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Representation of 3D cadastral boundaries - From analogue to digital

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ABSTRACT

This paper discusses problems and challenges concerning the process of conversion of 2D analogue cadastral boundary plans into 3D digital information and is based on experiences from a research project on visualization of 3D property boundaries in Sweden. An area next to a newly constructed sports– and event arena in Stockholm, where 3D properties are formed, is used as a case study in the project to illustrate the process and the problems related to it. Focus lies on legal issues, although other aspects are mentioned as well. The rights, restrictions and responsibilities (RRRs) are registered in the national Real Property Register, which also includes registration in the two–dimensional Digital Cadastral Index Map.

A description of the process of forming 3D property is included in the paper regarding the documents and parties involved. The result of the study is that it is necessary to interpret two–dimensional cadastral data and textual descriptions in order for it to be used in a digital 3D environment, *e.g.* BIM.

The study shows that current legislation has to be investigated and interpreted in detail to be able to add or transform into using 3D models as part of cadastral decisions in Sweden. The current cadastral process is also analysed and suggestions for further development are provided.

1. Introduction

This paper presents additional results to a study previously published in Larsson et al. (2018) on conversion of two-dimensional (2D) analogue cadastral maps into three dimensions (3D). The Swedish statutes for formation of 3D property units and associated rights, restrictions and responsibilities, RRRs, in Sweden was introduced in the Swedish Land Code in 2004, with the addition of apartment (condominium) ownership in 2009 (SFS (1970a,1970b:944)). The demand for 3D property formation has not yet been as high as expected (regarding reasons for this, see *e.g.* Paulsson, 2013), but national property formation statistics during the last 8 years indicate that there is interest in this three-dimensional real property today, see *e.g.* Lantmäteriet (2012; 2019). The registration of rights, restrictions and responsibilities in three dimensions creates a need for registration and visualization for the RRRs, which can be challenging in storage and representation of 3D property data, for example legal boundaries.

In recent years the conversion of 3D analogue cadastral information and the visualization of the same has been subject to research, see *e.g.* Andrée et al. (2018a: 2018b): Karabin et al. (2018); Larsson et al. (2018); Pouliot et al. (2016). This paper is a contribution to this research, focusing on issues on conversion and visualization of 3D analogue cadastral information into digital form.

The cadastral authorities often use digital building plans supplied by the entrepreneurs in the 3D property formation process and used as input for two dimensional analogue cadastral boundary plans. Digital information on 3D boundaries therefore exists, but is, however, not stored in the national Digital Cadastral Index Map or in other centralised registers. Although local cadastral authority offices may store the 3D building plans they use in the formation process, there does not exist any national tradition or guidelines for such procedures. The result is that digital 3D information may be stored locally, but is not part of the cadastral dossiers containing the legal documents necessary for property formation decisions and registration, see *e.g.* Paasch and Paulsson (2014) and Paulsson and Paasch (2013).

1.1. Problem description

3D property formation processes often include the use of digital buildings plans. However, the 3D properties are still registered using two–dimensional documentation, even if 3D digital information is used in the real property formation process.

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Drawings of 3D property units and associated building constructions are part of the cadastral dossier as two–dimensional drawings. The correct interpretation of two-dimensional data and conversion of it to be used in a 3D environment, *e.g.* BIM, is therefore necessary. 3D cadastre and BIM is much in focus in research today, see *e.g.* Ma and Ren (2017) and Oosterom and Dimopoulou (2018), but data collection and interpretation of 3D cadastral data has in our opinion been somewhat neglected, even if there have been contributions to legal issues and registration, see *e.g.* Kitsakis et al. (2018) and Dimopoulou et al. (2018). This paper exemplifies and illustrates with experiences of interpreting the analogue cadastral dossiers for presentation in a 3D digital environment.

As of today, there are no regulations or recommendations regarding what information should be submitted or how drawings *etc.* should be designed within cadastral procedures. The Digital Cadastral Index Map is a 2D representation of many registered boundaries of properties, as well as easements and other rights with poor geometrical accuracy. The reason is that the information today in the Digital Cadastral Index Map is a result of different conversions of older, both analogue and digital, material as well as more recent digital additions with better geometrical quality. In areas with a multitude of boundaries and RRRs, the Digital Cadastral Index Map is hard, or close to impossible, to interpret due to a simplified 2D representation of 3D boundaries, see *e.g.* El-Mekawy et al., 2014. In addition to this, the 2D representation of *e.g.* public regulations, such as detailed municipal development plans, can have major errors in regard to the actual location compared to what is shown on the index map, resulting in different accuracy in relation to the original legal documents, see *e.g.* Larsson et al. (2018).

1.2. Aim

The aim is to discuss problems and challenges concerning conversion of 2D analogue cadastral boundary plans into 3D digital information. The discussion is based on experiences gained in a research project on visualization of 3D property boundaries in Sweden, see Andrée et al. (2018a; 2018b) and Larsson et al. (2018). Converting the 2D cadastral information into 3D includes transforming already existing data into 3D, but even to find new processes for using 3D digital information in future property formation decisions. An area next to a recently constructed sports– and event arena in Stockholm containing 3D property units and RRRs is used as a case study to illustrate the digitization process and the problems related to it. The focus is on legal issues, although other aspects will be reflected upon as well.

1.3. Method

Studies of existing literature, cadastral documents and experience from practical work with 2D and 3D cadastre were used in order to present the current situation and identify existing problems and challenges in converting 3D cadastral boundaries from analogue to digital form. A case study was made in order to exemplify existing difficulties and to use as a basis for the created 3D model. The case was selected as a rather clear and limited area where data, 3D building models and experience were already available.

The work with the case study was conducted in stages. First, a suitable physical construction being subject to 3D property formation was identified. Then the cadastral dossiers and The Cadastral Index Map were analysed and interpreted in order to locate the 3D legal volumes. The boundaries were then manually digitized and parts of the City of Stockholm's digital building model was added.

A study of the Swedish CoClass classification system (Andrée et al., 2018a) and IFC (ISO, 16739:2013) standards were made as part of the investigation. The modelling in the study was done using MicroStation. Technical, standardization and categorization issues, such as XML, IndoorGML or the ISO 19,152 Land Administration Domain Model (ISO, 19152:2012) have not been in focus of this study, which focuses on the aspects of converting legal digital and textual data into 3D digital form.

2. 'Smart Built Environment' projects

'Smart Built Environment' ('Smart Built'), is a Swedish strategic innovation programme initiated by the government in cooperation with the private urban land development sector. The programme is financed by Swedish research agencies (Formas, Vinnova and the Swedish Energy Agency) in cooperation with the participating companies and authorities. 'Smart Built' focuses on a variety of issues, such as sustainable cities, new opportunities of digitalisation and resource management. Several studies and projects are part of the programme.[1] 'Smart Built' is part of ongoing national initiatives aiming at digitalization of the Swedish planning and building processes, see Ekbäck (2019).

A study within 'Smart Built' is part of the finished project '*Information for planning, real property formation and building permission*' (author's translation), see Andrée et al. (2018a; 2018b) and Larsson et al. (2018). The purpose was to investigate how to increase and develop the use of 3D models and other 3D data throughout the different stages of the planning and building process; idea, detailed planning, property formation, building permits and management. Three major fields were identified that need further investigation in order to be able to transfer from analogue 2D maps to a 3D cadastre; the legal matters, the financial aspects and the technical matters in form of data conversion and visualization (Andrée et al., 2018b). Financing for both investigations, implementation and management of a 3D system needs to be solved, but is not subject for research in this paper. Legal and technical aspects will, however, be reviewed further. The project resulted in several new coming projects within 'Smart Built', focusing on the issues that emerged and are in need of further investigation, such as legal and technical aspects for the different stages of the planning and building process. Two newly started continuing projects within these areas are *DigSam - Digital Built Environment Process*[2] (author's translation), and *Delivery Specifications for Geodata-BIM*[3] (author´s translation).

Another study within 'Smart Built' is the ongoing *'Smart planning, construction and management processes throughout the life cycle'* (author´s translation), which in part is a project on visualization of 3D cadastral data (Andrée et al., 2018a, 2018b) and Tarandi (2017). The study focuses on visualization of 3D cadastral boundaries. Findings from the study will be discussed further in this paper.

3. Swedish 3D property system

3.1. Property formation

The legal basis for 3D property formation in Sweden is primarily the Swedish Land Code (SFS (1970a,1970b:944) and the Real Property Formation Act (SFS (1970a,1970b:988).

A traditional 2D property unit is delimited horizontally with x and y coordinates and, in theory, contains a volume extending upwards into the sky and down to the centre of the earth. However, in practice the extension above and below ground is limited by how much the property owner can use. Special conditions apply for *e.g.* mining rights. In cities and other densely-built areas different activities compete for the same (physical) space with the volume of the 2D property unit, see Fig. 1. 3D property formation is an effective method for subdividing and thus separating the ownership of these different activities.

A three–dimensional property is formed using the same processes as

[1] See http://www.smartbuilt.se/in-english/ Accessed August 5th 2019

[2] See https://www.smartbuilt.se/projekt/standardisering/digsam/ Accessed August 5th 2019.

[3] See https://www.smartbuilt.se/projekt/standardisering/leveransspecifikationer/ Accessed August 5th 2019.

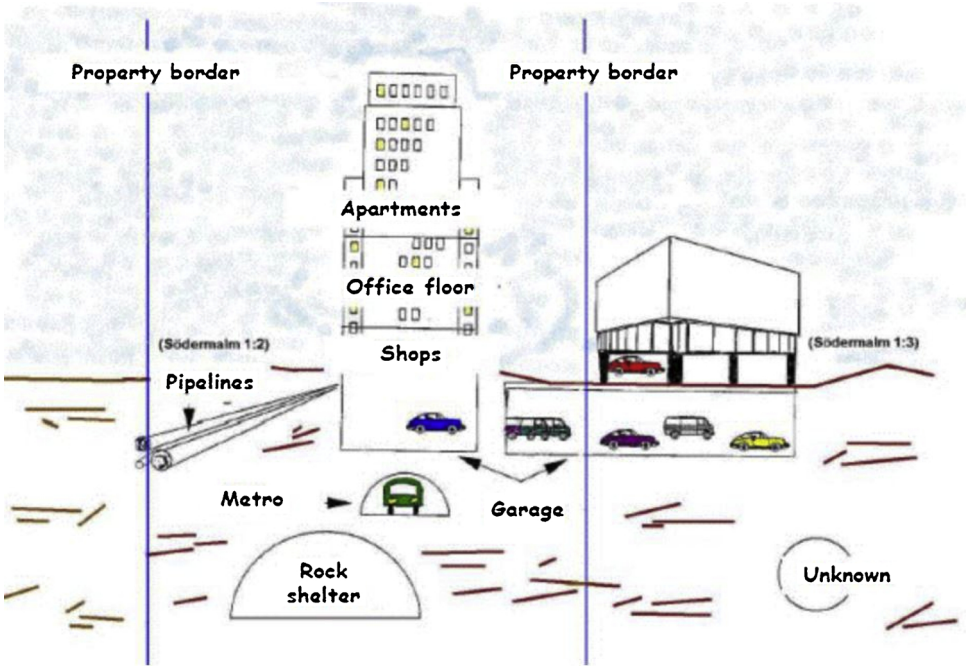


Fig. 1. Description of traditional real properties. Source: Lantmäteriet.

a traditional 2D property. The 3D property is considered as a property unit and thus the same rules are applied as for all other property units. However, some specific rules have been added for this type of property.

The extension of a 3D property is bounded both horizontally and vertically. The property is intended to accommodate a building or other facility, or part thereof. There are in the Swedish system, unlike other jurisdictions (see *e.g.* Paulsson, 2007), no specific legal rules for how to draw or visualize the cadastral boundaries in relation to the physical building construction. Although the boundaries in principle shall follow the construction, there is a possibility to include also a small volume of air to include protruding construction details for *e.g.* maintenance if deemed appropriate. This does, however, not mean that the 3D property can contain space for future building rights, like adding another floor at a later stage. In such a case a cadastral procedure, *e.g.* reallotment, will have to take place by adding parts of the neighbouring property unit to the 3D property unit. There is, although, a possibility to form 3D property for a future building or facility, with the condition that it will be developed within a fixed amount of time. It is even possible to make preliminary decisions for the property formation since it may be necessary to make adjustments when the construction is completed, *e.g.* for undeveloped buildings.

There are some conditions to follow when forming the 3D property unit, in addition to the need for a surrounding construction. It has to be investigated that no other types of property formation or property rights are a better legal solution to achieve the desired purpose, *i.e.* without 3D property formation. There is also a requirement to legally secure and arrange the necessary rights needed for the proper use of the 3D property unit. Another prerequisite is that the formation is warranted with regard to the construction and use of the facility and that it is intended to facilitate a more efficient management or ensure the financing or construction of the facility.

The 3D property unit must comprise at least three residential apartments if intended for residential purposes. Ownership apartments (condominiums) can only be formed in new erected buildings and in reconstruction projects where there has been no residential housing for the past eight years. 3D property formation must always be carried out in accordance with applicable land use plans.

An application is sent to the cadastral authority when a 3D property unit is to be formed. The authority assigns a cadastral surveyor who will check the application against the legislation, planning regulations, building permission, *etc.* If not correct, the application is returned to the applicant to change certain details. The cadastral surveyor will, together with the applicant, find the most suitable solution for the location of the 3D boundaries, *etc.*, in each specific case. It is required that the horizontal and vertical boundaries are described in writing, as well as shown on maps and drawings. This also applies to all other boundaries for rights, restrictions and responsibilities (RRRs), *e.g.* easements and joint facilities.

Today, documents used in the property formation process are mostly in paper format or frozen digital images, such as previous property formation decisions, planning regulations and building permissions (see *e.g.* El-Mekawy et al., 2014). The developer/entrepreneur often provides CAD drawings containing the 3D real property boundaries, but they are not archived in the national real property register.

3.2. Documentation and process today

All 3D property and 3D RRR boundaries are required to be presented both in a verbal description and shown on maps and drawings according to current Swedish cadastral legislation and established process. As described above, the cadastral surveyor checks the application against current legislation, planning regulations and building permits. The applicant provides the documents the land surveyor needs to make the decisions. Often the process results in the need to change some details in the application to get it approved. As mentioned above, the property formation documents are mostly in paper format or frozen digital images. This also applies to earlier property formation decisions, as well as *e.g.* detailed municipal plans and granted building applications, which are also used in the property formation decision. Decisions are registered in the Digital Cadastral Index Map and the cadastral dossiers are archived, see examples for ownership apartments in Fig. 2 and Section 3.3.

3.3. Property registration

The national Real Property register contains information of more than 3 million 2D and 3D real properties and numerous associated RRRs. The legal basis for real property registration is the Real Property

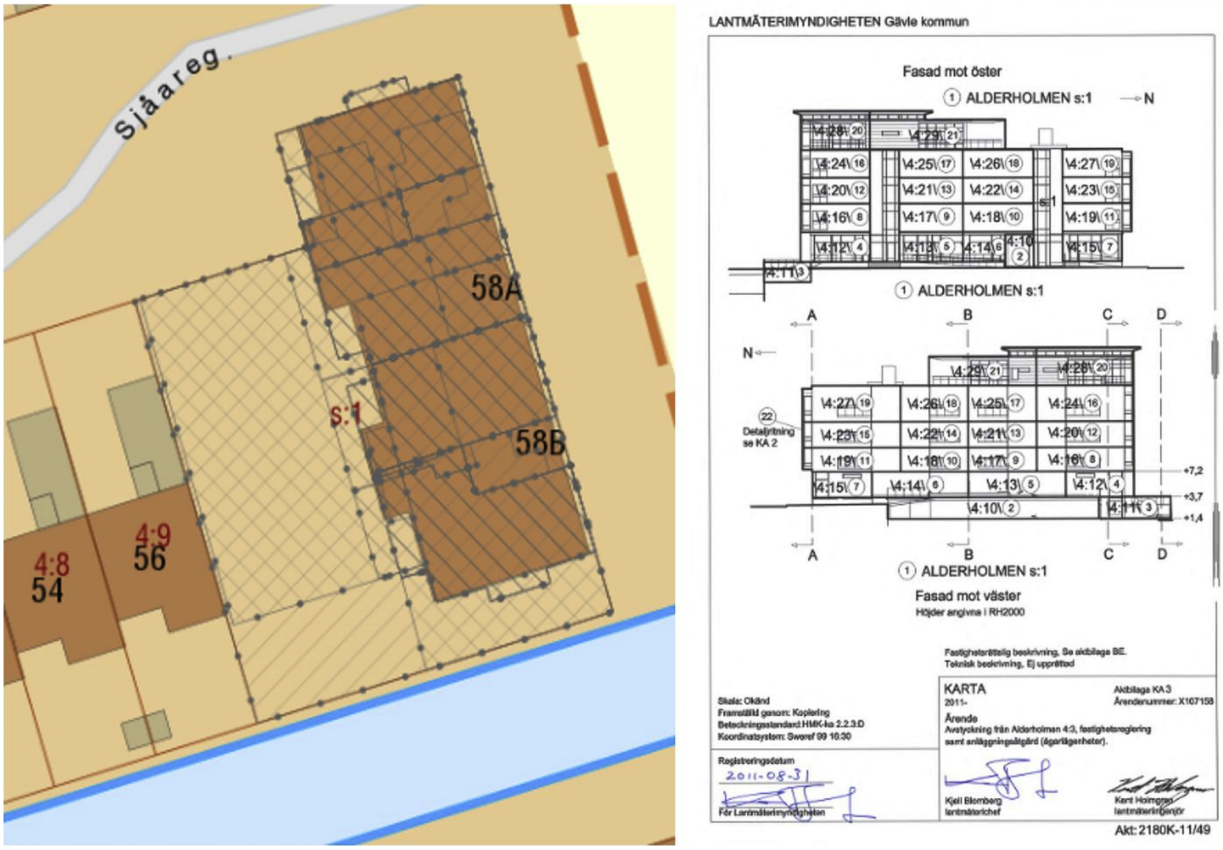


Fig. 2. Picture from the Digital Cadastral Index Map of ownership apartments (left) and cadastral plans of the same properties (right). Source: Lantmäteriet, Digital Cadastral Index Map and cadastral dossiers.

Register Code (SFS, 2000a, b:224), whereas the content of the register is regulated in the Real Property Register Ordinance (SFS, 2000a, b:308). The register is regarded a cornerstone in Swedish land administration and continuously updated online. The register consists of two parts; a textual part and the index map.

All 2D and 3D property units are given unique registration numbers independent from the land parcel they are located upon (or below in the case of subterranean objects, such as tunnels). The registration procedure of 3D property units in the register does not, in principle, differ from registration of traditional 2D property units. However, one specific difference in regard to 3D property and 3D RRRs is that the boundaries are either defined by x, y and z coordinates or defined by other types of description of the extent in the vertical dimension by referring to surrounding physical construction details on the construction drawing, whereas 2D property units and RRRs are defined by x and y coordinates. Detailed descriptions of boundaries and RRRs are not registered in detail in the register, but a reference in the form of a unique identifier is given to the property formation dossier.

The spatial extension of a 3D property is in the index map subject to a rather simplified 2D cartographic registration, since only the footprint of the 3D property unit is registered and marked with a dotted line, see Fig. 3.

Fig. 4 below is an example of registration of heights of 3D property in the textual part of the register, showing a 3D property located between level CA + 23.6 m and level CA + 58.5 m.

The cadastral authorities often use existing 3D CAD drawings in the cadastral formation process, when provided by the entrepreneur, as explained above. These CAD files may – or may not – be archived for future use by the cadastral authority. There is, however, no general national system for archiving such files in a standardized way, and different solutions exist. Analogue copies of the building plans may therefore become part of the cadastral dossier showing the building and (some of) the 3D boundary.

4. Case study

A case study was conducted by the 3D–BIM working group. The study included a variety of property rights and several 3D real properties in the Stockholm area. The existing data provided by the city administration of Stockholm was represented in form of polygons in the 2D index map. Those polygons were combined with height information extracted from the cadastral dossiers and height data provided by the city of Stockholm, which is the cadastral authority.

The study did not include any cadastral formation itself, but used an existing cadastral procedure, that was handled in the traditional manners. Parallel to this, the study also analysed a hypothetical digital 3D cadastre and cadastral procedure using 3D models instead of analogue 2D paper drawings. The cadastral procedure in the study was a reallotment transferring a three–dimensional space, containing part of a shopping mall, from one 2D real property unit to another 2D real property unit. Fig. 5 below shows the 2D drawings used in the traditional property formation dossier, as well as visualization of the 3D model of a part of the details produced within the case study. The 3D model could in future property formation dossiers replace or be combined with the 2D drawings.

The case study identified possibilities as well as challenges when comparing the cadastral process being used today with a possible future process of including a fully digital 3D cadastre for registration where 3D models are part of cadastral decisions and dossiers.

The use of 3D models as part of the cadastral dossiers and cadastre is a major advantage, since the 3D digital information can be reused, without, as in the present situations, having to transform 2D drawings to new 3D models. Provided that the information is reliable, a 3D registry index map containing volumes can provide a clearer picture of

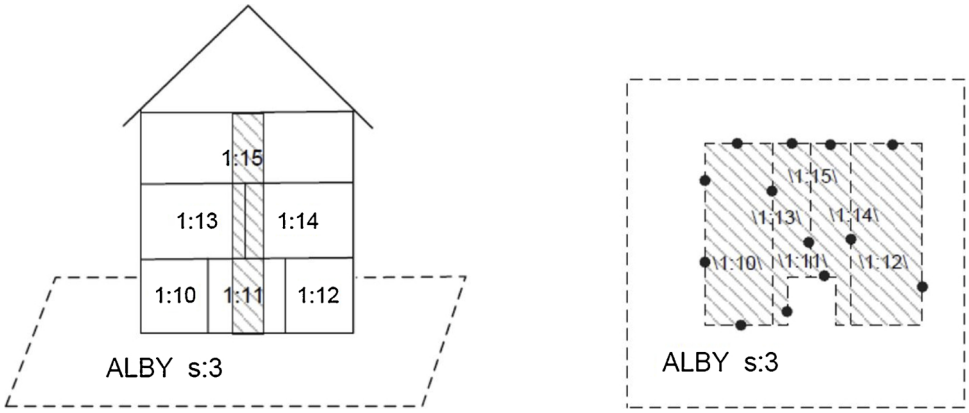


Fig. 3. Cross section of a building containing 3D real property units (left) and its 3D visualization on the Digital Cadastral Digital Index Map (right) (Lantmäteriet, 2004, ch. 3, p. 33).

the (often complex) land use within a particular area, which makes it easier for planning and management. This, however, requires that new and correct information is entered into the cadastral system, but also that older already existing (analogue) information is interpreted in a sufficiently correct way. It also has to be determined how information in the 3D index map and cadastral dossiers should be interpreted, for example, what accuracy different objects should have. When the information has been added, it is important to ensure that all users understand that different objects in the 3D cadastre can have different accuracy, this is a major part of the need for good visualization. Therefore, the use of metadata is important in a fully digitized cadastre.

The study also discovered that the textual description of where a boundary is located might be in need of revision. As of today, the boundary is described in a verbal description supported with drawings, often in scale 1:100-1:1000. For the reallotment subject for this study, one boundary was described as 'exterior of construction, windows are part of the 3D space' and the boundary illustrated on a 2D drawing in scale 1:400. This, however, did not provide any detailed information of millimetre-level precision. When creating the 3D model, the boundary line(s) had therefore to be placed more accurately, making the question as to where the boundary of the window should be placed more exactly (for example outside of glass, or some air left outside the glass, making a straight line between the window casings, *etc.*). During the analogue cadastral procedure it was found that the submitted drawings were based on incorrect data regarding the existing 2D boundary lines. The fact that incorrect data of current conditions had been used by the architect was discovered late in the process, this had probably been noticed much earlier if a digital 3D model and cadastre had been used. Visualization is discussed further down, including descriptive figures from the case study.

5. Possible future 3D cadastre

5.1. Possible future documentation and process

The 3D–BIM working group has presented a vision for a future procedure where the applicant has access to a 3D model of the real property subject for change, as well as regulations for the area in 3D data format. If the applicant cannot produce their own 3D model, it should be possible to obtain a model from the cadastral authority, under the condition that the authority has produced or otherwise obtained a 3D model of the area in question. These models should be stored *via*the 3D cadastre. If the applicant has a 3D model with more content than of cadastral information, only the section relevant for the 3D property formation should be submitted. In order to have a uniform and functional 3D cadastre, a level of detail (LOD) and the information content for the 3D model need to be specified.

5.2. Possible improvements in the property formation process

There are many different actors who are concerned with a cadastral procedure and the need for an improved process is different depending on whose perspective is reflected. Applicants in a 3D cadastral procedure can vary widely and can be anything from a tenant-owner association to a professional developer who handles several 3D cadastral procedures per year. From the applicant's perspective, even if it is a professional actor, it is a challenge to illustrate, in a manageable and understandable way, the desired boundaries, rights and joint facilities for a prospective 3D property unit.

It is difficult to correctly present a 3D volume only in paper drawings and it is also difficult to read a cadastral map in 2D with property units and rights in 3D. This is clear not the least when the application is submitted with claims to make changes to existing 3D boundaries. Then, the cadastral surveyor needs to go through the existing paper documents to try to understand where existing 3D spaces and boundaries are located, assess the suitability of the desired new boundaries and then in the decision documents clearly show how these will be changed.

There is a need for the applicant to get guidance on how to best specify the application so that the material submitted to the authority becomes as functional and complete as possible. By using materials that are produced in the design of a new building, the material is used more effectively. If there are clear instructions on how boundaries and rights must be defined and illustrated, it creates a more efficient process for property formation.

Additional elements in the cadastral procedure that need improvement are that the register map needs to be clearer (it is difficult to interpret today), previous decisions need to be easier to understand (they are difficult to interpret today), more uniform and unambiguous cadastral documents are needed, access to uniform data throughout the process is needed, reusable information is needed, and uniform visualization is needed.

Storlek: Utrymmet i horisontalplan är ca 6 kvm.
Höjd: Höjdläget är mellan CA+26,3 meter och CA+58,5 meter i RH00.
Urholkar: Solna Haga 4:20

Fig. 4. Example of textual 3D height information in the textual part of the Real Property Register. (In Swedish) (Based on El-Mekawy et al., 2014, p. 22).

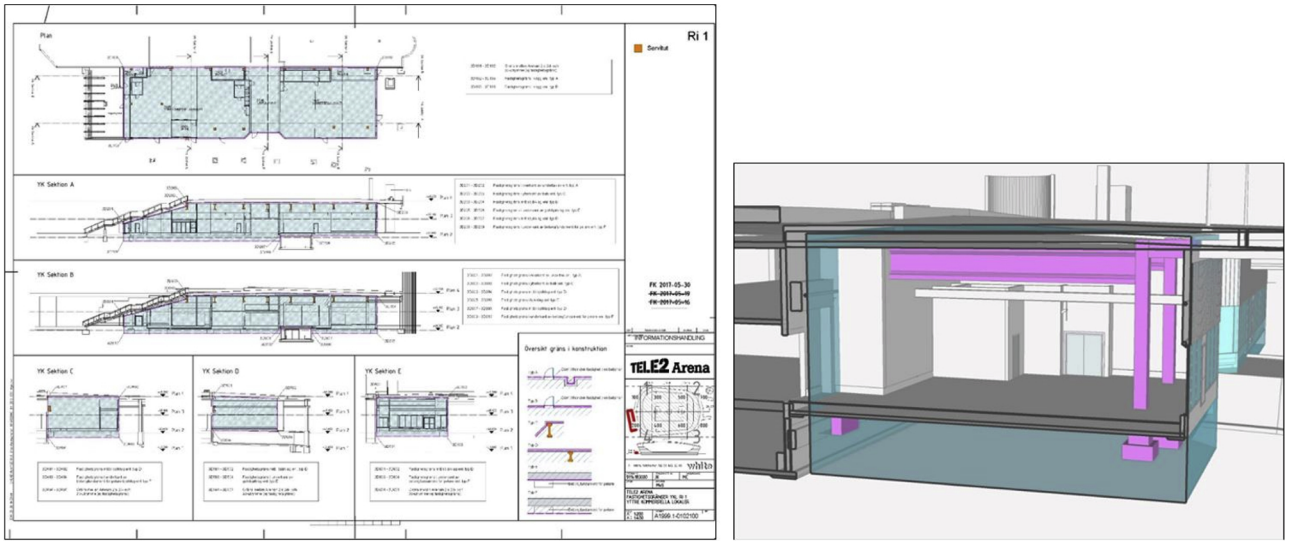


Fig. 5. Drawings as part of the actual property formation dossier (left) and possible future 3D information as part of property formation dossier (right) (Based on Andrée et al., 2018b).

A risk of not imposing requirements on the data (actuality, quality, possible 3D data, *etc.*) may be that property units become unsuitable and that disputes arise when the cadastral decisions cannot be unambiguously interpreted. If supporting documents are produced in very different design and quality, it may be difficult to obtain a consistent basis for decisions and registers, which can make it difficult for interpretation and future management, which in turn leads to costly processes for making future changes. 3D property formation decisions today are sometimes taken based on building permit drawings from the late 1900s with boundaries drawn by hand. An individual assessment is reasonably made in each case, however, this assessment should not be influenced by the basis on which the proprietor has access, but on the need for producing a legal and clear decision. A possible future cadastral process for 3D property formation is shown in Fig. 6, including the use of a proposed joint information platform for BIM and Geodata.

5.3. Data collection and visualization

The registration of boundaries in the Digital Cadastral Index Map, as mentioned above, does not allow any detailed 3D visualization of legal boundaries. The index map has no legal force and is only used for overview illustration purposes of cadastral boundaries. Most data therefore has to be collected from the cadastral formation dossiers, consisting of 2D analogue cadastral boundary plans and text–based descriptions. This information was in the study not easy to collect through the digitalization process due to difficulties to interpret some of the cadastral and building plans and/or the describing text in the dossier. An example is a RRR volume that covers the existing room and the hallway, as described in the dossier. To interpret the analogue cadastral boundary plans in an effective way, it is therefore necessary to access detailed building plans and textual descriptions, which was not always possible in the study.

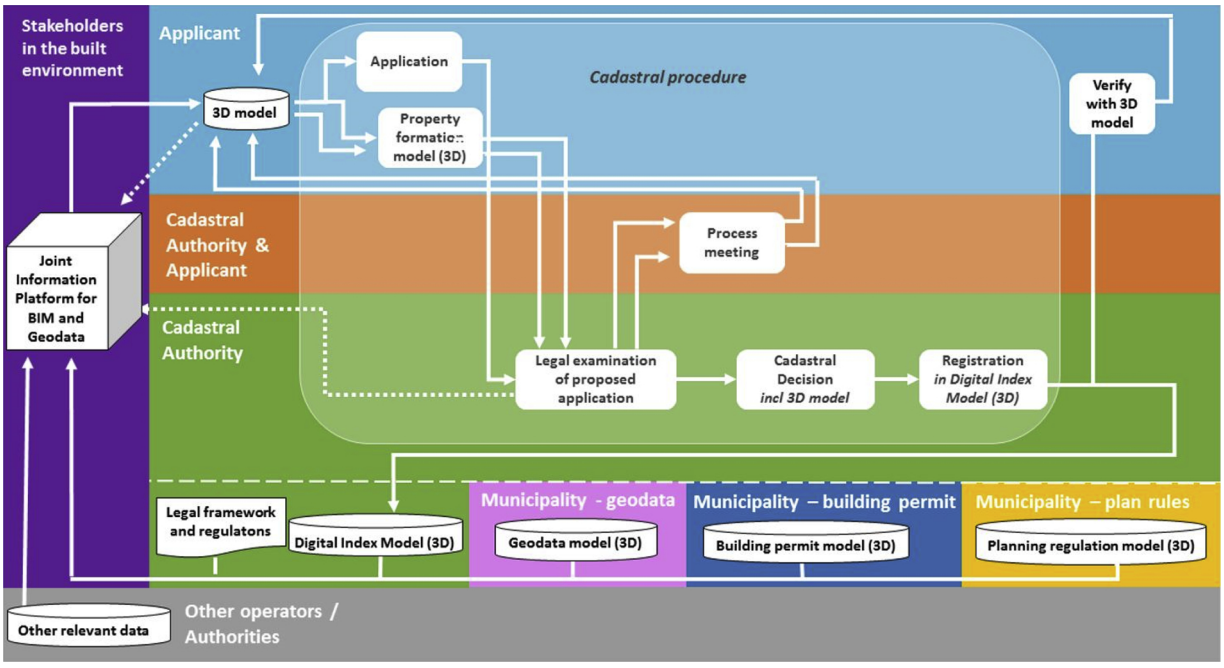
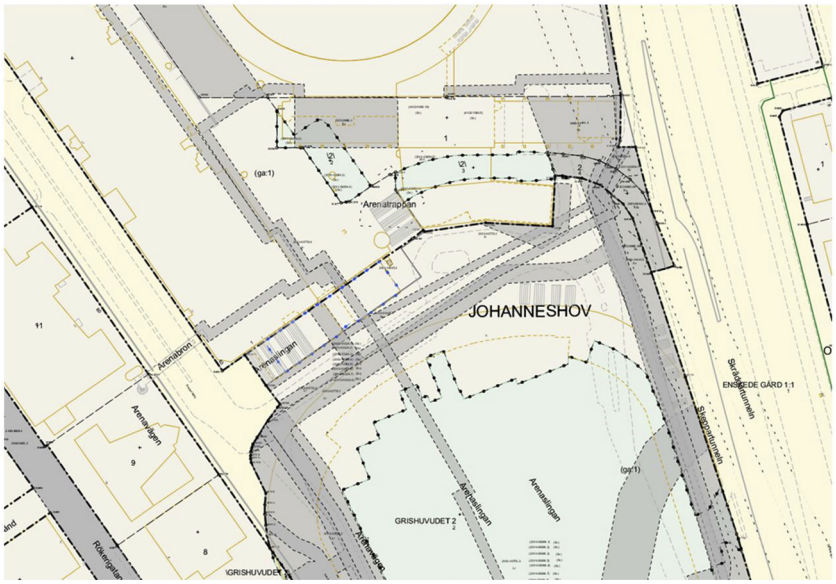


Fig. 6. Possible future process. Authors translations. (Based on Andrée et al., 2018b).

(a)



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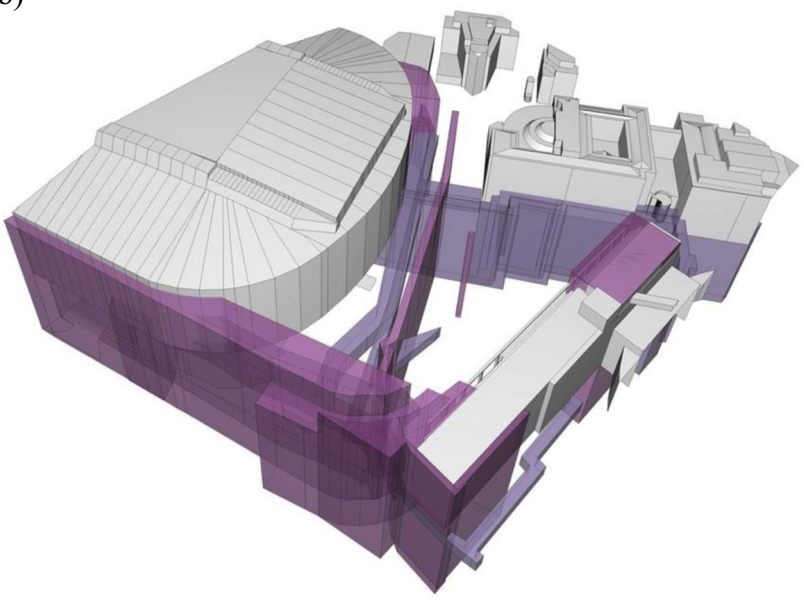

(c)

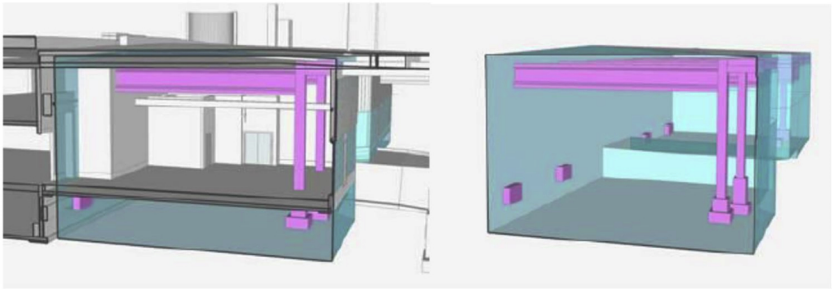

Fig. 7. A) Visualization on 2D analogue cadastral index map. Source: City of Stockholm, Cadastral Index Map.
B) 3D model of the RRRs and external building details (Andrée et al., 2018b, p. 44).
C) Left: 3D property boundaries (in turquoise colour) and property rights (pink colour) and internal construction details (Andrée et al., 2018b, p. 46). Right: 3D property boundaries (in turquoise colour) and property rights (pink colour) without internal construction details (Andrée et al., 2018b, p. 46).

Some legal information without specified geometry, such as some RRRs, were represented in the form of text on the conventional cadastral maps, since their spatial extent within the 2D plane is unknown. Within the 3D model, those objects are modelled as cylinders with some radius from the centre of the text label, even if it is not their actual geometric location.

In the case study of the 3D–BIM working group, the boundaries were digitized partly with assistance of digital building plans showing outdoor and, but less frequent, indoor features. The result is a 3D digital index map of varying degrees of detail. Fig. 7A shows RRRs and building footprints on the analogue cadastral index map, Fig. 7B shows RRRs in 3D in relation to outside building features and Fig. 7C shows RRRs in 3D with and without internal building features.

The new ongoing project 'Delivery Specifications for Geodata-BIM' within 'Smart Built' is looking deeper into the possibility to have standardized delivery specifications within the urban planning and building process.

Cadastral information has traditionally been displayed in 2D and visualization of 3D cadastral systems is still an emerging field, see Pouliot et al. (2018). This study has so far not been focusing on the legal aspects of visualization regarding interpretation of 3D information, even if they have been subject for discussions. The visualization has been challenging. Legal RRRs often, but not always, have the same outline as a construction detail, *e.g.* a wall. The boundary can be located inside or outside the wall and even pass through it. Therefore, both solid style rendering and transparent surfaces have been used for visualization, seeFig. 8A and B.

When cadastral boundaries are modelled in 3D from an existing BIM model, it is important to state the precision to which the boundary shall be true with a multitude number of architectural details, such as glass windows. A boundary can, for example, be exactly aligned with the window's frame and glass, or be more simplified with more tolerance to allow for different construction details in the final building. A property boundary which is exactly specified will of course increase the risk of disagreement with the actual building, due to that building details may be implemented differently or added compared to building plan.

Apart from 3D boundaries, also RRRs can have limitations in heights that need to be interpreted if a full 3D cadastre is implemented. In the case study of the 3D–BIM working group, the model representing a future 3D cadastre was created from the existing 2D Digital Cadastral Index Map. To be able to convert from 2D to 3D in a relatively efficient manner some rules of modelling were developed. This resulted in property boundaries and other RRRs represented by an area or a line in the 2D Digital Index Map automatically were given a certain height. For some RRRs, the archive cadastral dossiers then gave more information about the exact location in height, making the accuracy better by manual adjustments. In a future 3D Cadastre, each object would as well be given an attribute for accuracy, depending on whether the shape and location is based on automatic generation, manual specification based on archive dossiers or direct registration in connection to the cadastral decision.

The automatic generation was based on the existing 2D data being placed on a chosen zero level (representing zero level of the national height system of Sweden, RH 2000, that in turn is based on zero level Normaal Amsterdam Peil, NAP). Existing 2D boundary lines were extracted up 150 m and down 100 m from the zero level, making each boundary line creating a disc in the model. Existing 3D boundary lines were extracted up and down to the registered maximum and minimum height of the 3D property space, creating a volume within which the whole 3D property space fits, however, not showing the exact boundaries for the 3D property space. Existing easements represented by a surface in the 2D Digital Index Map were extracted up and down 50 m from the zero level, whereas existing easements represented by a line were widened 5 m on each side of the line, and then extracted 50 meters up and down from the zero level, creating volumes of each easement. Existing easements represented by a point in the 2D Digital Index Map were extracted to a circle with a radius of 10 m and then extracted up and down 50 m from the zero level, creating cylindrical volumes for each easement. In addition, data from the existing 3D building model, as well as the 3D geodata model from the City of Stockholm, was added. As part of the pilot study, data from an existing 3D model was also added, regarding the specific building parts related to the property

Fig. 8. A) Visualizations of legal RRR objects related to building details using solid style rendering (left) and transparent surfaces (right) (Andrée et al., 2018b, p. 47).
B) Visualizations of legal RRR objects related to building details using transparent surfaces (left) and edge–enhanced transparent rendering for enhanced visual appearance (right) (Andrée et al., 2018b, p. 47).

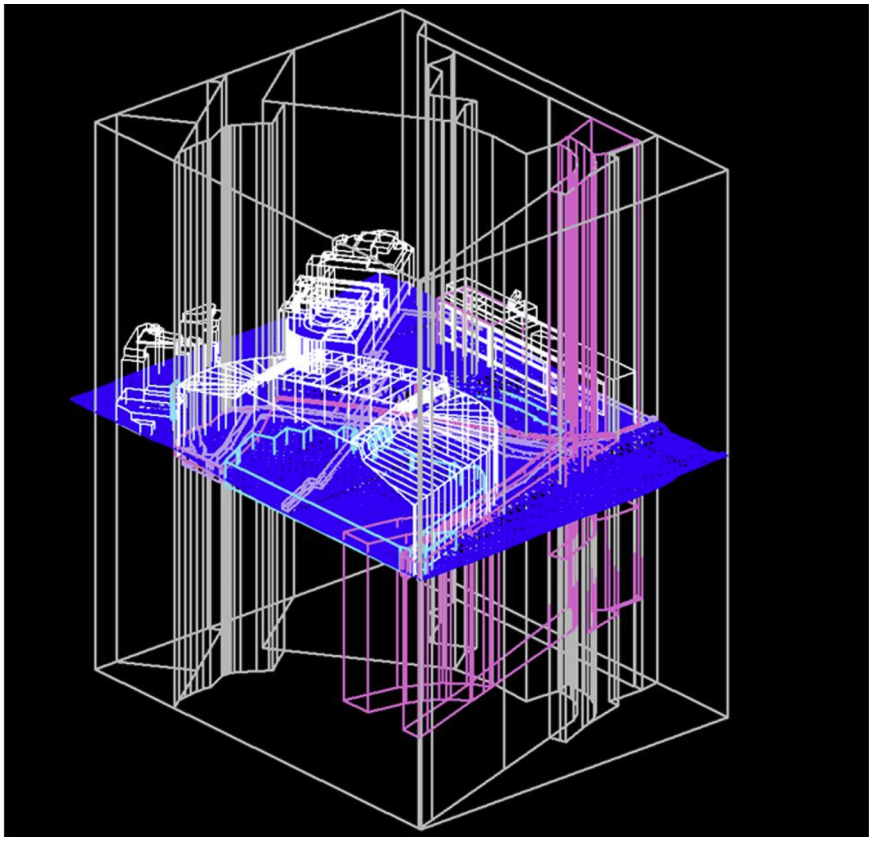

Fig. 9. View of 3D Cadastre Model from 3D-BIM project. (Illustration by Fanny Nordqvist-Darell).

formation (Andrée et al., 2018b, p.43). See Fig. 9.

In the project 'Smart planning, construction and management processes throughout the life cycle' the 3D model created in the 3D-BIM project was further developed into a prototype interactive 3D cadastre, including illustrative possible future connections to the information found in the written property registry, as well as decisions and other information found in archive cadastral dossiers. Since the 2D boundary lines in form of discs were difficult to represent in a visualization without major readability difficulties in the prototype, the 2D-boundaries are represented by lower 'fences' at zero level, as well as a 2D representation at zero level. Easements represented by a point in the 2D Digital Index Map are in the prototype represented by a spherical volume at zero level. For an extract image from the prototype, see Fig. 10.

6. Legal, economic, organizational and competence aspects

The 3D–BIM working group, from the previously mentioned 'Smart Built' project, did not, contrary to the study presented in this article, look at the legal aspects of managing property formation using 3D models *etc.* The group established that a review of existing Swedish property formation legislation is needed before it can be determined whether changes to current laws and regulations are necessary or not in order to enable further use of 3D digital data in the cadastral procedures. However, a newly started project within 'Smart Built' is looking deeper into the legal aspects of 3D digital information as part of authority decisions regarding property formation, planning and building permits. The 3D–BIM working group highlighted the need to investigate how to handle some legal, economic, organizational as well as competence aspects of using 3D digital data in the cadastral process. Some of those issues are described more in detail below.

6.1. Basis for decisions, archives and storage

Current cadastral legislation needs to be examined to determine whether a digital data file could have the same status as a paper document, or if changes need to be made to enable the use of 3D digital information. Another legal issue is that of copyright of 3D models, since when submitting documents to an authority it normally becomes public. The status of digital data in this aspect needs to be investigated.

In order to make cadastral decisions based on 3D digital information it needs to be determined what is the original data file, where it should be saved and who should have access to it. The system needs to ensure the quality and accuracy of the data, as well as that the data cannot be manipulated. 3D data also tends to be big data, resulting in the need of finding a functional way to store the data.

According to Swedish law, documents that are received, created and/or expedited at governmental or municipal authorities are considered public documents, meaning that anyone has the right to access them. Each authority should also keep records of the public documents. For paper documents, it is quite easy to determine what is a public document and what is not. E-mails are considered and interpreted in the same way as paper documents, and routines have been developed as how to keep records of public documents in form of e-mail as well as pdf-files. However, if for example a 3D model in dwg-format is received, it is not clear how to define the file, as well as how to archive it and how the public can get access to it. Could a public document require the public to have certain equipment, *i.e.* a computer and special software, to be able to read a public document? Does a public document have to be possible to get a print out of? Those issues need to be investigated and possible requirements to change current legislation proposed, if that is needed to be able to use data in form of digital files as part of authority decisions.

Copyright is thus another factor that needs to be considered when looking into using 3D digital information as part of authority decisions.

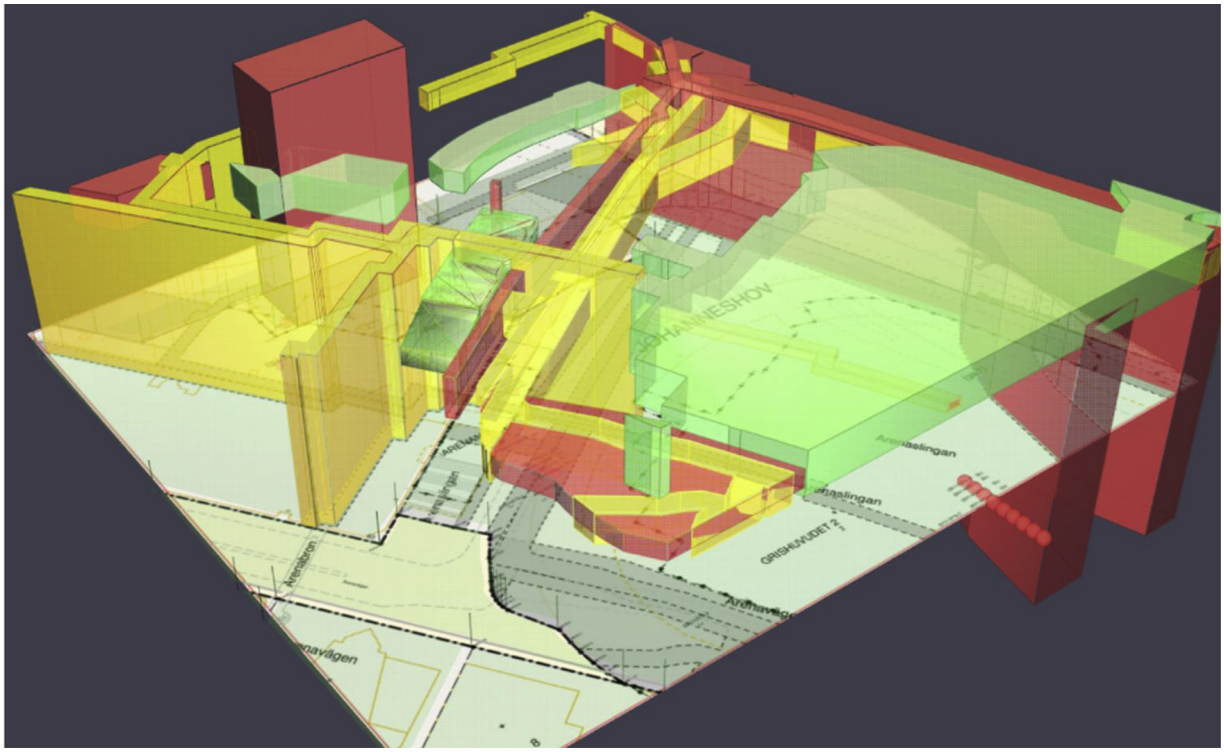

Fig. 10. Extension of 3D RRRs. (Illustration by prof. Stefan Seipel).

If a file consisting of a 3D model is handed in to an authority and/or is used as part of an authority decision, the file is considered a public document. If the architect has copyright to the model, can the two work together? If not, it needs to be investigated what changes need to be done in Swedish legislation in order to facilitate the further use of 3D digital information in authority decisions.

6.2. Accuracy and purpose of a 3D cadastre

The content of the Swedish Digital Cadastral Index Map in Sweden is more and more being published by third parties, without information to the users about accuracy, *etc.* The need to get that information through to the users will be even more important if a 3D cadastre is used. It needs to be decided how to interpret a 3D model as part of a cadastral dossier and also how to interpret and visualize information in a 3D cadastre. Connected to this is the issue of how to interpret detailed planning regulations if they are transformed into 3D models. Today, with 2D analogue detailed plans and cadastral maps there is an interpretation allowance depending on the scale of the document, and the question is if that will disappear with 3D models, or if it can still be included? If it disappears, what effects would that have? Either way, it has to be described how to interpret the models and the users need to comprehend it. Of course, visualization will be of great importance for this.

If the majority of the cadastre contains more detailed information, the full content may be expected to have the same accuracy. This also applies to existing decisions of *e.g.* 3D properties and RRRs, as they never can be represented with the same accuracy as new decisions which are based on a reliable 3D model. How to resolve this needs to be investigated.

6.3. Classified information

Another aspect of transforming a 2D system, that might be more diffuse, to a 3D system, that could be more detailed, is that of classified information. Today, some drawings or a full cadastral dossier can be classified as confidential (*i.e.* not visible for all parties), and only part of the information may then be shown in the index map. Therefore, it needs to be determined how to handle this information within a future 3D cadastre that has the capacity of, and might have the expectation of, showing more details than a 2D cadastre.

6.4. Plan provisions in 3D

Some time ago, the planning documents in Sweden were only in paper format. This allowed, with the 'wide' lines found in the detailed planning map, a certain amount of interpretation. The digital maps have tightened the interpretations a bit. Today, a lot of planning documents are in pdf-format, which also allows for interpretation of lines. However, the more accurate it becomes, the less opportunity there is for the authorities to interpret the regulations as part of decision making.

If planning regulations are decided in the form of 3D volumes, how is it reported and handled in an appropriate way so that there is still interpretation margin in a detailed plan? Or should no interpretation margin remain? What level is then required for investigation in the planning stage to ensure that these lines of regulations end up in line with reality? Is there any possibility of deviation from the regulations if they are decided exactly? These questions need to be addressed and the answers might result in a need of new regulations and recommendations, as well as the choosing of pathway regarding whether there should remain an interpretation margin or not.

6.5. Presentation and visualization of cadastral decisions

Some legal aspects regarding how to present and visualize existing and new cadastral decisions have been identified from the project and have to be discussed and solved. One issue concerns how a register map model should be presented in 3D, *e.g.* if it should be possible to look at this model both as 2D and 3D. It can be discussed whether or not there is a need for 3D presentation in areas where only 2D properties exist and where the rights are clearly defined at ground level. Perhaps the

model could contain certain areas where there is a presentation available in 2D and other areas where it is available in 3D. A related question is if 3D spaces could consist of the maximum volume presented in text in the cadastral register (*i.e.* the maximum area that will get a ground level area at the lowest height and an upper area at the tallest height). This would mean that the exact design of the property boundaries would not be presented, but rather referred to the decision. This would require the possibility for 3D volumes to overlap in the model, as the same maximum space can accommodate more than one 3D space, even if the actual boundaries do not overlap.

Other related questions concern the cadastral decisions made before the 3D model would be introduced, and how the register map model in 3D should present previously decided 3D boundaries and rights. It must be considered if they should be added as some form of standardized volume, or if the model only should be updated when new boundaries and rights are formed and changed. If this would be the case, it has to be decided how this should be clearly reported, *i.e.* that there are *e.g.* 3D spaces presented both as 2D (older) and as 3D (new).

6.6. Economic aspects

In addition to the purely practical possibilities of creating a register model, the question regarding financing must be handled. The presented study has not looked into this, but it is obvious that it must be clarified who is going to carry out and pay for a build-up of a register model and continuous updates and improvements of it. The future proposed process requires more documentation and work than the current process, as well as increased and new competence of cadastral surveyors and property owners (or consultants), which can also result in increased costs, at least initially. It should be discussed and clarified who should pay for this. In all property formation, the property owner must weigh the cadastral costs against profit in *e.g.* market value at completed property formation. Developing 3D documentation can also have management benefits for the property owner after the property formation.

From interviews with parties concerned with 3D property formation the issue of cost and time to process existing 3D objects in the Cadastral Index Map into a 3D Cadastre was raised. The interviews were conducted in projects within 'Smart Built'. The responses indicate, and the authors also believe, that the cost of transformation between systems is higher the higher number of existing 3D units there are to convert. Since the number of 3D properties and other RRRs constantly increase in Sweden, the time and cost of digitalisation of existing 3D RRRs is therefore believed to be lower the sooner such a transformation is conducted.

The economic aspects of a transformation into a 3D Cadastre and the use of 3D data in property formation have not been further investigated in the performed studies and projects within 'Smart Built', and are also not elaborated further in this paper.

6.7. Competence and organizational aspects

CAD and BIM expertise among 3D expert consultants who work actively with 3D assignments is today low in Sweden. This applies to both more experienced consultants and those who recently graduated. This lack of competence combined with a more general lack of cadastral surveyors who are experts on real property development are reasons for why it might take time before there are available surveyors who are both skilled at 3D property formation and at CAD and BIM. However, there are good possibilities to overcome this shortage in the long run, if demands for more advanced digital documentation in connection with the implementation of 3D property formation will be introduced. Lack of knowledge about BIM is generally large in municipalities and, above all, in smaller municipalities, since it has not been required to handle BIM models to any great extent.

7. Problems and challenges

Despite the fact that 3D digital information is used in the real property formation process, it is still the case that the 3D properties are registered using two–dimensional documentation. There are problems and challenges related to this when it comes to converting 2D analogue cadastral boundary plans into 3D digital information.

The cadastral process concerning new 3D property formation usually includes, as mentioned, the developer/entrepreneur to supply a CAD file containing 3D real property boundaries. However, the 3D cadastral representation and connected documentation in the cadastral dossier is still recorded in 2D (El-Mekawy et al., 2014). Since the CAD file might not be archived for future use by the cadastral authority, it might be necessary to interpret the 2D data and convert it when using it in a three-dimensional environment such as BIM.

It might be a challenge for the applicant to illustrate the intended boundaries, rights, joint facilities, *etc.* in a comprehensible way for the property units that are involved. It can, for example, be difficult to accurately present a 3D volume only by using 2D drawings. It is also difficult to read and interpret a cadastral index map in 2D when the included properties and rights are determined in 3D. Interpreting and converting the data will be even more difficult when the 3D property formation is based on building drawings from, perhaps, the late 19th century where the boundaries are drawn by hand.

Due to the fact that there are no standard requirements on how to present the data, when it comes to actuality, quality, 3D basis, *etc.*, disputes may arise due to unclear documentation. If data is produced in varied design and quality, difficulties in obtaining consistent decision and registry support may occur. This can complicate both interpretation and future management, and will also lead to costly processes for the property management.

The current registration of boundaries in the Digital Cadastral Index Map involves only overview illustrations of the boundaries and it does not allow any detailed visualization. When collecting data from both the 2D analogue cadastral boundary plans and the descriptions based on text, it may be difficult to interpret some of these plans and/or text. The different ways of interpreting the information have to be made as clear when interpreting it from a 3D digital image.

The fact that the digital index map contains many existing registered real property boundaries, as well as easements and other rights with poor or uncertain accuracy, may also cause problems, since it will be difficult to discern and interpret all information in such cases. In addition, there may be major errors and various accuracy in regard of actual location in existing detailed plans and other regulations compared to what is shown in the index map, also depending on the original legal document.

Another challenge to consider is how to connect the 3D digital information to the legal decisions and cadastral procedure. One step in this process is to convert all necessary parts of the cadastral map into 3D, but other further steps that might be taken are to make all decisions connected to and visible in the 3D digital information. The large amount of text related to the cadastral decision that is not present on the drawing will not be possible to transfer to a digital image by digitalization and automatization.

Apart from the more technical and legal aspects, there are also economic issues that have to be addressed. It can be noted that the number of 3D real property units has been increasing ca 9–13% annually during the last three years, and a total of 2329 units were registered in the Real Property Register on December 31 st 2018 (Lantmäteriet, 2019). Considering this increase, it could also be expected that the costs for digitizing already existing 3D property units therefore also will increase in the future, unless new and more efficient ways of registration are not implemented.

A question related to this is how to include previous decisions in the system, how it should be possible to interpret the information in these decisions, how to deal with the legal issues, *etc.* So, the question would

be how a register map model in 3D should present previously decided 3D boundaries and RRRs, *e.g.* if they should be added as some form of standardized volume, or if the model only should be updated as new boundaries and RRRs are formed and changed. It must also be discussed how this can be clearly reported, *i.e.* if there are 3D spaces reported both as 2D (older) and as 3D (new). Furthermore, how should RRRs that have no area or exact location represented in the 2D Digital Index Map be represented in a 3D Cadastre? Questions arise here regarding what the chances are of the user of the 3D Cadastre not realizing that there can be existing RRRs within a certain area that are not visible, even though everything else seems to be represented as 3D volumes that appear to be very exact.

This study focuses on digital representation and data capture of analogue 3D legal boundaries and transferring them to digital vector based format, and the visualization of them. The study has shown that it is not a simple task to interpret and register textual legal information, as described above. This study focused on manual data capture, but in order to achieve any automation in the data collection process for existing 3D properties and the formation of new 3D properties it is advised to carry out cost-benefit analysis and decide what types of RRR should be registered in 3D. An additional aspect is that an improved digital cadastral process can be a step towards the increased automation and automated decision making. See *e.g.* Hjelmblom et al. (2019) for an example of a structural and logical analysis of a part of the Swedish real property formation process.

8. Conclusions

This study has presented a way of converting 2D cadastral information into 3D and finding new processes for using 3D digital information in future property formation decisions. In connection with this, it has revealed some problems and challenges related to the conversion of 2D analogue cadastral boundary plans into 3D digital information.

From the results of the study, it could be discussed further whether it could possibly be more effective to register 3D boundaries and volumes in the national cadastral index map using indoor building plans showing internal walls, beams and other details being subject for 3D property formation. Further the study suggests that the cost of transforming existing 3D property units into 3D volumes in a 3D cadastre most likely is smaller the sooner such a transformation is made, since new property units are registered continuously creating more and more objects in need of transformation, the further ahead a change into a 3D cadastre is conducted. The possible cost-efficiency would also be in line with the aims of the Smart Built project to decrease costs in the processes.

It is time-consuming to analyse and register 3D boundaries in existing cadastral dossiers. Cost-benefit analysis have to be made as part of development and management. The cadastral formation and registration processes should be further developed to register and present 3D digital boundaries as volumes.

Current legislation has to be investigated and interpreted to be able to add or transform into using 3D models as part of cadastral decisions in Sweden. New regulations also may have to be introduced and analysed. In this paper, some of the legal issues that need to be addressed are mentioned, however, more work needs to be done in order to obtain answers to what changes may be needed regarding legislation on this matter.

9. Recommendations

Sweden does not yet have a fully 3D digital cadastre, but if such a cadastre is to be developed, it is recommended that 3D registration in a 3D cadastral index map is done in connection with the property formation process. Until then, the digital CAD files often used in the 3D property formation process today by the cadastral authorities are to be stored and used instead of 2D plans in order to avoid loss of legal information which may be difficult to interpret afterwards. The results of the study also indicates that legal issues need to be investigated before a 3D cadastre and 3D models as part of cadastral decisions can be introduced.

A precondition for the above–mentioned recommendations is a political will and need in society to create a full 3D cadastre. This seems not to be the case in the near future, since the existing technical and infological solutions are working well. However, the continuous digitalization of society, and, for example, the evolving concepts of smart cities, are in our view indications for the coming need for a better cadastre to meet the needs in a more digitized society.

9.1. Future research

Further research in this matter is already ongoing in a project that will involve practical tests according to specifications identified and focusing on visualization of 3D property. A model for digitization and visualization of 3D property formation will be tested in a test bed environment, where the described case study will be used in order to see how it could work in practice. Additional cases should also be tested further on to capture different types of property situations and investigate how they can be included in the proposed recommendations. Long time archival of preservation of 3D cadastral information is also recommended as a subject for future research, as well as economic and legal aspects of a 3D cadastre.

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