the model and creates the 3D property units against the current legislation and regulations. The property boundaries of those models have been changed slightly to meet all the cadastral legal requirements.

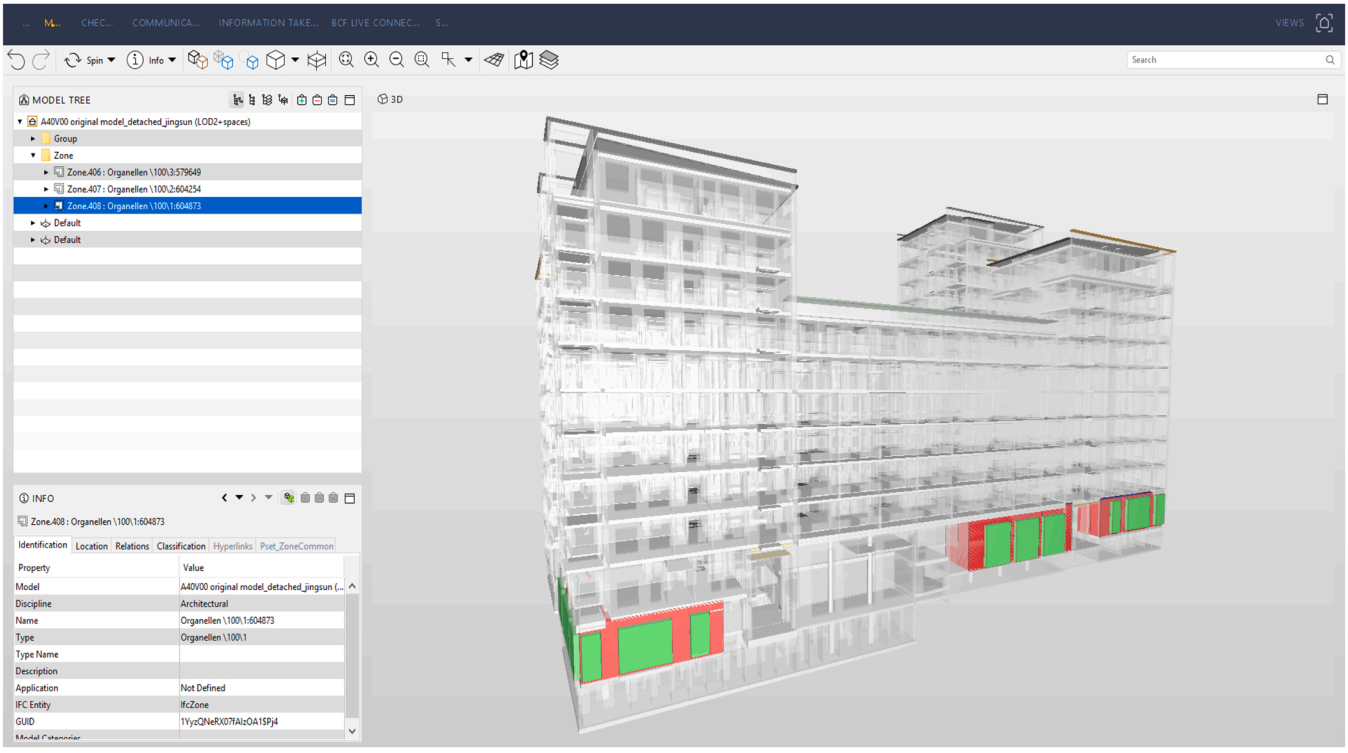

Fig. 17. 3D property formation model visualized with transparent exterior wall.

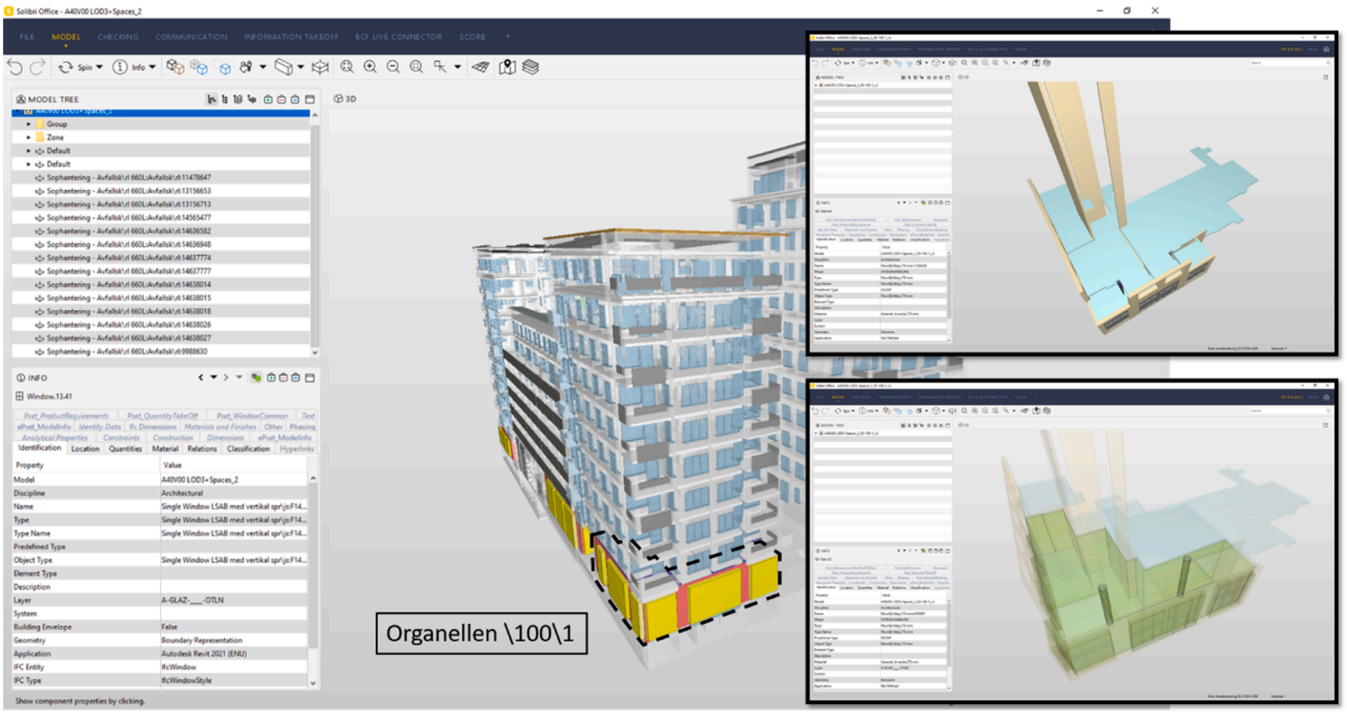

Fig. 18. Example: 3D property unit and property boundaries of Organellen \100\1 are inspected and reviewed in Solibri.

4.2.4. *Registration phase*

The cadastral surveyor finalizes the registration of Organellen as a new real property. The new 3D real properties are also registered in Stockholm City and used to update the 3D cadastral index map. The cadastral index map should be based on a 3D city model in CityGML LOD2 where all the 3D properties and easements are stored as (simplified) 3D objects (Sun et al., 2019a). This cadastral index map has no legal force, but should be seen as an illustration of the 2D and 3D property units. Since no such 3D cadastral index map is created in Stockholm (in 2022), a simplified approach is used in this case study.

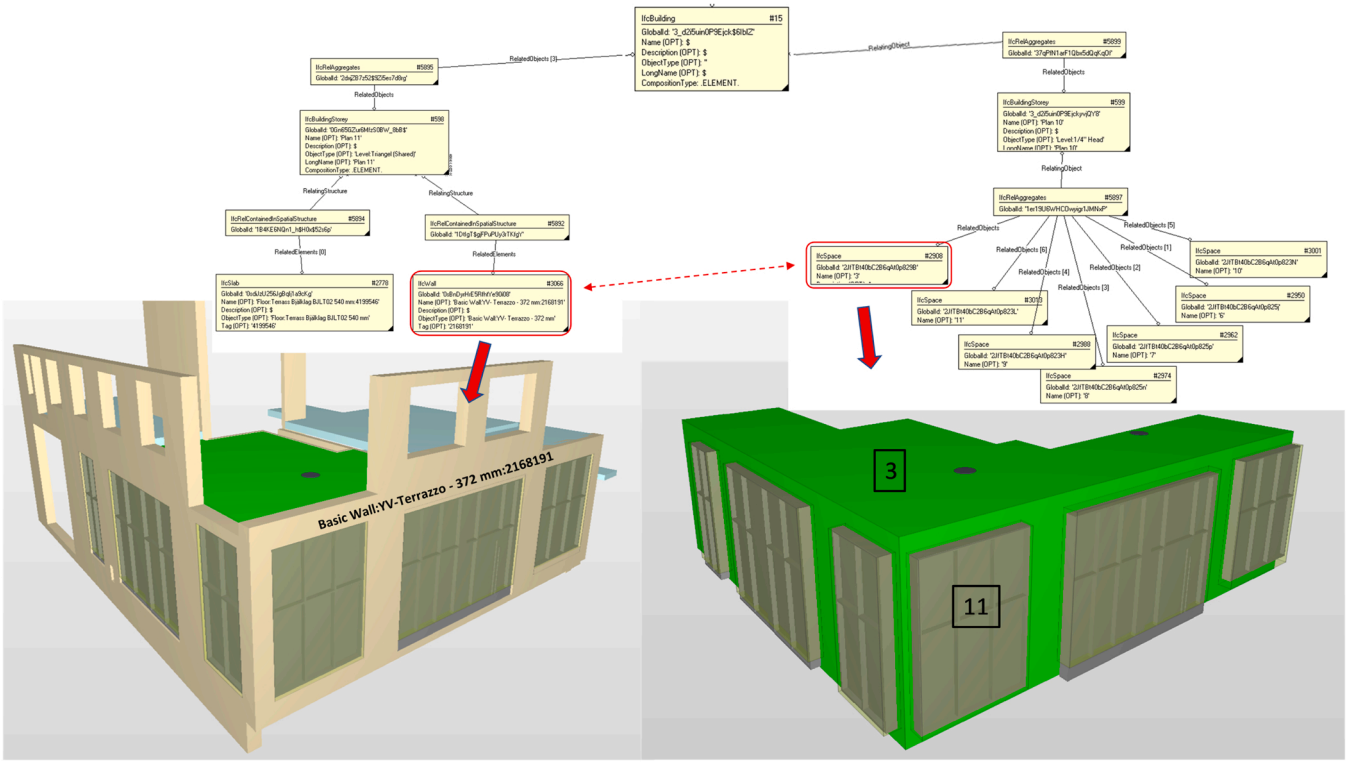

Fig. 19. The relationships of IFC spaces and building elements of Organellen \100\1. An example of the relation between the outer wall and the main space volume 3.

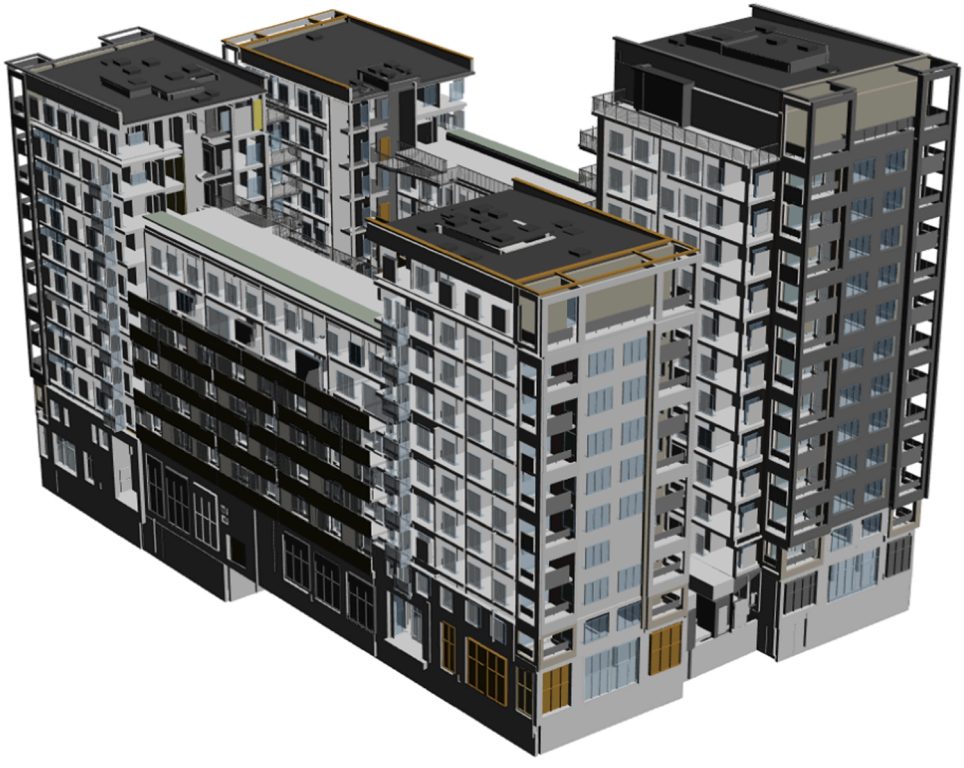

Fig. 20. Visualization of the property formation model in 3D PDF.

What is available is building objects in LOD2. This dataset has, however, not been updated recently, so the building in our case study is not present in the data set. Therefore, the final property formation_v3 has been simplified (using an FME script) to CityGML LOD2/3, see Fig. 21.

In this case study, we use Google Earth for visualizing the 3D cadastral index map. In this conversion process, the building is also georeferenced to *Stockholm stad* system (Sweref 99 18 00) that is used for most geodata in Stockholm, including the 3D building model. This georeferencing utilizes that the IFC file has information of a georeferenced base point (corresponds to georeferencing method LoGeoRef 40 in

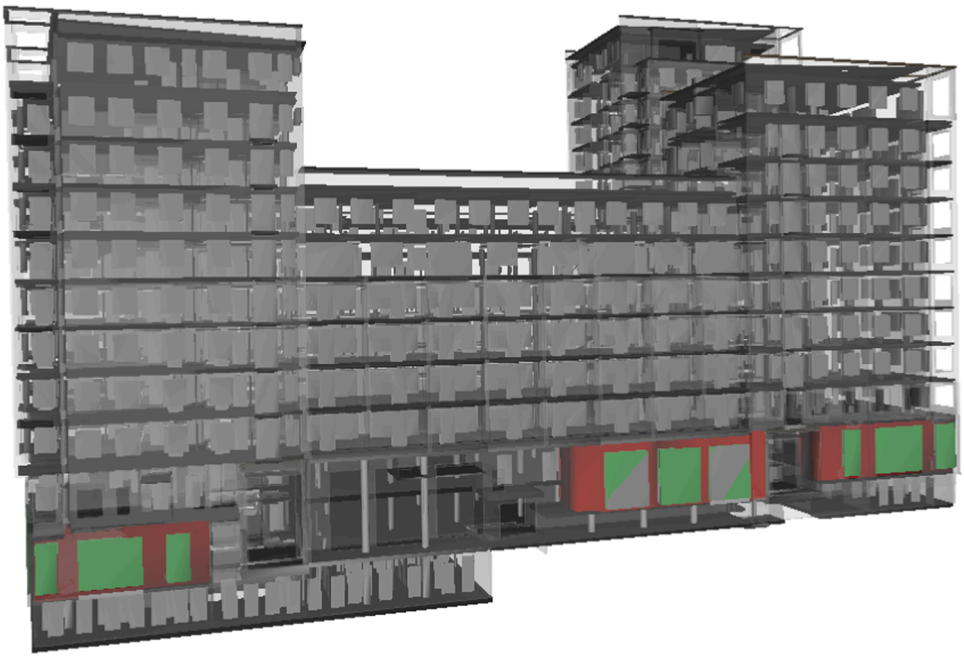

Fig. 21. The building and the new 3D properties in GML format, corresponding to CityGML LOD2/3. The data is converted from the final 3D property formation model using the ETL-tool FME.[1]

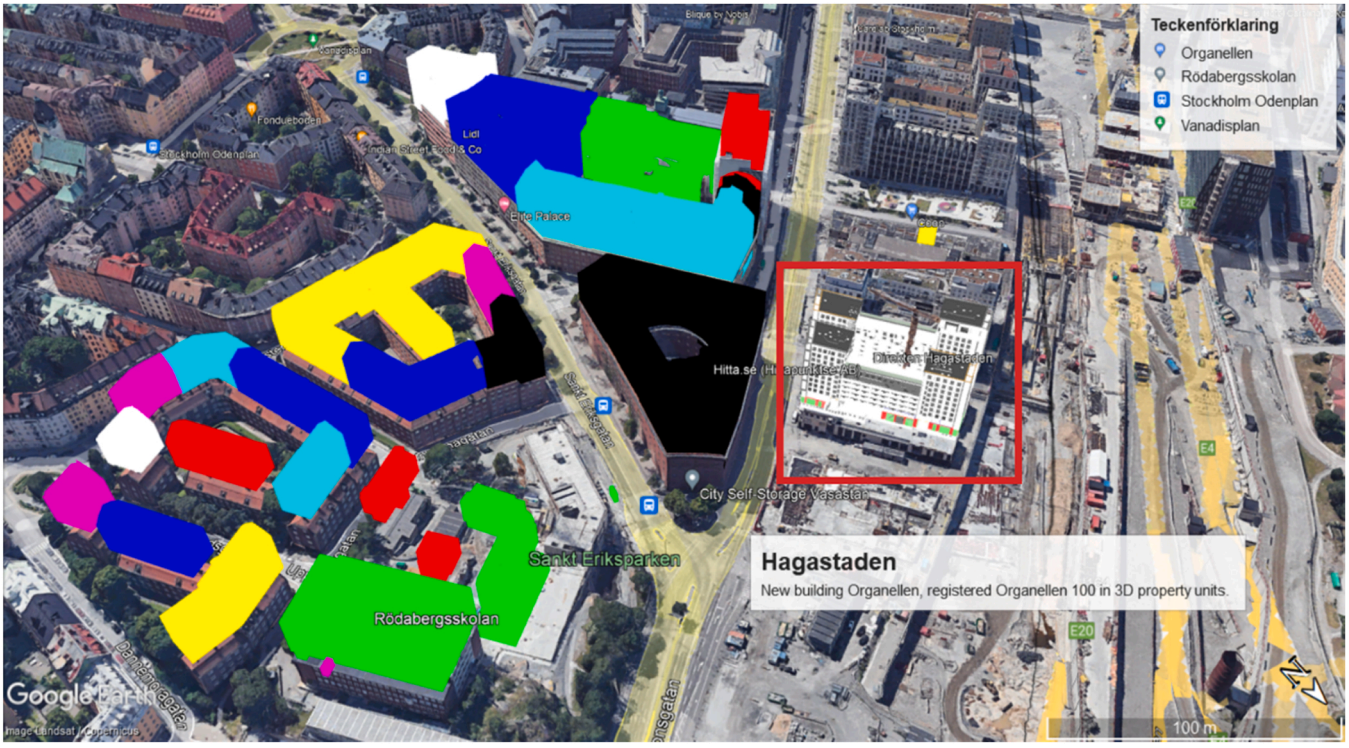

Fig. 22. Visualize the updated 3D cadastral index map in Google Earth (new 3D properties shown in red rectangular).

Clemen and Görne, 2019). Then a coordinate transformation from a local coordinate system to a global coordinate system is required. The transformation is done by FME, from Sweref 99 18 00 to WGS 84. In Fig. 22, the new building (including the 3D properties and easements) is shown (see red rectangle) as well as part of the 3D city map. The colors for building in the updated 3D cadastral index map is only for visualization.

Finally, the applicant receives the formal property documents. After the payment is settled by the applicant, the whole process ends. The cadastral dossier is stored in the agency's digital archive and the

[1] https://www.safe.com/

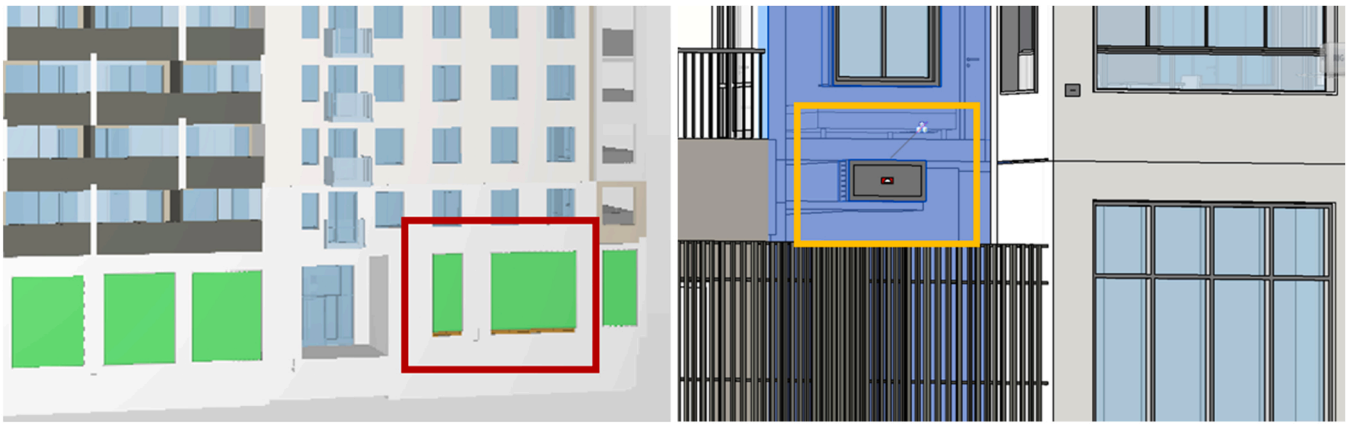

Fig. 23. Problems of 3D property boundaries: left for Organellen \100\1 in red; and right for Organellen \100\3, in orange.

updated 3D cadastral index map is published.

5. Discussions and suggestions

3D property formation is complex for management and delivery of relevant 3D cadastral models to the involved actors through different phases. As mentioned in Section 2, previous related research in Andrée et al. (2018) and Sun et al. (2020), however, did not provide a detailed description of data exchange requirements and flow between each actor in each phase. Therefore, the paper has proposed a BIM-based approach to form 3D property for a lifecycle 3D cadastral management by using IDM. From a point of organization, we identified the involved actors, their roles and values in the 3D property formation process. Meanwhile, from a legal perspective, the IDM process illustrated the detailed procedure of 3D property formation including general 3D cadastral events and activities. Moreover, from a technical perspective, we defined the data exchange requirements and designed a process map where a property formation model has been proposed to use as a main register model in version management to represent and visualize the 3D property units and property boundaries according to the data requirements.

However, the research has shown that there are a number of practical issues and limitations in need of attention when implementing a more digitized and BIM-based approach to design and develop a 3D property formation process. The discussions and suggestions are listed from organizational, legal and technical aspects as follows:

1) Organizational aspects:

   In the initiation phase, there are requirements and guidelines for the proposed 3D property model, but no requirements as to whether the applicants (e.g. owners or AEC companies) should be authorized by relevant government/municipal organizations. In other words, if the applicant is unable to develop such a qualified model, then the applicant may consult or hire an external expert or firm to develop it.
2) Legal aspects:

   The practical issue for the current property formation process is that there is no general guidelines or requirements of 3D property units and property boundaries for applicants and cadastral surveyors on the national level. Current guidelines/requirements are formulated by some large municipal cadastral authorities for their own areas, for example in Stockholm or Malmö. If there are clear instructions in a uniform way on how boundaries and rights are to be defined and illustrated, it will create a more efficient and unambiguous process in the property formation. To facilitate sustainable cadastral management, it is better to be formulated by the national cadastral authority.

   It should be noticed that the current real property register does not facilitate the storage of BIM files but only 2D documentation in the form of e.g. PDF or jpg format. The property formation models are more capable for lifecycle cadastral management, but nevertheless with no legal force. To realize the procedure above requires legal changes in national standards. How to make 3D models with legal force to register and store the legal information is a practical and essential problem that needs to be solved. 3D PDF may be a transitional way (BIM/IFC models can be exported or converted to 3D PDF) as 3D property formation documents with legal force, which may be easier to be accepted by the cadastral authorities.
3) Technical aspects:

In general, the proposed IDM defined the specific cadastral information requirements for each actor and specified how the information should be delivered, when it should be delivered, and in what format. In addition, with the help of 3D property formation models, the applicant enables to clearly represent the new property boundaries or express the changes of the property boundaries and RRRs in versioned models, as well as unambiguously state and visualize the relationships between the property units and building elements. Furthermore, the cadastral authorities and cadastral surveyors can inspect and review property units and property boundaries easily with the version management, make better decisions to fulfill requirements, register the property units unambiguously and update the property units in the 3D cadastral index map accurately. However, it should be aware of the challenges to put the proposed process into practice and further attention should be devoted to problems of the legality, validity and storage of the process and models.

- 3D property units: The 3D property unit registered in the system is a whole unit from conceptual and legal perspectives. However, the spaces created in Revit with different heights cannot be generated as a whole space but several separate sub spaces since the spaces are bounded by different building elements (e.g. walls, doors, windows, slabs). Spaces thus need be grouped into one zone to represent the property units. 3D property boundaries:

a. The vertical boundaries of windows in Organellen \100\1 have been suggested to the bottom of window by the applicant and been registered as + 17.7 m in RH2000 (see Table 6) after inspection by the cadastral surveyor. However, as shown in the Fig. 23 (left), the building element of the BIM model (shown in the red rectangular) named *Lokalparti* belongs to generic models not windows. The bottom of this element is to + 17.45 m, which means that without general guidelines the relative differences could be on the order of decimeters. This also confirms the previous suggestion.
b. The building element in Organellen \100\3, shown in the orange rectangular of Fig. 23 (right), is a smoke hatch belonging to doors not

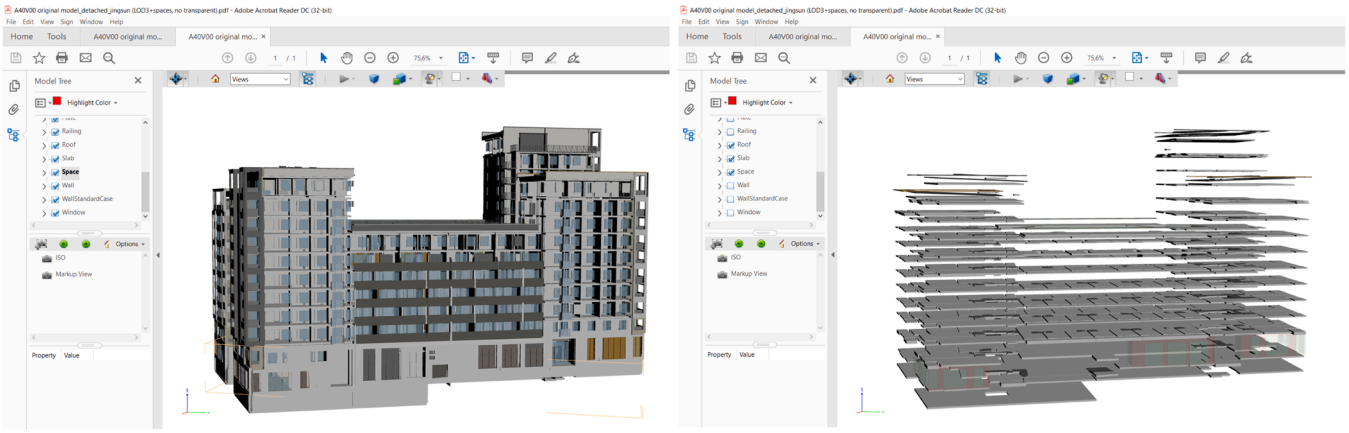

Fig. 24. Left: 3D PDF with highlight spaces; right is visualized with only space, slab and roof (Model render mode: Solid).

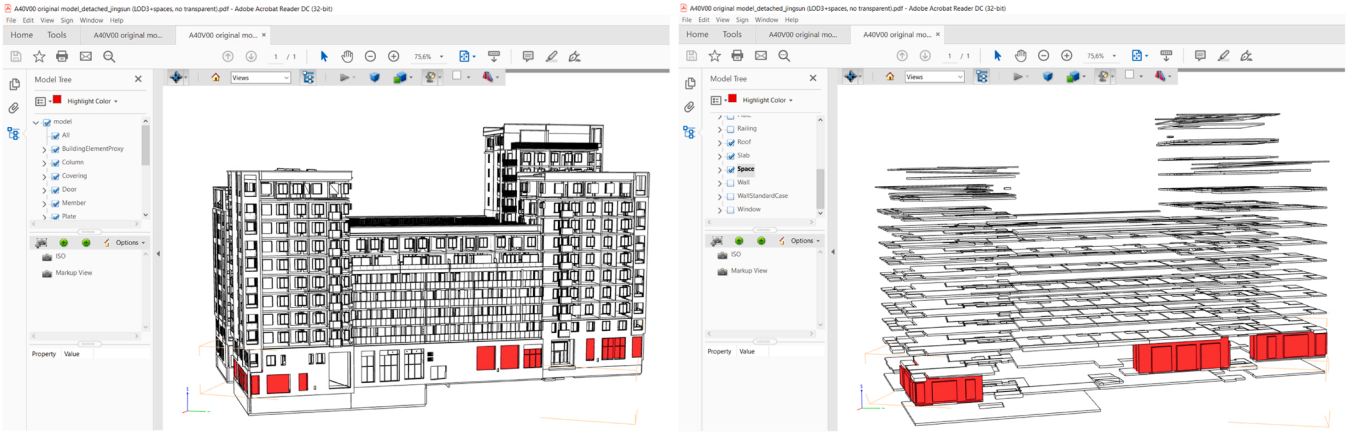

Fig. 25. Left: 3D PDF with highlight spaces; right is visualized with only space, slab and roof (Model render mode: Illustration).

windows. Even through there is no suggestion stated about it (see Table 6) it has been treated as window that uses exterior line as property boundary. However, this element is created by cutting the external wall in Revit, which makes it invisible to see and impossible to create space boundaries in the floor plans view (see Fig. 16).

- 3D cadastral visualization:

In Sweden, 3D PDF has been currently used as an additional way to visualize 3D property units without legal force. To obtain a good view, the visualization system should allow different levels of transparencies in the visualization. In 3D PDF, *model tree* can be toggled and different *mode of model render* can be chosen (Fig. 24 in solid mode and Fig. 25 in illustration mode). Even then, it could be difficult to discern the extent of the 3D properties, e.g. due to the color mixing problem (see Seipel et al., 2020). In the case study, the three property unit areas of Organellen 100 visualized in 3D PDF show weak visualization of spaces, compared with Fig. 13 and Fig. 14. Moreover, it is difficult for the cadastral surveyors to check the relationships between property units and building elements, compared with Fig. 18 and Fig. 19.

- Data standards:

According to recent legal changes, the detailed development plans have to be machine readable (which might also be the case for future building permit documents), which would facilitate a more automated and standardized process at this stage. On the other hand, for the 3D cadastral index map, transformation of coordinate system and height system is needed if using Google Earth for visualizing the updated 3D cadastral index map.

6. Conclusions

Traditional cadastral systems register property and share cadastral information in 2D. From a technical aspect, 3D property registration can represent and form legal objects in a 3D reality world in order to represent complex spatial structures and avoid ambiguous property boundaries. However, 3D property formation faces practical difficulties, for instance when and which the cadastral data and models should be exchanged and stored from/to whom. Therefore, in this study we proposed a BIM-based approach for 3D property formation process from organizational, legal and technical aspects. The IDM as the international standard process of BIM was used to design a developed process of Swedish lifecycle 3D real property formation including five actors and clear data exchange flow. By identifying the actors' role and value and specifying the 3D cadastral information requirements and delivery methods, the proposed IDM process can help to improve the efficiency and accuracy of the 3D property formation process. Compared with the current cadastral dossier only by text and CAD drawings, combining with a 3D property formation model is a hybrid way of transition from 2D to full 3D that will optimize the effect of the 3D registration process, strengthen cooperation from the organizational aspect and thus improve lifecycle cadastral management.

Overall, the proposed method aimed to facilitate a general and unambiguous 3D property formation procedure through the lifecycle phases in order to improve and enhance digital Swedish Cadastral and Land Administration Systems. It will take another step up the maturity ladder by developing the 3D formation property process based on a BIM

approach. With a holistic view of digitalized cadastral management, the proposed 3D formation property process has the possibility to increase efficiency and improve cadastral information exchange. However, the 3D property formation process for individual 3D properties may vary in complexity from different requirements of legal regulations in different municipalities, to the practical situation of different projects, to different actors involved in the property formation process. As suggested in Section 5, general guidelines/requirements are necessary to be formulated by the national cadastral authority. In addition, legal changes in national standards are required to realize 3D property formation legal force.

Declaration of Competing Interest

None.

Data Availability

The authors do not have permission to share data.

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