3D Property Ownership Map Base for Smart Urban Land Administration

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SUMMARY

Most governments provide property ownership map bases as an enabling infrastructure for decision-making. These map bases represent the most complete, authoritative graphical representation of land parcel and property boundaries (cadastral information) - an invaluable source of intelligence to support land and property decision-making across government, businesses and communities. Current property ownership map bases only represent 2D land parcels and omit an array of property objects that are vertically located: apartments, tunnels, underground shopping malls, car parks and utility networks are common examples. The implications are significant, particularly in urban areas due to the density of development.

This paper presents solutions for accommodating 3D data derived from regulatory urban subdivision processes into the current 2D property ownership map base. Considerations in institutional aspects are discussed, technical specifications for incorporating spatial information about 3D property rights, restrictions and responsibilities (RRRs) into the map base are identified, and finally, policy recommendations around transforming current 2D-based work processes to support a digital information environment are outlined.

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1. INTRODUCTION

Most governments provide property ownership map bases as an enabling infrastructure for decision-making. These map bases represent the most complete, authoritative graphical representation of land parcel and property boundaries (cadastral information) – an invaluable source of intelligence to support land and property decision-making across government, businesses and communities. Current property ownership map bases only represent 2D land parcels and omit an array of property objects that are vertically located: apartments, tunnels, underground shopping malls, car parks and utility networks are common examples. The implications are significant, particularly in urban areas due to the density of development, for example:

- Additional surveying work often required at cost to businesses to overcome knowledge gap.
- Development of proprietary databases that result in data duplication, which:
- Incurs costs, e.g. in Victoria, such duplication is estimated to cost $1.8 million annually (Sinclair Knight Merz, 2011).
- Undermines governments' reputation as providers of critical spatial information infrastructure and erodes community's trust in, and expectations about their services.
- Unforeseen damages – especially to underground assets – during development, such as:
    - More than 30 incidents around asset damage are estimated to occur every year in Victoria, Australia alone due to misalignment of the map base and infrastructure locations provided by authorities from their own proprietary information.
    - An incidence of unintended contact with underground fibre cable in Sydney resulted in $1 million worth of damages and business disruption costs of around $30 million.
    - Failure to support decision-making: the lack of 3D representation of properties has impacted on the rollout of the National Broadband Network for multi-storey properties.

How can we make smart decisions about planning and managing our urban environment if the map base does not include 3D representation of above and underground properties and infrastructure, which dominate the urban setting?

This paper deliberate on this shortcoming. It aims to identify solutions for accommodating 3D data derived from regulatory urban subdivision processes into the current 2D property ownership map base. This will facilitate the delivery of a 3D property ownership map base for smart urban land administration, responding to core business objectives for many governments around the world. Fundamental and applied research agenda in both technical and institutional aspects will be discussed to propose technical specifications for incorporating spatial information about 3D property rights, restrictions and responsibilities (RRRs) into the map base, and policy recommendations around transforming current 2D-based work processes to support a digital information environment.

2. CHALLENGES

A range of research has been, or is currently being undertaken into modelling 3D property objects, but this has mainly focused on legal registration purposes (Shoshani et al, 2004; Ying et al, 2011; Elizarova et al, 2012; Aien et al, 2012; Shojaei et al, 2012). Current methodologies around defining vertically delimited property objects vary around the world according to local registration legislation. In many countries, 3D property objects are often indexed in relation to its 2D land parcel, but in others, they are recorded separately (Dimopoulou & Elia, 2012).

Post-registration, 3D data about properties and infrastructure should be integrated into the 2D map base; however, this requires an upgrade so that 3D data can be recorded, retrieved and maintained, which requires substantial development work. To facilitate this development several key research questions, need to first be addressed:

2.1 How can 3D RRRs be validated before integration into a 2D-based property map base?

There are many cadastral data models that have been developed for land administration purposes and amongst these, those which can support 3D RRRs include the Land Administration Domain Model (LADM) and the 3D Cadastral Data Model (3DCDM). These data models have different methods of representing 3D RRRs (Peres and Benhamu, 2009) e.g. LADM uses a multi-surface approach (Pouliot et al., 2011, 2013) while 3DCDM utilises both multi-surface and solid models for modelling the geometry of 3D spatial objects (Aien, 2013). Other methods include solid models, which can facilitate visualisation of 3D RRRs (Jarroush and Even-Tzur, 2004) and enable volumetric computations and various 3D analyses required in land administration (Navratil and Fogliaroni, 2014). The common shortcoming for all the proposed methods is that they remain as conceptual data models: theoretically, they can model 3D RRRs but the approach into the validity check of 3D objects constructed by these data models have not yet been substantially examined. To enable the integration of 3D RRRs into the current map base, the first research challenge to emerge is around ensuring data integrity.

2.2 How can invisible (in real world) boundaries of 3D RRRs be spatially analysed in relation to associated physical boundaries?

For governments to retain the authoritative nature of the map base, 3D RRRs must be unambiguously represented, as is the nature of property ownership in reality. Representing 3D RRRs requires a different methodology to that used for other 3D spatial objects due to the way 3D boundaries are defined by legislation, but also complicated by its relationship to physical objects. 3D boundaries can also be defined using building structures/infrastructure (see Figure 1), which brings into play the need for defining spatial relationships between 3D RRRs and building elements (e.g. walls, floors, ceilings, etc). The second research challenge is spatial relationships.

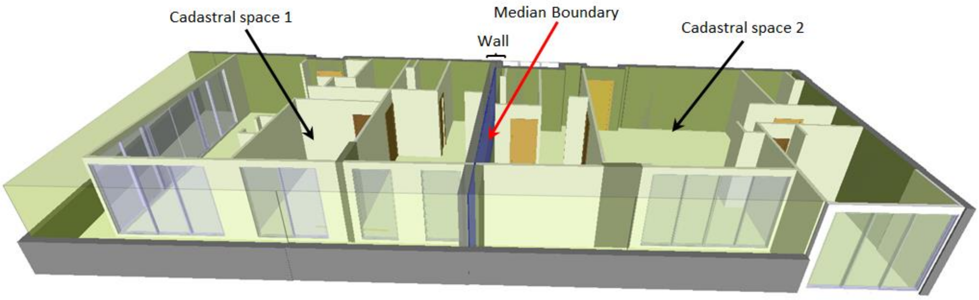

Figure 1. Example of ownership boundaries defined by building structures.

2.3 How can the community of users utilise information about 3D RRRs and associated physical components?

Efforts in applying 3D information and communication technologies to better represent and manage vertically located property and infrastructure has been challenged by a range of social and organisational issues. Primarily, there is a longstanding view that the absence of an appropriate legislative framework has been the main obstacle (Banut, 2011). Since van der Molen (2003) first argued the importance of investigating institutional issues more than ten years ago, there has been little research undertaken to develop this aspect of the research agenda. Recently, a review on relevant literature by Paulsson and Paasch (2011) demonstrated a clear imbalance in current research efforts, one that has been biased towards technical initiatives to the detriment of progressing the range of non-technical issues pertaining to 3D innovation. The importance of addressing institutional issues has been a recurrent theme throughout the history of technical innovation (e.g. Giddens, 1984; Pinch and Bjiker, 1987) since the challenge of innovation is not only in creating new physical products, but also the development of supporting processes (Henfridsson et al, 2009). Therefore, the third research challenge is inherently an institutional one.

3. SOLUTIONS

This section addresses these challenges by proposing new methodologies in enabling digital integrity and analysis of 3D RRRs and provide the requisite data architecture that the inclusion of 3D RRRs in the property map base is predicated on. This directly addresses fundamental deficits in a core land administration tool and represents a significant step towards decreasing the risks associated with using the map base for decision-making and improving social and economic outcomes for countries.

3.1 Develop authentication guidelines for spatial integrity of 3D RRRs in properties and infrastructure.

3D property objects can be represented using different geometrical shapes including polyhedron, regular polytope, triangulated irregular network, tetrahedron, constructive solid geometry or boundary representation (Karki et al, 2012). One solution is to adopt the boundary representation recommended by LADM as the international standard for the land administration domain and develop axioms for engineering validation rules accordingly. Samples of the axioms are discussed below using the Figure 2. In the figure, a node is a point that represents an edge; an edge is a line that connects two nodes, a face is formed by a simple cycle of directed edges and may include a hole, a hole is defined using a face. A property is then defined by a set of faces and a set of closed holes. An axiom for a 2D land parcel validation is that a node is defined by interesting two boundaries. Extending this axiom into a 3D space, in a 3D object, each node must have at least three incident faces. Based on the axioms spatial integrity rules specific for 3D RRRs can be developed. Every 3D RRR before entering the map base must pass the integrity rules. For instance, a rule will be that edges used in each 3D RRRs must be directed, must not cross over other edges within each face of the RRR and all faces of a RRR must close. One then can apply this rule to all created and extinguished properties, easements and common properties before updating the map base.

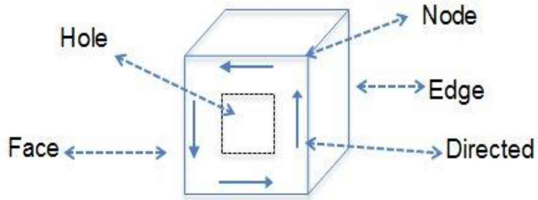

Figure 2: Samples of validation axioms

3.2 Engineering spatial relationship for analysing boundaries of 3D RRRs in relation to physical boundaries.

The legal and physical object proposed by (Aien 2015 et al) and the 9-intersection model by (Egenhofer and Herring, 1990) to define spatial relationships can advance the 3D RRR boundary analysis.

$$I = \begin{bmatrix} A^o \cap B^o & A^o \cap \partial B & A^o \cap B^e \\ \partial A \cap B^o & \partial A \cap \partial B & \partial A \cap B^e \\ A^e \cap B^o & A^e \cap \partial B & A^e \cap B^e \end{bmatrix}$$

Figure 3. 3x3 adjacency matrix for spatial objects A and B (Egenhofer and Herring, 1990).

As shown in Figure 3, for each 3D object (A), the 3D topological space can be divided into three regions: 1- Interior of spatial object (A^o) 2- Boundary of spatial object (∂A) 3- Exterior of spatial object (A^e). According to the decomposition, a 3×3 adjacency matrix can be constituted to determine topological relationships between two spatial objects (A, B). The values of this matrix can be empty ($\emptyset$) or non-empty ($\neg\emptyset$). It can be assumed that A is a physical component of a building of infrastructures and B is an associated legal space. Then, the possible topological relationships between two will be: Disjoint, Contains, Inside, Equals, Touches, Covers, Covered by, and Overlaps (Figure 4).

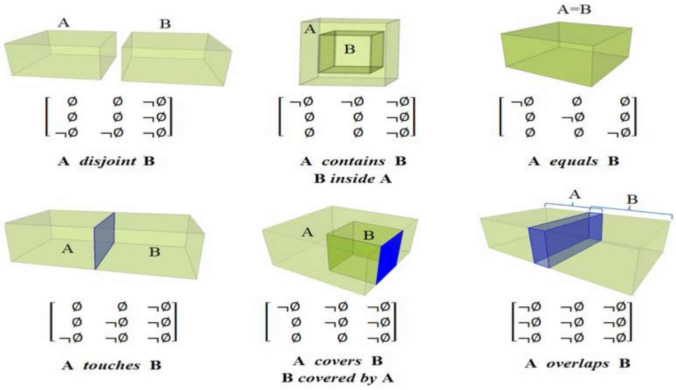

Figure 4. Range of topological relationships between spatial objects A and B.

To define the boundaries of a 3D RRR, the adjacency matrix for representing the relationship between legal and physical objects can be constructed. For instance, in Figure 5, it is required to analyse if the ownership boundary is limited to the interior face of the walls, stops at the median of the wall or extends to the exterior face of the wall. In this approach, one could analyse the 3D RRRs in relation to the physical objects and form the adjacency matrix. In this example, the adjacency matrix shows that Cadastral space 1(a 3D RRR) adjoins interior face of the wall. Similar Cadastral space 2 (another 3D RRRs) also touches interior face (it is the exterior to Cadastral Space 1) of the same wall. This implies that the boundaries of both of the spaces are limited to the face of the wall. This also implies the wall is a kind of 3D RRR such as Common Property. This will enable support of a range of common queries about the 3D RRR boundaries. This includes queries such as: "What are the 3D rights associated with this property?", "What are the rights associated with an apartment unit?" and "what is the association of an infrastructure with the surrounding RRRs?"

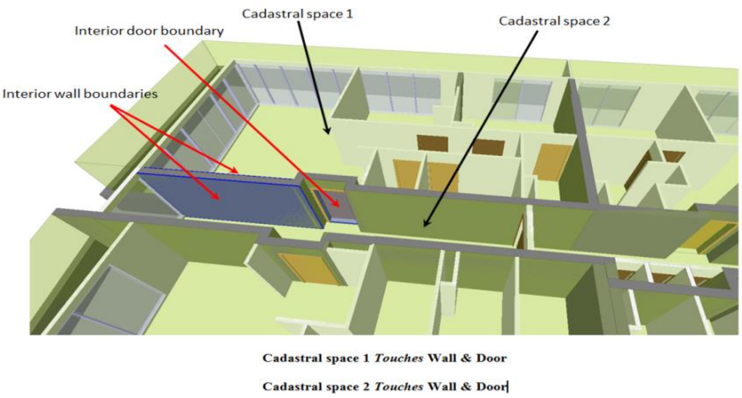

Figure 5- Using topological relationship in 3D cadastres

3.3 Review the impact of technical changes to recommend accompanying changes in organisational workflows and policy frameworks.

Fountain's (2001) Technology Enactment Framework can be used as it focuses attention on the impact that organisational structures have on the design, development, implementation and use of new technologies. In particular, for governments, the underlying assumptions of designers have been found to play a key role in the type of systems developed and the way in which systems are enacted (Fountain, 2006). “Enacted technology” refers to the way a system is used by actors in an organisation. Some of the questions that could be examined include: to what extent do new e-rules contradict traditional rules (e.g. legislation/regulations)? Which human work process might become routinised and subsumed under a 3D property map base? Fountain also argues that two of the most important factors influencing technology enactment are bureaucracies and networks – both of these are significant and will influence the final design and development of a 3D property map base.

4. CONCLUSIONS

This paper proposed a methodology to upgrade from the current 2D property ownership map base to a 3D one. It argued that the map base represents a coherent representation of all land-based parcels, providing valuable intelligence to support land and property decision-making across government, businesses and communities. In 2D form, the map base omits above and underground properties and infrastructure common in urban settings, forcing stakeholders to rely on fragmented streams of data for their needs. This paper outlined challenges and solutions to achieve a 3D map base that provides a connected, digital source of intelligence about urban property objects to support smart urban land administration.

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BIOGRAPHICAL NOTES

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