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A Proposal for a Level of Implementation Framework

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Key words: 3D cadastre, multi-level property registration, research-to-practice

SUMMARY

During the past decade, hundreds of research papers have been published on the challenge of registering multi-level properties in land administration and cadastral registrations. In addition, many pilots have been carried out to show potential solutions. However, fundamental and standardised solutions for 3D cadastre are still rare. In this article we analyse the reasons for few 3D cadastre solutions in practice and we propose a 3D cadastre definition framework that can distinguish between different levels of 3D cadastre implementation depending on a specific context. Based on a level of detail logic, it supports an incremental pathway for the implementation of 3D cadastre solutions. We list the scope of the framework and finish with conclusions and future work.

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1. INTRODUCTION

3D digital cadastre solutions for multi-level property situations have been studied for more than 20 years. While such 3D innovation is perceived to deliver public value (Ho, Crompvoets, and Stoter, 2018), sustained adoption by land registries and governments is still rare. Instead, a business-as-usual approach prevails as surveying drawings have evolved to keep up with architectural complexity alongside an increasingly liberal use of various extant legal instruments (e.g. easements, common property) to help ensure a multi-ownership building can be lived in and enjoyed reasonably independently by its tenants.

Most jurisdictions contain a variety of real rights to establish multi-level property but there is no clear framework for multi-level properties, specifically since there are many different types of multi-level properties. Over the years, as complicated 3D property rights become the norm in urban contexts, solutions to register and clarify the legal situation – so that it is unambiguous – have been sought (Stoter, Ho, and Biljecki, 2019). Practice-based approaches from land registries have provided a range of options, for example: (optional) verbal descriptions and sketches in deeds; recommendations for revising legal prescriptions for survey plans (including floor plans and cross sections) for apartment rights registered as strata titles; tags on 2D cadastral maps, cross sections or isometric overviews in other documents.

Research, however, has provided a much broader range of potential solutions and many of these deal with the technical aspects such as data management (Višnjevac et al., 2019), data modelling (Cemellini et al., 2020), and data querying (Behnam Atazadeh et al., 2019). Attempts to translate research to practice is also evident in the range of pilot studies that have been undertaken. Some examples include pilots in The Netherlands (Stoter et al., 2017), China (Guo et al., 2013), the Australian states of Queensland (Smart & Priebbenow, 2018) and Victoria (Shojaei et al., 2018) and Korea (Jeong et al., 2012).

These are only a fraction of the numerous pilots and prototype studies published in the literature. Regardless, very few – if any – of these have been extended into real structural 3D cadastre implementation in practice. From what can be seen in the literature, it can be argued that most of the proposed solutions not only remain theoretical, they are *ad hoc*; thus, different approaches emerge for similar situations. What this means is that for those jurisdictions seeking to learn from and leverage other countries' experiences, it is not always apparent how best to match current problems to proposed solutions.

This is the main issue that has been driving 3D cadastre research over the past twenty years and many solutions have been proposed to provide better insights in multi-level situations.

Research has shown the possibility of 3D representations that can be included in different parts of the registration (as part of the deed and varying from 3D surveys to interactive 3D visualisations in PDFs; in the cadastral map; or with a tag in the cadastral map that opens a 3D visualisation). Additionally, most research efforts have been focused on the technical potentials; rarely has research in the 3D cadastre domain addressed how technical solutions can be institutionalised in legal, organisational, and professional procedures.
Therefore, despite significant research in this domain, and a multitude of pilots, there remains a significant gap between research and practice that is yet to be bridged.

The aspects to consider for a 3D digital cadastre approach are diverse and therefore to adopt a 3D cadastre approach in practice is not straightforward. Apart from technical innovations, there are multiple types of multi-level property situations and resulting property rights to be considered. There are standardised mandated legal prescriptions in current legislation to be considered as well as non-standard individual interpretations. There are the non-legal representations to be considered (e.g. the property map) that enables 3D cadastral data to be represented in a format that is easily understood by the broader community. Finally, there is the information workflow that determines how cadastral data is produced, and how this might be related to the production of other types of property data in multiple ownership buildings. These multiple considerations reflect different needs, perspectives, and expectations. 3D cadastre solutions may still be rare in practice because **there is not a single definition of what a 3D cadastre should be and therefore, there is also no single solution that fits all purposes**. The use of one, single term obscures (and has obscured) a wide variety of problems and needs.

To respond to this problem, this paper aims to propose a Level of Implementation (LoI) framework to provide a uniform, refined definition of the 3D cadastre concept. This framework draws on the Level of Detail (LoD) work of Biljecki et al (2016) and it is extended to allow us to think through incremental solutions for adoption and implementation that better addresses the degrees of legal possibilities and (even more) degrees of technical possibilities of 3D cadastre implementations. In this way, the framework can offer a way forward to match specific 3D cadastre solutions to specific legal, technical and organisational contexts and will allow us to more clearly consider policy and regulatory implications, thus bridging the research-to-practice gap and enhancing scalability. This will also contribute to the ability to have a discussion around more feasible innovation, implementation and institutionalisation pathways.

In this paper we provide justification and present initial ides for the LoI framework. For this, we analyse the possible reasons for few 3D cadastral solutions in practice in Section 2. Based on these findings, in Section 3, we give a definition of 3D cadastre that enables us to propose a scaled implementation framework for a specific 3D cadastre context (technical, as well as legal and organisational/institutional). We close with conclusions and future work.

2. POSSIBLE REASONS FOR FEW 3D CADASTRE IMPLEMENTATIONS IN PRACTICE

The FIG publication "Best Practices 3D cadastres" (FIG, 2018) provides a good overview of the state-of-the-art of 3D cadastres from different perspectives. The chapters "legal foundations" and "initial registrations of 3D parcels" describe the current state by comparing 15 jurisdictions representing 7 countries (provinces/regions). They indeed conclude that current cadastral recording does not involve 3D representation or recording within a full 3D object model. Possible reasons mentioned are that definitions of a 3D cadastre are not consistent and that many involved professionals are not familiar with 3D real property concepts which hinders the implementation of 3D cadastre.

In this section we further analyse the possible reasons for few structural, 3D cadastre solutions in practice.

3D cadastre needs are diverse and context dependent…
A reason for few 3D cadastre implementations in practice is the variance in needs for a 3D cadastre. These needs can vary a lot per country depending on their point of departure, context and/or pathway. For example: a combination of floor plans or a sketch may be significantly helpful in understanding the property situation if no other registration or technical knowhow is at hand (it is estimated that 50% of private land in capital cities around the world is unmapped or unregistered (Deininger, 2018)). On the other hand, expectations regarding "clear information" in jurisdictions that already support the definition and surveying of 3D parcels are most likely higher. The authors of the FIG publication confirm the variation in needs of 3D cadastre by concluding that more extended research, including African and Asian countries, would be of great benefit to 3D cadastre research and the establishment of national 3D cadastres.

…and therefore the concept "3D cadastre" has not one single meaning
Extending the argument above, another hurdle for 3D cadastre implementation is that there are multiple needs that have been conflated in the concept of 3D cadastre, as we can conclude from looking at the literature of the past decades (see for example the two-yearly workshop series by FIG on 3D cadastre). This makes the definition ambiguous and this does not provide one solution to the problem. We argue that within the concept of a 3D cadastre as a digital product, three key aspects of the problem can be distinguished:

1. Registration of multi-level property with real rights.
2. Spatial representation of multi-level property rights i.e. (a) legal plan drawings (registered in land administration systems) that collectively make up the cadastre, as well as (b) the non-legal representation of a spatial index to 3D rights, i.e. cadastral/property map/digital cadastral database (DCDB).
3. (Re)Usability of cadastral data for future changes in the registration as well as for decision-making in the built environment, from re-establishment of 3D boundaries to other more complex tasks.

(1) and (2a) have a legal aspect. Countries who cannot currently do these will necessarily have the legal question as core to their change pathway (Ho et al, 2013). The FIG report described indeed that the few case studies where although 3D cadastre legislation has been established (Victoria, Queensland, and Sweden), there was a need to re-define real property in 3D space using unambiguous 3D terminology as well as the establishment of legal instruments to subdivide, consolidate and manage 3D real property in 3D space.

On the other hand, for those able to do (1) and (2a) with current legal instruments, legality is not a serious issue. The problem of implementation stems from trying to get from (2) to (3) and making the business case to do so. Countries are reverse engineering – to see what is possible or how to do (2b) and then working backwards to see how this affects (2a).

There is perhaps also an assumption that a 3D cadastre must be a universal initiative, i.e. the whole cadastral system evolves from 2D to 3D. This is not necessarily the case. For although most countries have high value urban centres that can benefit from a 3D cadastre, they also have large tracts of peri-urban or rural land where implementing a 3D cadastre does not present a realistic value proposition (although a country like Singapore may be an exception). Indeed, there are few studies that have looked at how a 2D and 3D system can exist in parallel. In conclusion, the term '3D cadastre' implicitly covers a lot of different needs that are context dependent and this context-dependency has had little attention to date.

Proposed standardisation solutions do not solve the fundamental 3D cadastre issue
Standardisation solutions have been suggested in studies to support the implementation of 3D cadastre in practice, for example LADM, CityGML, LandInfra/InfraGML (that supports land divisions in 3D), and IFC (for data in the Building Information Modelling domain). Examples are found in Lee et al (2015); Vučić et al (2017); Rönsdorf et al (2014); Atazadeh et al (2017; 2019); and Tarun et al (2019).

Standards enable exchange of 3D data representing property units and they provide data models to store these data, an important condition for implementation. However, proposed standardisation solutions also have not closed the gap from 3D cadastre research-to-practice for several reasons.

Firstly, the main issues of 3D cadastre are not related to a lack of interoperability or lack of a data model. A data model or standard can express the 3D data that is needed for 3D cadastre, but first it requires determination of what data is needed, how this data is collected, validated, certified, etc., that is: there are professional, organisational and process implications. This is often not clear and may vary between jurisdictions. Failure to consider these aspects also leads to underestimation of the inherent politics of coordination.

Secondly, there are now multiple studies that have developed standards-based solutions for 3D cadastres, or have shown the potential of exchanging data across domains (e.g. tenure and property) using those standards. While the solutions work well on (controlled) prototypes and on data sets specifically created for the purpose to populate the data model with data, in reality, these data models and standards face problems. For example, in practice for some of these standards, few data sets exist (i.e. InfraGML); the software support is limited and standards are too flexible and need profiles to enforce standardised data for 3D cadastre purposes (CityGML, IFC); editing functionality to easily structure the data according to the proposed standard/profiles and assign the required semantics is missing; and, data sets produced in practice still contain errors (IFC, CityGML) which makes it difficult to use them directly in downstream applications such as 3D cadastre (Biljecki et al, 2016b).

One increasingly studied standardisation solution for 3D cadastre is the use of IFC to define 3D cadastre-related concepts (e.g. (Atazadeh et al., 2017; El-Mekawy & Östman, 2015; Oldfield et al, 2017). However, this does not address the 3D implementation issues as listed above. Although IFC data could be the source for the 3D property unit (and this can be specified in an IFC-data model), it still requires a (n authorised) person to convert the BIM model that commonly consists of thousand volumetric elements in IFC to a few 3D property units modelled with their outer shells and structure it according to the proposed standard/profile. In this conversion, cadastre-related decisions need to be made that are not solved by providing a BIM-based 3D cadastre data model to technical drawers. These decisions cover questions such as which surface from a wall (left, right, inner) represents the property boundary, how to draw the property boundary if the property unit is not bounded by a physical element at all and how to assign the 3D cadastre-standard compliant semantics.

Some of these aspects are currently prescribed in legislation, but not all. Also, the designers of the original BIM data may be reluctant to share the original BIM data because of copyright issues or building contracts may prevent this. Therefore, it is likely that data sharing may only extend to 3D property units once generated and therefore a link to the original BIM data model is not needed (or even wanted). A final issue that is not solved by BIM-based data models for 3D cadastre is that the as-built situation is not guaranteed to be consistent with the data submitted to the cadastral registration. The design may have been altered in a later phase or even changed during the construction phase which is rarely fed back in the original data. The question of how to guarantee the juridical validity of the 3D property units in this lifecycle needs to be answered when using a BIM-extended data model for 3D cadastre implementation.

In conclusion, 3D cadastre as well as BIM-related standards offer potentials for 3D cadastre implementations, as shown in literature. However, for 3D cadastre implementation in practice, the professional, organisational and process implications need further attention.

From controlled pilots to real practice: dealing with uncertainties

Research and pilots on 3D cadastre have mainly focused on showing the technical potentials. However, technical inventions - such as regarding 3D geo-information in general and 3D cadastre specifically- that look promising in (controlled) prototypes and pilots, may encounter problems in practice where they have to work for any case.

In contrast to controlled academic or pilot environments, in practice there are many different professionals involved (technical, cadastral, and legal) and often these professionals are not all familiar with 3D real property nor cadastral concepts. Therefore, it is not always apparent

how best to match problems from practice to technical solutions that have been proposed in research and/or pilots. An implementation in practice cannot only be limited to a technical solution; instead it should also address how the technical solution operates in a legal and organisational context and this is often still unclear. There are, for example, uncertainties about costs/benefits and uncertainties about who is legally responsible for what kind of 3D cadastre information (BIM based; surveys; sketches; 3D geometries describing right-volumes).
An important uncertainty is caused by the (often still unknown) interaction between technical with legal and organisational/institutional aspects. From the legal perspective, the main purpose of laws and other juridical guidelines are to minimise risks (and hence, costs) in transactions and prepare for the worst (e.g. disputes). And from this perspective, current practice for multi-level property registration (that has been practised for decades) works and there is reluctance to change without having 100% control on the impact; whereas technical developments focus on improving (i.e. changing) the solutions to optimally support changing needs, expectations etc, accepting uncertainties that come with these developments (or even seeing them as challenge).
Such uncertainties and how to deal with them have received little attention in research that studied the potentials but become relevant when it comes to real world implementation in a specific country or jurisdiction.

In conclusion
In this section, we analysed the reasons for poor 3D cadastre implementation in practice. From this we can conclude, that the structural implementation of a 3D cadastre solution in practice requires a more precise definition of the concept of a 3D cadastre in relation to the problem it needs to solve, its (registration) workflow, specifications and validation mechanisms as well as understanding how this interacts within the specific legal and organisational context. To address this issue, we propose a context-dependent definition of 3D cadastre based on a level of implementation framework in the next section.
The proposed framework offers specific implementation solutions for specific multi-level property situations considering technical, legal and organisational and wider urban 3D data aspects.

3. CONTEXT-DEPENDENT DEFINITION OF 3D CADASTRE REFINED IN A LEVEL OF IMPLEMENTATION FRAMEWORK

To bridge the gap between research (driven by showing technical possibilities) and practice (where legal and policy context play a role as well and where technical conditions are different than in a research environment), we propose a policy/practice Level of Implementation (LoI) framework for scaling 3D cadastre solutions to facilitate implementation following a Level of Detail (LoD) rationale that is practiced in the 3D city modelling domain.

The support of LoDs in 3D city modelling (with its origin in the open standard CityGML (OGC, 2012)) enables to represent objects at different geometric and semantic level of detail to meet different data needs of different applications.
For example, a building (see Figure 1) can be represented by a surface representing the footprint or roof-edge at LoD0; by a block model at LoD1 usually obtained by extruding an LoD0 model; by a model at LoD2 with roof shapes and possibly semantics assigned to parts of the building (e.g. roof, wall); at LoD3 by a model with windows and doors; and at LoD4 also including indoor features. Biljecki et all (2016) refined this model to provide a stricter specification of these four Levels of Detail into sixteen levels to allow less modelling freedom in order to improve implementation.
The LoDs of 3D city models increased the use (and therefore value) of 3D city models in practice by linking the geometrical and semantical content of a city model to a specific context (i.e. applications) and to make this explicit in a definition framework. This is our motivation to apply the LoD rationale to the 3D cadastre domain to improve uptake of 3D cadastre implementations in practice.

Figure 1: The five levels of detail of CityGML 2.0 (taken from Biljecki et al, 2016)

Context-dependent definition of 3D cadastre
Given this motivation and analysis in Section 2, we refer to '3D cadastre' as the ***legal possibility*** to establish multi-level property, the ***technical possibility*** to represent the property situation with digital 3D information, and the ***organisational possibility*** to implement 3D cadastre as a mainstream product and data service.
This conceptualisation explicitly acknowledges different degrees of implementation that reflects the context and conditions of the implementing jurisdiction. Hence, there are degrees of 'legal possibilities', degrees of 'technical possibilities' and degrees of 'organisational possibilities'. For example, a '3D Cadastre lite' consisting of a tag in the registration, can provide important insight into multi-level property situations in countries where urbanisation rate is high, but technical knowhow or digital level of 2D registration is low. Because 3D cadastre solutions can vary in the extent they support both legal and technical possibilities, we define the aim of a 3D cadastre as: to establish and represent the legal situation of multi-property **as clearly as possible given the specific context**.

Refinement of the 3D cadastre definition in a LoI framework
Based on this general definition of '3D cadastre', we will refine it in a LoI framework. This will enable a way forward to match specific 3D cadastre solutions to specific legal, technical

and organisational contexts and will allow us to more clearly consider policy and regulatory implications, thus closing the research-to-practice gap.

The framework defines implementation solutions at increasing impact levels for legal, technical and organisational aspects resulting in a matrix. Figure 2 shows the matrix as conceptualisation of the LoI framework.

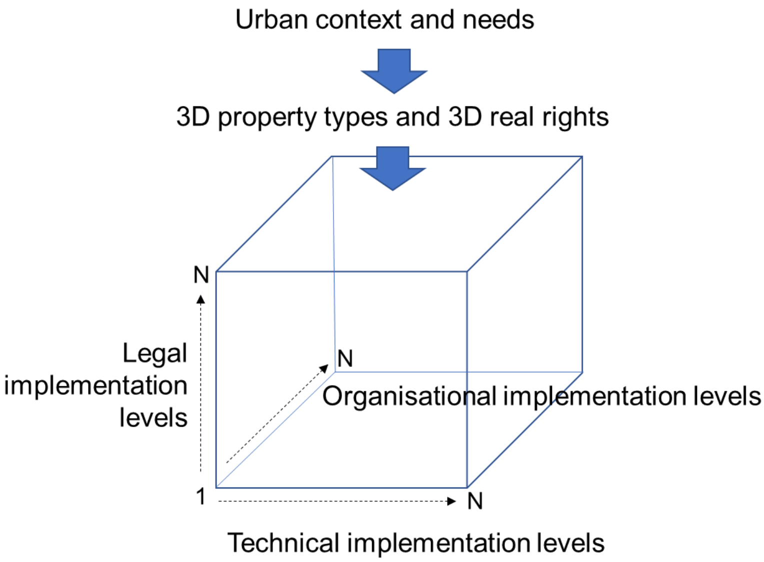

Figure 1. Draft LoI framework concept

The axes of the matrix represent:

Legal implementation levels: e.g. how to legally establish (define) and register the property rights for multi-level property situations (in which different types of such situations can be distinguished) ranging from using (recommended or not) traditional legal instruments to developing new legal instruments to accommodate 3D properties (and 3D parcels).

Spatial-technical representation implementation levels: e.g. how to spatially represent the 3D boundaries in the land administration and cadastral registration, ranging from simple sketches and verbal descriptions in deeds/titles to 3D surveys and BIM based solutions, the most advanced solutions including data responsibilities, validation, etc. with corollary data management tasks based on international standards (e.g. ISO definitions of geometry).

Organisational implementation levels: e.g. how to manage, use and disseminate the information within the organisation, across government and to the public, ranging from tags, cross sections, and georeferenced floor plans in 3D to interactive 3D visualisations and eventually providing the 3D boundaries (i.e. geographical data) of the property units as data.

4. CONCLUSIONS AND FUTURE WORK

In this paper we identified a gap between 3D cadastre research and its implementation in practice, and analysed the causes for this gap. In order to bridge this gap, we propose a definition framework for 3D cadastre following a level of detail/implementation logic that defines specific solutions for context-specific multi-level property situations at a certain legal, cadastral, and technical degree of implementation. The framework consists of a matrix with axes that represent increasing implementation levels for the three aspects (i.e. legal, technical and organisational) and enables incremental implementation of 3D cadastre following feasible pathways.

In the next step of our research, we will identify the specific levels per axis by determining in detail the implementation solutions of the different axes (for different property situations). To investigate the combinations of the different axes - constraining certain combinations that make sense, rather than allowing all - we will also investigate use cases and locate them in the matrix. This will help us to refine the initial setup of the matrix as represented in this paper with respect to fitness-for-practice. The LoI framework will match specific implementation solutions to specific 3D cadastre problems in order to make implementation more feasible and bridge the gap between 3D cadastre research and practice.

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BIOGRAPHICAL NOTES

Jantien Stoter chairs the 3D Geoinformation research group at the university of technology in Delft. She also works as innovations researcher at both Kadaster and Geonovum. Jantien did her PhD on 3D Cadastre (2004), received a personal grant from the Dutch Science Foundation on 5D modelling (2011) and was awarded a grant from the European Research Council for her current research on urban modelling in higher dimensions.

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