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3D Cadastres in India: Examining the status and potential for land administration and management in Delhi

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ABSTRACT

Urbanization and the trend towards complex infrastructure development challenges the traditional two-dimensional (2D) cadastral representations used in conventional land administration. Three-dimensional (3D) representations are argued to serve as the future basis upon which to spatially define rights, restrictions and responsibilities (RRRs) in these environments. In Delhi, the capital city of India, where horizontal expansion via new settlements in peri-urban areas, and vertical expansion by densification of city infrastructure, are both prevalent, the need to manage this increasingly complex 3D infrastructure environment presents a great challenge for land administration and management agencies. This paper explores both the current and potential future application of 3D representation in Delhi, with respect to land use planning, development and management. A cross-cutting thematic case study analysis is undertaken: policy drivers, legal frameworks, organizational aspects, and technical standards are considered. For each aspect a separate analytical approach is used. Based on the results, it is concluded that current practices related to 3D representation are somewhat immature and not adequate for capturing the future vertical growth of Delhi. This could lead to legal and physical boundary inconsistencies and irregularities, and dispute cases. However, by learning from international developments and standards-based approaches, agencies have the potential to enhance and support processes in their respective land administration systems. To realize this potential, internal and external policies, institutional settings and, technical and financial arrangements need to be reformed. In the short term it is recommended to focus on raising awareness for the widespread adoption of 3D representations in relevant agencies in Delhi.

1. Introduction

Urbanization is a global phenomenon increasing the density of infrastructure and dwellings to accommodate growing populations in limited spaces. The phenomenon creates economic incentive to adopt development of vertical structures (Urban-hub, 2018; Kodmany, 2012; Antoniucci and Marella, 2017). These vertical developments raise political, economic, legal, and social demands to define and demarcate legal and physical rights, restrictions and responsibilities (RRRs) for individual and commonly owned units (Paasch et al., 2016). Clearly demarcated RRRs may assist in removing social conflict and can boost economic development through transparent land dealings (World Bank, 2019; Enemark et al., 2014; Dale and McLaughlin, 2000).

Cadastres play an important role in securing land tenure: they help to determine legal and physical boundaries of RRRs, and thus to secure and enforce them. A complete and up-to-date cadastre helps land administrators to determine ownership of land. Cadastres are seen as core element of land administration system and the land management ac-

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tivities they serve[1] (Williamson et al., 2010). Traditionally, land administration has managed cadastral requirements with two-dimensional (2D) maps (Stoter and Oosterom, 2006). However, for increasingly complex infrastructure, 2D systems are challenged to represent depths or heights in a graphic manner (Oosterom et al., 2011; Ying et al., 2012; Kitsakis et al., 2016).

It is increasingly argued that three-dimensional (3D) representations should be adopted in land administration to support all the phases of urban development (Oosterom, 2013). These urban developments are occurring fast and in different ways: urban land is in increasingly high demand and creating economic scarcity. They change the spatial landscape and also the economic and social paradigm in urban areas. These complex urban developments need to be captured to secure land tenure, enhance the land value and optimize its use. 3D representations would support more participatory approaches for decision making, helping the sustainable development of cities (Hassan et al., 2011; Lane, 2015).

Emerging technologies and standards provide the opportunity to meet these demands, although, moving towards 3D representation requires more than a techno-oriented response: engagement with citizens, and active involvement of land planners, developers, managers and administrators is essential. Governments will need to play a lead and coordinating role in the shift from 2D to 3D legal and digital representations, ensuring upgraded datasets and workflows are supported by policies, law, organizational arrangements, standards and technologies.

The combination of above-mentioned challenges and opportunities are manifest in Delhi, the capital city of India – although, until now very little has been researched on developments relating to 3D cadastres within the city, or land administration in Delhi more generally, for that matter. Responsible agencies for cadastre and land administration in Delhi are the Revenue Department of Delhi (RDD), traditionally responsible for performing land administrative functions; Delhi Development Authority (DDA), primarily responsible for land planning and development; and the Municipal Corporation of Delhi (MCD), responsible for the physical maintenance of a large part of the city. The Delhi Urban Shelter Improvement Board (DUSIB) is involved in rehabilitation of slum clusters (Revenue Department, 2018; DDA, 2018; MCD, 2018; DUSIB, 2018). Generally speaking, across India, cadastral maps are hardcopy and maintained at the State level, by revenue departments. A central government supported pan-India programme, Digital India Land Record Modernization Programme (DILRMP), is ongoing and includes 3 major components: a) Computerization of land records; b) Survey and re-survey of parcels; and c) Computerization of registration processes (DOLR, 2019). In Delhi, paper based land records of Delhi are therefore being computerized, and boundaries have been digitized for storage and management in a GIS environment (GSDL, 2019). However, the digitized records are only in 2D format. The district level has been taken as the unit of implementation.

Unpacking the strategic and operational status and opportunities, relating to 3D cadastre in Delhi, is the focus of this paper. The work explores the current status of 3D data usage, representation and cadastre in land-related planning, development and management works - of the major land administration and management agencies in Delhi. The specific aims are to consider: i) how agencies currently use 3D representation, data capture, and related technologies and standards; ii) the current policy, legal, and organizational provisions related to 3D concepts; and iii) the potential benefits for land administration and management agencies from enhanced utilization of 3D. Accordingly, the paper is structured as follows: Section 2 outlines the overarching approach and specific methodologies used to consider each aspect of analysis (e.g. political, legal, organizational, and technical). Sections 3 to 6 present the result of the analyses in terms of the current state of play and prospects. These sections describe Delhi's journey towards modernization of infrastructure, the major land administration and management agencies in Delhi, laws related to the real estate sector and building construction, and relevant international standards for 3D representation. Section 7 synthesizes the preceding results section drawing out major findings, challenges and opportunities with regards to 3D representations in Delhi's land administration systems. Section 8 concludes and provides recommendations for future research.

2. Approach and methodologies

As outlined, the study explores the current needs, practices and potential future practices of 3D representations and cadastre, acknowledging the already documented benefits of 3D cadastral representation, and uses the key land governance agencies in Delhi as units of analysis. Overall, a case study approach is applied (Fig. 1), and this approach supports exploratory inquiry on policy, legal, organizational, and technological aspects relating to 3D representation in those agencies, and for Delhi more generally.

For this study, the RDD, DDA, MCD and DUSIB were selected due to their involvement in the process of land administration, building development, construction and monitoring. Data was gathered from observations of available paper and digital documentation, available directly from the agencies, and online sources throughout 2018. Author experiences also informed the analysis.

For the policy driver analysis, existing government policies and contemporary media relating to urbanization, infrastructure provision, housing, and development were studied – and the potential role of 3D representation and technologies hypothesized. For the legal analysis, statutes, laws, and regulations available online, were considered with regards to how 3D aspects are currently considered and managed. Potential changes and enhancements were examined. The organizational analysis considered the roles, interactions and current function of the studied agencies – with a view to identifying capabilities and areas for capacity development. This was informed by van Oosterom's (2013) work and enabled assessment of the form, function, and implementation of 3D representations and cadastre. The technology assessment looked at international developments including LADM and BIM, amongst others, and considered how and whether these were being incorporated into Delhi's land administration systems in any way. Further, the results were then synthesized with a view to drawing out the major threats and opportunities relating to 3D adoption in Delhi, India.

3. Policy Drivers

Like many urban centres in developing economies, Delhi has grown rapidly over the last few decades: much of its outer extent has been converted from agricultural land use into a variety of urban forms. Infrastructure density has increased, and different land use types compete for space (Jain et al., 2016a, b). Competition is not only restricted to horizontal space, but also results in overlapping claims in the vertical dimension. In addition to four-storey apartments in both regular and unauthorized colonies, Delhi now has areas with high-rise residential apartment developments, with, for example, more than 1 million residents in Patparganj, Mayur Vihar, Rohini, the subcity of

[1] Note: This paper uses Williamson's (2010) Land Management Paradigm as a basis for definitions of 'Land Administration' and 'Land Management'. Land Administration is seen to include the functions of land tenure, land value, land use, and land development. Land Management uses those functions to deliver societal objectives related to land (e.g. sustainability objectives, land consolidation, and so on). Both Land Administration and Land Management are suggested to be informed by a Land Policy(s) and supported by Land Information Infrastructures, of which the data and technologies of Cadastres and Land Registries are said to be part of. For the purposes of this paper, the terms 'Cadastres' and 'Land Registry' are considered synonymous with a broad definition of both terms taken in terms of the data, processes, people, and laws involved.

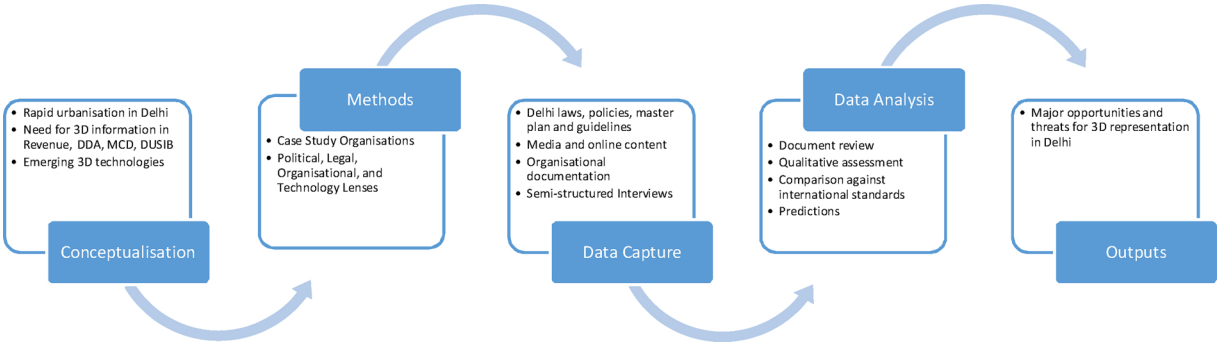

Fig. 1. Steps Applied.

Fig. 2. High rise flats built in Kirti Nagar, Delhi; Source: Magicbricks, 2019.

Dwarka and Kirti Nagar being houses (Fig. 2). This type of high rise development is happening all over the urban area. Different types of utility networks, owned or managed by various agencies, have occupied the space under, on and above the surface of the city. Ghawana et al., 2013 provided an insight to the overlapping rights situation using a specific and detailed case study of utility networks on the Dhaula Kuan traffic point; one of Delhi's busiest traffic points (Fig. 3).

In terms of land related policies, the planning department of DDA prepares the 20-year master plan, the culmination of various theories, policy directives, circulars and acts related to land use planning, development visions and modifications in development norms, through various legislative assembly decisions. This master plan is intended to act as the guiding principle for 20 years for the economic, environmental and social development of Delhi. Delhi is also guided by the smart cities mission of India (smartcities-India, 2017). This seeks to redevelop urban centres and move towards infrastructure modernization. The redevelopment is leading to densification of infrastructure and generating complex 3D structures for different purposes. With ongoing redevelopment plans such as in East-Kidwai Nagar (existing government housing project) and Shajahanabad (Old Delhi), while continuing the trend of establishing new metro lines and flyovers, 3D infrastructure development will continue to be a dominant issue in city policy focus, and governance more generally. To date in Delhi, digital representations of the spatial units, infrastructural plans and blueprints are generally understood to be in 2D format, with very few exceptions, and little policy work commenced towards 3D land information policy. No specific 3D cadastre policy exists in Delhi today. That said, the media and contextual analysis revealed specific policy drivers for 3D representation of physical and legal spaces, with regards to core land administration and land management tasks.

First, enhanced engineering works accuracy constitutes a significant policy driver. All types of engineering works, be they for new developments or repair and regular maintenance by DDA and municipal corporations, often require 3D visualization of boundaries, volumes and spaces. Similar arguments go for DUSIB, which is now going for vertical developments to rehabilitate squatter settlements. Currently, the demarcated boundaries or volumes are not fully represented in 3D and many times, paper copies are used. 3D representation of properties would enable engineers and planners of the respective organizations to visualize the dimensions of property and perform their job with more certainty. For example, in the case of adjoining boundaries in densely populated colonies, which is often the case in Delhi, a 3D representation of boundaries would allow engineers to approve a building layout plan submitted by a landowner to construct a multi-storey building. They could easily check whether the submitted plan is as per the rules, and does not encroach adjacent properties.

Second, more efficient infrastructure planning and design would be possible and constitutes a significant policy driver for 3D representations. With new high-rise redevelopments and other complex infrastructure emerging, the risk of errors and resource inefficiency will increase. Costly mistakes can be avoided during construction by adoption of 3D representation in the planning and design phase (Chou and Chen, 2017; Autodesk, 2014). 3D representation will allow the designers to develop designs which can communicate the planned

Fig. 3. Recent Urban Infrastructure Development at Dhaula Kuan, Delhi; Source: NDTV, 2019.

structures with much more realistic impression, and in. Using better information and previews available through these designs, plans can be made with higher accuracy, especially regarding complex and dense structures with multiple ownership and management.

Third, the potential for national and international compatibility of data emerges. Whilst this policy driver is perhaps less important to Delhi citizens, it is a backend necessity to aid interoperability between Delhi's land related agencies. A complete 3D dataset will allow compatibility with international standards of 3D representation and cadastre. Following international database management standards will allow integration with software for the recording of all the necessary features related to infrastructure and land. It will enable land administration and management officials to maintain records in a synchronized and holistic manner.

Fourth, clear demarcation of 3D spaces and claims represents another policy driver for 3D land information. Delhi is witness to an upcoming World Trade Centre development and other large residential high rise developments. These new complexes can have clear demarcation of separate holdings across multi-dimensions and multi-stories Registration by RDD of RRRs for individual units in spatial format, compatible with 3D data, would bring the required clarity for the case of 3D spatial units.

Fifth, enhanced taxation accuracy is also a policy driver. Delhi is generating a lot of physical space in multi-floor complexes which can be a significant source of revenue through sale or rental and further through annual taxation for DDA and MCD. With clarity in tenure claims over land or property in complex structures, for both exclusive and common areas, authorities can determine taxation with accuracy.

Sixth, the policy driver related to higher certainty in insurance premium and assessments would mean property insurers and economic valuators can have more certainty in determining respective premiums and valuation assessment of complex 3D structures.

Finally, improved disaster response and compensation claim verification is considered another important driver for 3D land information. Delhi is prone to earthquakes as it falls in Zone IV which is defined as high risk zone. East Delhi and other parts of Delhi located in the Yamuna river floodplain are prone to flooding which can cause severe damage to infrastructure. Delhi has a significant number of unauthorized colonies with a large number of multi-storey constructions built without following structural engineering norms. Such colonies and the Old Delhi area are similar in terms of population density, mixed land use, encroachments, and illegal constructions, with additional floors or space divisions. These areas are prone to fires and even terrorist attacks. With 3D representations, better preparation and quick responses can be generated. In disaster recovery phases, authorities can also verify the claims to compensation with higher accuracy based on the 3D records available.

A range of social, political, and economic policy drivers can be found to support the case of 3D representation in Delhi's land administration systems. In general these align with those outlined by Henssen (2010) and include less disputes over land, improve access to credit, streamlined land transactions, and a key register etc. In summary, the current land policy context in Delhi reveals awareness of the need for urban redesign and redevelopment, and even shows that information services are a core part of the infrastructure mix. However, the policy setting also seems to miss the importance of upgrading existing land information systems to support 3D data capture, storage, and services.

4. Legal Provisions

In terms of legal provisions that support 2D and 3D land administration in Delhi, there are a number of legal instruments used to regulate the planning and development activities. Land tenure is regulated through registration of land or property, under the **Registration Act 1908**, for selling or renting purposes, as well as converting property from leasehold to freehold.

Spatial planning and development is primarily regulated at state level via the Delhi Master Plan, although, the special situation of Delhi as capital means a mix of federal and state authorities influence this process, and it is not always well coordinated. The Central government has the role in land administration and management as the DDA and MCD comes under the Central government. On the other hand, the State government is mandated to manage revenue including those generated from lands, under the Revenue Department of Delhi.

The current **MPD2021** emphasizes a shift from single plot housing to grouped housing for land optimization and enhancement of ground coverage, Floor Area Ratio (FAR) and height specification for all categories of residential plots. Considering the fixed boundaries of a plot horizontally, promotes vertical growth for residential purposes. Provision of mixed land use has been made to support increased demand for commercial space. It is accompanied by new parking policies including multi-level and underground parking. Large proportions of underused land and dilapidated built-up areas are recommended for redevelopment with higher densities. The plan recommends having restrictions on tall-buildings in important areas and to identify areas for tall buildings in cases of urban extension (Delhi Master Plan-2021, 2019). All these facets of the plan suggest supportive information in 3D would be highly advantageous.

To implement land use plans in line with such an ambitious Master Plan also calls for government to be able to acquire land previously held by private people. The "Right to Fair Compensation and Transparency Land Acquisition, Rehabilitation and Resettlement Act," 2013 is the basis to acquire land for public purposes. However, the following acts, bye-laws and guidelines are linked to the built-up infrastructure development in Delhi. Along with these acts, bye-laws and guidelines, there are special provisions for other buildings not covered under the Master Plan and including building bye-laws such as those for hospitals, prisons, court complexes, art galleries, museums, amongst others. The provisions in the Development Control Regulation of MPD (DDA, 2014) and any other statutory provisions of India and International Guidelines also can be seen to apply.

The Real Estate (Regulation and Development) Act (RERA) 2016 is a parliamentary Act "to establish the Real Estate Regulatory Authority for regulation and promotion of the real estate sector and to ensure sale of plot, apartment or building, as the case may be, or sale of real estate project, in an efficient and transparent manner and to protect the interest of consumers in the real estate sector" (RERA, 2016).

The Act provides the legal definitions of the infrastructural works related to the property sector such as Immovable Property, Buildings, Apartment, Common Areas, Internal and External Development Works. It also clearly defines the stakeholders and describes their responsibilities such as Allottee, Local Authority, Real Estate Agent and Promoter. The RERA Act 2016 protects the group housing individual owners by inhibiting the sale of common areas such as parking space by the promoter of the housing project. This Act talks about components of property development by providing legal definitions of common areas which could be the linkages between units vertically connected, the internal and external utility networks placed in subsurface, or vertical shafts of the buildings. It also briefly mentions enclosed spaces which could allow definition of 3D volumes. With clearly defined 3D components as well as responsibilities of stakeholders of a built-up property, the Act could serve as the legal basis to clearly demarcate the 3D RRRs of stakeholders.

The **Unified Building Bye-Laws for Delhi (UBBL) 2016** are applicable for all building activities in Delhi. It also provides some useful definitions regarding plot/site, building, high rise, dwelling unit/tenement, floor, and storey. It clearly establishes that the building plan indicates the use of the building along with all the floor plans of all floors. They shall also include rooms, staircases, ramps, exit ways, lift wells, and indicate the use or occupancy of all parts of the building. The section in Building Plan details that these must indicate the total height of buildings, rooms and also the height of the parapet. Service plans for

utility networks such as water, sewage and gas are to be shown. Details are to be shown for all elevations: facade with total height of buildings, permissible projections beyond the permissible building line, location of doors, windows and other openings including ventilators with size in a schedule form (UBBL, 2016).

As State level bye-laws, the emphasis of UBBL to include all the necessary 3D components in the floor plans to be submitted with the authority would help to bring clarity about the 3D RRRs of each 3D unit owner in a building at the planning and approval stage. With an approved design with a higher level of clarity about physical and legal boundaries, the stakeholders would have more confidence to invest in the construction of such units.

The **National Building Code (NBC) 2016** was first published in 1970, serving as a directive principle to be followed as a broad framework. It provides regulating guidelines and a model code for building construction in India to be adopted by the governmental or private agencies. It mainly contains administrative regulations, development control rules and general building requirements; fire safety requirements; stipulations regarding materials, structural design and construction (including safety); building and plumbing services; approach to sustainability; and asset and facility management.

Since the 1970s there has been large scale changes in the building construction activities such as changes in the nature of occupancies, with the prevalence of high rises and mixed occupancies, greater dependence and complicated natures of building services, development of new or innovative construction materials and technologies, greater need for preservation of environment and recognition of the need for planned management of existing buildings and built environment, bringing a paradigm shift in building construction scenarios. Due to this, a revised version of NBC was released in 2016 as the National Building Code 2016.

Some salient features of the revised NBC, 2016 are as follows: a) detailed provisions for digitalization of approval processes which enables online submission of plans, drawings and other details, and sanctions thereof, meaning speedier approval processes; b) strengthened certification mechanisms for structural safety of buildings by the competent professional and peer review of design of buildings; c) revised provisions on fire and life safety for modern complex building types including the high rises; d) latest structural loading, design and construction codes including those relating to wind load, earthquake resistant design of buildings, steel design and foundations; e) provisions pertaining to metro train ways and metro stations with respect to fire and life safety; and air conditioning, heating and ventilation for metro stations; f) new chapters on escalators and moving walks; information and communication enabled installations; solid waste management; and asset and facility management (NBC, 2016).

NBC as a directive principle for all the construction agencies, has a role of providing a model code and guidelines with a pan-India approach. It acts as a broad framework for State level acts and byelaws related to building construction. NBC as a national level code provides the features related to a building which could be absent in State level laws due to no precedence in India. This could be expected with the rapid urbanization and development of complex infrastructure in various cities. Details about asset management, waste management, earthquake resistant design and construction, fire safety provisions in complex structures or high rises, are further examples of 3D RRRs.

Considering all the above laws in the context of 3D representation, both presently and for the future, the Real Estate Regulatory Authority (RERA) Act 2016 and Unified Building Bye-Laws (UBBL) for Delhi 2016 can be said to comprehensively provide definitions related to building, high rise buildings, building height, room height, floors, individual flat units, common spaces, basement; obligations of promoters, allottees and authorities. Moreover, UBBL, 2016 makes it mandatory that the section in a Building Plan must indicate the total height of buildings, rooms and also the height of the parapet. Service plans for utility networks such as water, sewage and gas are to be shown. Details are to be shown for all elevations:. This includes façades with total height of buildings, permissible projections beyond the permissible building line, location of doors, windows and other openings, including ventilators, with size in a textual schedule form. In fact, the RERA Act 2016 includes enclosed spaces in its definition of the self-contained part of an immovable property. Like other contexts, this analysis suggests Delhi's legal and policy system is actually prepared for 3D representation and is demanding it within its administration systems.

Land being a State subject constitutionally, means States usually follow the State level land laws and policies. If something is not provisioned into the State level land laws, then NBC is referred to. Sometimes if a provision is not found even in the NBC for a particular construction complex, then international standards of the relevant sector serve as a reference. For example, during the makeover of Delhi's international airport, when there was no reference found in NBC to deal with the complexities of a huge construction, including 3D aspects of aviation, underground metro, and multi-storied departure and arrival sections, in addition to other services, the authorities referred to the International Civil Aviation Organization (ICAO) Guidelines. By following international standards for large multi-complexes, where different agencies are stakeholders, it is expected that 3D RRRs could be considered during construction and operational activities. A 3D representation and subsequently 3D cadastre could be a near future activity to meet the demand for clear legal and physical boundaries to determine RRRs of individual units in a building. The demand could be expected to be driven from the above-mentioned land use planning developments, envisaged in MPD2021. The described legal provisions and national guidelines will help the existing land administration and management system to adopt a 3D approach. It can be initiated by introducing 3D elements in the land and property registry in graphical form, taken further during the design and construction of buildings during the development phase implemented by DDA. Municipal arrangements to manage the developed areas would require 3D approaches for identifying the civic requirements, responsibilities and rights of individual unit holders in a building. Table 1 summarizes the legal provisions in Delhi pertaining to land and buildings with a description of linkages with 3D aspects.

5. Organizational Arrangements

Policies and legal basis pave the way for organizational arrangements and enabling them to formulate rules and regulations in accordance for achieving their strategic and operational goals. Multiple land administration and management agencies handle operations related to land in Delhi. Some of these agencies play a major role in meeting public service requirements and have most of the area of Delhi under their jurisdiction. The agencies not only maintain public and private land records, but also provide various other services to the public. The RDD, DDA, MCD, and Delhi Urban Shelter Improvement Board (DUSIB) are the major land or property administration and management agencies (Fig. 4).

RDD is responsible for maintaining the land records of Delhi which are primarily the basis of original tenure information for all the land parcels or plots in the city. On receiving requests for land acquisition from the Land and Building Department of Delhi on behalf of other government departments, it acquires private land. It also makes compensation payment and provides land and property registration services (Revenue Department, 2018). DDA is the land planning and development agency and prepares master plans, zonal plans and constructing buildings for new settlements or colonies. It also delivers various public services such as land or housing allotment and land/property mutation. MCD in its trifurcate form of Southwest, North and East Delhi municipal corporations, is responsible for the management of a large area inside Delhi. MCD is primarily an executing body with responsibility for land management. After the de-notification of an area by DDA, MCD take control of building activities and applies provisions of the Municipal

Table 1
Summarized regulations in Delhi or India pertaining to land and building.

Act/Regulation	Highlighted Aspects
'Right to Fair Compensation and Transparency Land Acquisition, Rehabilitation and Resettlement Act, 2013'.	Land Acquisition, Rehabilitation, Resettlement; No direct link with 3D aspects except the cadastral check for boundary determination in 2D.
Master Plan 2021 for Delhi (MPD 2021)	Major tool for spatial planning for Development in Delhi with a vision for 20 years; emphasizes landuse planning; Links with 3D aspects in the form of emphasis on mixed landuses which will increase the density and prompt vertical growth; redevelopment with higher density; identifying areas for tall buildings in urban extension areas.
The Real Estate Regulatory Authority (RERA) Act 2016	Legal definitions of the infrastructural works related to property sector; emphasizes protecting the rights of group housing individual owners; Link with 3D aspects in the form of definitions provided for buildings, its individual units, common areas as well as scope for enclosed spaces.
The Unified Building Bye-Laws for Delhi (UBBL) 2016	Focused on buildings, provides definitions of individual units in a building or high-rise buildings. Describes the requirements of floor plans including rooms, stairs, lifts; Link with 3D aspects in the form of total height of buildings, rooms and the height of the parapet; usage of floor plans including components vertically connecting two or more floors in a building as stairs, lifts, ramps, utility networks.
National Building Code (NBC) 2016	Mainly contains administrative regulations, development control rules and general building requirements; fire safety requirements; stipulations regarding materials, structural design and construction (including safety); building and plumbing services; approach to sustainability; and asset and facility management; Link with 3D aspects in the form of provisions for metro ways; fire safety for complex and high-rise buildings, design and construction codes.

Corporation Acts. MCD also engages in surveys, anti-encroachment activities, construction and maintenance of roads of certain size and property tax collection. Both agencies request the RDD to acquire land for building construction activities. RDD acquires land from the private land holders, distributes land compensation and handover the land to DDA, MCD or other governmental agencies. RDD, DDA and MCD provide land or property mutation services to the public. These agencies handle spatial units of land and built properties. The Slums (referred to as 'JJ Clusters' in Delhi) are under the mandate of Delhi Urban Shelter Improvement Board (DUSIB). The board organises slum residents into resettlement colonies, of which there are currently 44 in number. It also allows these rehabilitated residents to convert leasehold into freehold. It also captures certain attributes of these clusters in a survey (DDA, 2018; MCD, 2018; DUSIB, 2018).

Taking the organisational analysis further, using van Oosterom's (van Oosterom, 2013) work as an analytical framework to study 3D use and uptake within the agencies, Table 2 reveals that at the initial stage of land acquisition and zonal level planning, 3D representation is not put into practice, but during the design phase for new spatial objects, such as buildings, both 2D to 3D graphic representations, are generated. Registration of spatial objects and use permits do not have 3D graphic representations, but bye-laws and permissions define 3D rights and restrictions in textual format. Engineering surveys, using total stations, are used to record data, but that is currently stored and analyzed in 2D. 2D CAD drawings are created with 3D positions marked as annotations. Checks and validation of submitted data involves the 3rd dimension, as mentioned in text format. Information related to spatial units is also disseminated usually in 2D, but also in 3D as per requirement.

Overall, the 3D representation practiced is quite low, at least in graphical form, for various aspects of 3D property unit administration

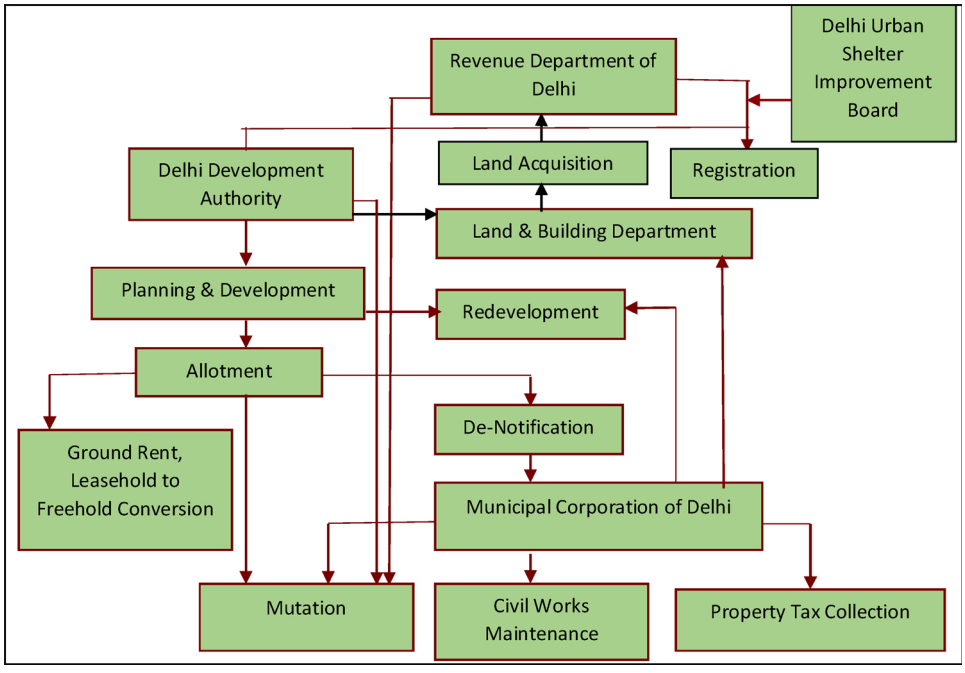

Fig. 4. Functional Relationship between Revenue Department, DDA, MCD, and DUSIB.

Table 2
Current practices related to 3D representation in Delhi land administration and management agencies.

Activities (partially based on Oosterom, 2013)	Delhi Development Authority (DDA)	Municipal Corporation of Delhi (MCD)	Revenue Department Delhi (RDD)	Delhi Urban Shelter Improvement Board (DUSIB)
Develop and register zoning plans in 3D.	No	No	No	No
Register (public law) restrictions in 3D	No	Exists in bye-laws text but not in 3D Graphics	No	No
Design new spatial units/objects in 3D	Yes	Mostly 2D designs except when submitting to a particular agency	No	Not in drawing layout but in text
Acquire appropriate land/space in 3D	No	No	No	No
Request and provide (after check) permits in 3D	Not done in DDA and other Departments	Permits are given in text	Registries of flats textually mention the usage purpose of basements or floor units	Unknown but will allot individual flats in buildings
Survey and measure spatial units/objects (before or after construction) in 3D	Total Station Surveys now in practice	Survey drawings mark 3D positions and record elevation contours in 2D	Total Station Surveys now in Practice	Unknown
Submit associated rights (RR)/parties and their spatial units in 3D	No	N/A	Only 2D layouts with flat area in texts	Unknown
Validate and check submitted data (and register if accepted) in 3D	No	3D is mentioned in text form	Unknown	Unknown
Store and analyze the spatial units in 3D	Unavailable special tools and trained manpower in DDA	3D is mentioned in annotation form in 2D CAD files	No	No
Disseminate, visualize and use the spatial units information in 3D	No but may be in future	Dissemination of the spatial units' information in 3D as required.	No	No

and management by the relevant agencies.

6. Technologies and standards

In terms of technology and standards, to come to a practical 3D cadastral system, it is important to define the 3D spatial unit as the elementary block of a building cadastre for individual properties. Defining a 3D unit could include land and water spaces, both above and below surface[2]. These definitions require translation into logical data models that can be used for storage and creation of the 3D primitives and the related rights. Work surrounding data models for land administration has been prevalent throughout the 2000s globally, and has matured to the point of delivering global standards (Lemmen, 2015). Relevant 3D components of emerging international standards are presented in Table 3, and whilst application for the case Delhi was found to be limited, the potential uptake in Delhi is subsequently discussed.

The Land Administration Domain Model (LADM) as a knowledge product has conceptual components for land administration including elements above and below the surface of the earth. It defines the spatial unit in legal terms (LADM, 2012). For the conceptual development of 3D Cadastre for Delhi, LADM could provide a foundational concept with flexibility to accommodate legal and administrative aspects for demarcating RRRs of 3D units with exclusive and common ownerships.

Translating the relevant components of the LADM conceptual model to an open standard data model and exchange format data standard such as CityGML, the land administration and management agencies could digitally store city level infrastructure and landscapes as 3D representations (CityGML, 2018). This model would allow common feature descriptions in Delhi city, such as buildings, roads, and so on, along with their relationships in different levels of detail as per the requirements of planners, designers, modelers and developers. It could also enable storage of the specific 3D relationships between objects such as an underground Delhi metro station, connecting to its surface level vehicle parking.

An intermediate conceptual model could be considered in the form of LandInfra model, where division of land is not only based on administrative jurisdictions, but also the property units as built-up infrastructure. Combining this model with CityGML and LADM could bring the possibility of city-scale 3D representation closer to the reality (refer to Table 3 - LandInfra, 2016).

Furthermore, transforming the concept and city level data standard for registered unit level in complex infrastructure could help to accommodate more efficiently, the demands of legal, physical, topological and geometrical natures inherent to complex infrastructure. Building Information Management (BIM) is a relatively new concept to modern building development and management requirements (BIM-ISO19650, 2019; Buildingsmart, 2019). It involves describing the legal and physical elements of a building and also describes the spatial relationships, among the elements, using 3D digital spatial information about the buildings. Building Information Modelling (BIM), as an output of this process, also supports the decision-making process for building management (Paasch et al., 2016).

On a technical front, much is happening globally to deal with 3D representation requirements, however, the agencies in Delhi are largely dealing with digital 2D drawing files, and using CAD technologies. Geospatial technologies have been used to prepare plan maps and visual analyses. BIM is known and may have been under use by MCD using commercial software for the purpose of design. However, the existence of LADM, CityGML, LandInfra, Indoor GML are unknown to

[2] As a more formal definition, it can be defined as the spatial unit against which (one or more) unique and homogeneous rights (e.g. ownership right, lease or other land use right), responsibilities or restrictions are associated to the whole entity, as included in a Land Administration system (Oosterom et al., 2011).

Table 3
3D components of popular international standards.

	LADM (LADM, 2012)	CityGML (CityGML, 2018)	BIM (MIT, 2019)	OGC-Land Administration (OGC, 2019)	LandInfra/InfraGML (LandInfra, 2016)
Conceptual / Physical Dimensions	Two specailized spatial units: building unit and a utility network concerned with its legal space.	Building 'Level of Detail' (2,3,4) including Height, Roof Top, Facade and Indoors	Plan (4D modelling)	Legal and spatial dimensions in 3D (e.g. Indoor Modelling)	Land division: administrative jurisdictions; interests in land (e.g., land parcels, easements, and condominiums). Support for terrain and subsurface information.
Topology / Spatial Relation	Class Spatial Unit: Attribute- 'Surface Relation' indicating whether it is above or below surface and 'Volume' of the 3D spatial unit.	Specific 3D relationship between objects	Design (3D Coordination; Lightning/ Sharing, MEP Analysis; 4D Modelling)	LADM integration with BIM, IndoorGML.	Alignment2DVertical specifies a geometry/location in the vertical direction for the Alignment2DHorizontal using the Cartesian engineering reference system
3D Methods / Attributes	Methods: 'computeVolume ()', 'createVolume ()', & 'volumeClosed ()'	Application Domain Extension (ADEs) such as an ADE for 3D topographic objects in the Netherlands	Construct (3D Coordination; 3D Control & Planning; Virtual Mockup; 4D Modelling)	3D + profiles required.	Requirement classes with objects of 3D nature defined. Combine the two 2-D geometric representations into a single 3-D representation called an Alignment3D.
Tenure	Apartment Owner RRRs in a building (Individual Unit, Common space & Land Parcel)		Operate (Building Maintenance Scheduling; Asset Management; Space Management; Disaster Planning; 4D Modelling)		A PropertyUnit is a unit of ownership in land. Ownership in land (as specified by a PropertyUnit) includes buildings and fixtures on the land parcel.

the agencies. The 2D cadastral boundaries in Delhi are digitized and available online through a geoportal as shown in the Fig. 5.

With the changing landscape, the agencies need to adopt the new technologies to be able to cater to the new 3D requirements.

7. Discussion and Synthesis

Overall, a number of core messages are revealed from each of the policy, legal, organizational, and technological analyses. Moreover, several cross-cutting messages also emerge.

7.1. Ensure 3D policy-pull over 3D technology-push

First, Delhi with its growing population and infrastructure is looking for alternatives for using and governing space. One alternative is to grow vertically with 3D developments. With development of complex 3D structures, a socio-economic need has been generated to identify and demarcate clearly the tenure rights in multi-storey buildings with individual and common ownership claims. Numerous use cases were identified within the study, and whilst these are yet to be assessed in terms of costs against economic gains, like other contexts (Bennett et al., 2013) it is these drivers that likely will pull the development of any 3D land information systems. With advances in data capture, storage and visualization technologies, and relevant international standards emphasizing the design, spatial and building material sciences, suitable policy measures need to be devised.

However, despite this near future need, there is no dedicated policy which explicitly strives to achieve 3D representation or 3D cadastres, as part of the land administration arrangements, in Delhi. Some 3D representations could be existing and generated using CAD technologies for visualization of design purposes. Achieving a 3D cadastre is not the current focus of the land agencies.

7.2. Utilize existing 3D-ready legal provisions

The legal and policy provisions studied call for the representation of individual features and units in a building. Besides providing the legal definitions related to 3D aspects of these units, the regulations make it mandatory to describe these 3D aspects at building plan level. Not only open, vertically unbounded spaces are talked about: the scope entails the provision for enclosed spaces too. Stakeholders' obligations are also clearly given. National level guidelines are revised considering the complex multi-storey developments and their specific requirements including being 3D in nature. In some cases, due to the unprecedented infrastructural complexities, at the national level there is already the practice to refer to relevant international guidelines or standards.

3D RRRs for a building can be linked to the RRRs derived from the land parcel in terms of permissible landuse, height of the building and each floor, projections from the building, number of individual units, basement construction, common areas and so on - however, there is no single regulation creating the linkage between tenure, landuse, or value for that matter. UBBL, 2016, MPD2021 and the freehold registry process of an individual unit in a building by the RDD are the regulations which regulate RRRs derived from the land and the building pertaining to it. As per the designated landuse described in MPD2021, which is followed by area wise different zonal plans, a builder or an owner can use the land in that zone for residential, commercial or industrial purposes. Accordingly, the building design will take place as per the desired landuse while following building bye-laws described in the UBBL, 2016. Further, the registry process for each separately owned unit in the building will be performed by the rules or acts followed by the revenue department. All the above demonstrate that, at least in a legal sense, Delhi already has supportive laws and regulations to support, if not demand, 3D cadastral development.

A dedicated law, establishing the fact that 3D cadastre or a compatible hybrid cadastre is essential, may be a future approach, so that

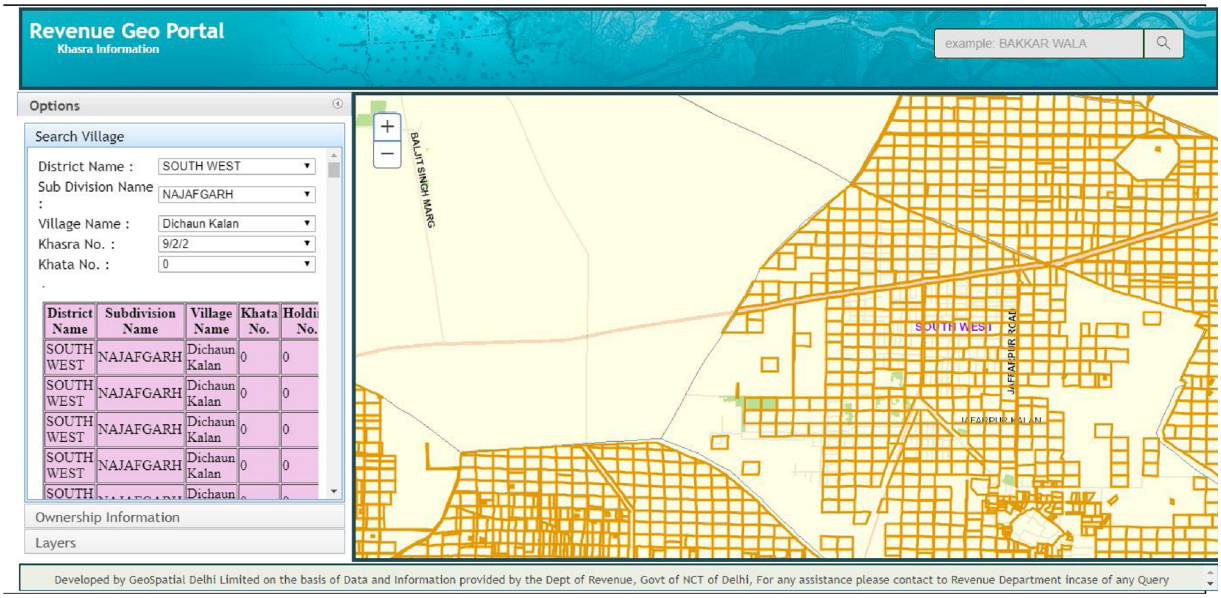

Fig. 5. GIS enabled portal for Revenue purposes in Delhi; (Source: GSDL, 2019).

all agencies associated with it, on different levels, can utilize it in a synchronized manner.

7.3. Seek more organizational cooperation on 3D

Due to the very nature of the land administration and management agencies work, they are functionally related in many ways. Thus, it is imperative that while discussing 3D representation options for Delhi, current 3D representation practices of different land administration and land management organisations are explored and shared. This study provides an initial foray, and demonstrates the necessity for interplay between politicians, technocrats, and international communities. Awareness of Delhi's development challenge is acute amongst politicians, however, supportive technical solutions appear as though they could receive more exposure in development policies. This is where administration and professionals working within the land sector must be more active in promoting the importance of 3D data representation to decision makers. Moreover, engagement with international communities would help strengthen capacity within the agencies, and also enhance arguments for redeveloping land administration systems. This calls for systemic changes so that the coordination rules and policies can be formulated to enhance cooperation, with clearly defined authority and accountability, around 2D and 3D land data and processes.

7.4. Increase international engagement on 3D

International and standards-based approaches for adopting 3D representations and cadastre were described as being applicable to the context of development of infrastructure in Delhi, especially high-rise buildings. Delhi's government should look more internationally, particularly towards emerging global standards, via engagement in the literature and conferences around that. This would serve to increase the support network available in terms of linking Delhi professionals with the global LA community.

It is apparent that LADM, an ISO19152 conceptual model, can provide predefined spatial and administrative information components with enough flexibility to adopt a 3D representation and 3D cadastral approach. It has defined methods having 3D primitives to compute and create 3D volumes which could be important for demarcating boundaries and defining RRRs in 3D structures. Delhi's land administration agencies should seek to engage more fully with developments surrounding LADM, OGC, and other data modelling standards. As an initiative towards capacity building, linking professionals in Delhi with the global land administration community should be considered.

7.5. Use 3D standards as a bridge

In addition to the adoption of this conceptual model, agencies would need to have a standard data model and exchange format which can capture 3D alterations of landscape on city level. CityGML as an open standard allows such data structuring, capturing the infrastructure development. This standard allows to digitally describe and store the common features related to buildings and streets along with their relationships. The city-wide database, with flexibility to introduce new extensions, classes and attributes, could be customized by different organizations involved in land planning and management. With Building Information Management (BIM) models, the citywide database could be focused for individual complex buildings to facilitate multi-disciplinary coordination and integration of 3D design, analysis, cost estimating and construction scheduling. This kind of model can in fact bridge the time gap between land acquisition by RDD, and planning and development of infrastructure by DDA, DUSIB, and setting up municipal regulations at a later stage by MCD, such as maintenance or monitoring schedules.

The integration between CityGML and BIM has not settled yet in terms of methods and practice, however, such models can be expected to allow the related agencies to work in an integrated manner in the context of complex infrastructure. Delhi's land agencies should examine the body of these standards to verify the necessity and strategy before adopting them. MCD staff have awareness of the BIM concept and might have been using it in a limited manner, but the standards like CityGML are not in there purview yet. Further, it might be necessary to use, with increased emphasis on digitalization of processes, software and standards able to conceptualize city scale infrastructure as an interoperable data model. Adoption of conceptual standards like LADM and data models like CityGML could be a future strategy in support of this. At the initial stage, Delhi can adopt a hybrid approach, with 2D data, including height as attributes, being used to create simple extruded models, or working in 2.5D, for terrain integration, with building layers for the creation of integrated terrain-surface models, using LandInfra requirement classes. CityGML or LandInfra could be adopted by the DDA for the preparation of master plan for Delhi, so as to capture the entire city Infrastructure. The RDD as the nodal agency for land and property registration, needs to be innovative by adopting LADM

concepts for spatial units. Adopting a true 3D primitive based approach such as the tetrahedron or polyhedron, could be feasible when the 3D practices are mature enough to handle the true data - or the requirement for calculating overlapping 3D legal volumes is urgent and feasible. All these above shows that in a complex and densely built environment such as Delhi, to meet the demands of the future, standards like BIM can be adopted collaboratively on a wide scale by the different agencies involved in planning, development and management of land and property: they can be considered a bridging opportunity between agencies and shared data and processes.

7.6. Foster high ambition, with realistic actions

Whilst the mentioned standards and tools appear relevant and applicable to the Delhi context and can raise ambitions, expectations for short- and medium-term implementation should be realistic. The results obtained from primary data collected on current practices related to 3D representation and 3D cadastre in activities of land administration and management agencies show that quite some disparity exists: existing 3D graphical representations are at a very limited scale for design or visualization purposes, and to some greater extent in non-graphical or textual manner, in documents or database related to 3D rights and restrictions. The above-mentioned benefits and opportunities aside, any strategy aimed at transitioning to a 3D representation and cadastral environment, clearly requires deeper analysis on legal, financial, and socio-economic constraints. The trade-off between the cost and benefits of such a system for the citizens require scrutiny. Implementation issues also require examination, and in a diverse and dynamic context such as Delhi, it is likely that piloted, phased, or context specific roll out (e.g. trialing on specific developments), would be the most realistic approach. In the short term, awareness raising, and development of extended use case descriptions appear the most pressing needs.

8. Conclusion and recommendations

With complex infrastructure development in Delhi challenging traditional 2D land administration to meet the RRR requirements of vertical growth, 3D representations, using 3D concepts are argued to serve as the future for land administration. The current and future applications of 3D representations for Delhi are explored in this paper. A cross-cutting case study analysis, using a discrete methodology for each, was performed on the context of policy drivers, legal frameworks, organizational aspect, and technical standards. It is concluded that current practices related to 3D representation are inadequate to capture the future vertical growth of Delhi which could lead to legal and physical boundary inconsistencies and irregularities, and dispute cases relating to structures and land use. However, agencies have the potential to enhance and support processes in their respective land administration systems using international and standardized approaches. It is recommended to focus on raising awareness for the widespread adoption of 3D representations in relevant agencies in Delhi. In terms of further research, components related to 3D representations and 3D cadastre, such as developing and registering a zoning plan in 3D, registering 3D property restrictions, designing 3D spatial units, acquiring 3D data for city model, or presenting legal documents in 3D - could add valuable insight for the specific case of Delhi, and Indian cities more broadly.

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