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3D Cadastre in Australian and New Zealand Jurisdictions: Similarities and Differences

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Key words: 3D cadastre, Australia, New Zealand, 3D land parcels, legal boundaries

SUMMARY

Many research studies have been recently conducted in Australia and New Zealand to explore a range of technical, legal, and institutional aspects related to modernisation of 3D cadastre. Most of these studies focus on a particular jurisdiction. This stems from the fact that each jurisdiction is responsible for their own cadastral system. Therefore, the requirements, guidelines, and procedures for implementing 3D digital cadastre are also specific for each jurisdiction. However, the Intergovernmental Committee on Surveying and Mapping (ICSM) develops national frameworks and data models, e.g. ePlan, for cadastral systems in Australia and New Zealand. Therefore, understanding the differences and similarities between existing cadastral systems is critically important to support 3D cadastre at a national level. In the current literature, comparisons of 3D cadastre for some civil law jurisdictions as well as standards have been conducted. Nevertheless, the common law jurisdictions, including Australia and New Zealand, have not been compared in terms of 3D cadastre.

Thus, this research aims to develop an overarching framework comprising differences and similarities in current practices pertaining to subdividing ownership of vertically stratified properties to support 3D cadastre in all jurisdictions of Australia and New Zealand. The study scope is limited to technical aspects of 3D cadastre in these jurisdictions. A survey based on a questionnaire has been conducted to identify the important data elements used in current 3D cadastre practices in Australian and New Zealand jurisdictions. The survey outcomes indicated that there are some similarities in terms of managing 3D cadastral data. One main similarity is that 3D legal boundaries are typically delineated by either referencing physical structures or fixed survey measurements. The differences mainly refer to various types of primary land parcels and secondary interests in each jurisdiction. In addition, similar ownership concepts are named differently in each jurisdiction. For instance, the “Lot” primary parcel, which defines the ownership space of a private property, in Victoria is the same as “Unit” parcel in Northern Territory. Each jurisdiction uses its own representation of 3D cadastral data. For instance, cross section diagrams are used in Victoria while isometric views are used in Queensland. These research outcomes could help with developing a framework for multi-jurisdictional 3D cadastre in Australia and New Zealand.

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1. INTRODUCTION

Cadastral systems have been developed and implemented by governments across the world. These systems are used to assist land and property decision-making across government, businesses, and communities by using land surveying techniques to convey the most complete depiction of land parcel and property boundaries, which is known as cadastral information. Current cadastral systems rely heavily on 2D base maps and survey plans which fall short of meeting future land development demands and community expectations.

As cities in Australia and New Zealand have grown rapidly in the last decades, the demand on land development and use has been tremendous. For these nations' urban areas, this has resulted in the growing dominance of complex aboveground/underground developments. The common examples are buildings with many stories and multiple uses, shopping malls, passageways on top of and below streets, gas pipes, electrical cables, subterranean parking lots or tunnels. In these developments, the spatial dimensions of ownership rights, restrictions, and responsibilities (RRR) are often three-dimensional (3D), invisible and multi-layered spaces.

The problem is that current practices for subdividing urban land and property ownership are predicated on silo-based and fragmented 2D approaches, which do not provide a reliable, unambiguous, and coordinated representation of the legal and physical aspects of underground and aboveground areas. For instance, the inaccuracy and unreliability of 2D as-builts resulted in several delays and disruptions in a railway project in Sydney (see Figure 1). However, if there had been a comprehensive and accurate 3D digital model of underground properties during the planning phase, the railway project could have been completed at least one and a half years sooner, at less cost and a much lower level of risk (Acil Allen Consulting, 2017; Zeiss & Shinoaki, 2020).

In Australia, there are eight jurisdictions: Australian Capital Territory, New South Wales, Northern Territory, Queensland, South Australia, Tasmania, Victoria, and Western Australia. There is a unique method to represent 3D RRR spaces in each jurisdiction. Therefore, there are currently eight types of methods used for 3D cadastre in Australia. Furthermore, New Zealand has its own approach for representing 3D legal limits of RRR spaces. So, depending on the legislations and processes created especially for that jurisdiction, each jurisdiction has different needs when it comes to capturing, curating, and communicating 3D cadastral information.

According to Australian and New Zealand legislations, the legal limits of vertically situated properties are typically delineated on analogue 2D subdivision or survey plans. When it comes to urban developments with basic structural shapes, 2D-based representation

approaches are quite effective and efficient. However, a built asset with a spatial and functional complexity raises questions about the efficiency of 2D representations. The communication and management of 3D RRR spaces within vertically placed properties create several issues for long-established 2D-based paradigms. Some consequences of using 2D concepts can be summarised as (Rajabifard, Atazadeh, & Kalantari, 2019):

- It is only the surveyor, who created the initial drawings, can provide a complete sense of the abstract (plan) version of reality.
- Planar, isometric, and cross-section views are difficult to interpret whey they are used to represent complex RRR spaces.
- Multiple pages of 2D drawings are required to accurately reflect the legal extent of all RRR spaces in a high-rise building.
- A variety of technological approaches are now used to register 3D RRR spaces in current 2D cadastral systems; however, technical ambiguities pose critical challenges to the security of tenure in urban areas.

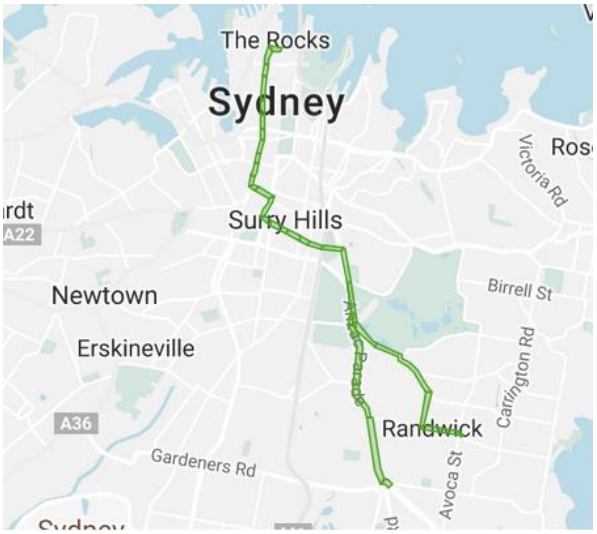

Figure 1. Sydney Light Rail Project, source (Zeiss & Shinoaki, 2020)

Increasingly, 3D digital models are being researched as possible solutions for improving the recording and representation of urban land and property to overcome communication and management challenges in complex urban environments. In the existing literature for 3D digital cadastre, a significant number of studies related to legislative, institutional, and technical aspects have been conducted in different jurisdictions. In an international context, many countries including the Netherlands (Stoter et al., 2016), Sweden (Sun, Mi, Olsson, Paulsson, & Harrie, 2019), China (Ying, Guo, Li, Chen, & Jia, 2018), and Korea (Lee, Kim, Kwak, Lee, & Choi, 2015) have developed different research approaches to showcase the feasibility of 3D digital cadastre.

In Australia, States of Victoria, Queensland, and New South Wales have been active in researching aspects of 3D digital cadastre in isolated investigations. However, there is a lack of research regarding a national approach for 3D cadastre in Australia. In addition, New Zealand jurisdiction is also part of the Intergovernmental Committee on Surveying and Mapping (ICSM) together with Australian States and Territories.

Therefore, there is no comprehensive and holistic approach in advancing knowledge to support a move towards 3D digital cadastre and address the general problem of modelling and managing complex 3D RRR spaces in underground and aboveground developments in rapidly growing built environments of Australia and New Zealand. As these countries are planning to move towards an approach for implementing 3D digital cadastre, this research aims to identify and compare 3D cadastral data elements in these jurisdictions. The expected outcomes of this study include similarities and differences between all Australian states and territories as well as New Zealand to develop a new nationwide framework for 3D cadastre.

2. LITERATURE REVIEW

In this section, a review of 3D cadastre research will be provided with a particular focus on the existing studies comparing different jurisdictions. Investigations in different countries, including Australia and New Zealand, have identified three generic aspects for modernisation of 3D cadastre: technical, legal, and institutional.

The technical aspects of 3D cadastre have been investigated significantly in different jurisdictions including Australia and New Zealand (Gulliver, 2015; Gulliver, Haanen, & Goodin, 2016; Rajabifard et al., 2019; Smart & Priebbenow, 2018). These aspects typically refer to various stages of the digital data lifecycle, namely 3D data acquisition (Jazayeri, Rajabifard, & Kalantari, 2014), 3D data models and standards (Atazadeh, Rajabifard, & Kalantari, 2018), 3D data storage (Janecka et al., 2018), 3D data visualisation (Jacynthe Pouliot et al., 2018), 3D data validation (Asghari, Kalantari, & Rajabifard, 2019; Karki, Thompson, & McDougall, 2013), 3D data query and analysis (Atazadeh, Rajabifard, Zhang, & Barzegar, 2019; Barzegar, Rajabifard, Kalantari, & Atazadeh, 2020). 3D data visualisation and 3D modelling are two of the most used technical solutions for 3D cadastral data management. Developing an integrated approach including the important phases of the full lifespan of 3D cadastral data is still a relatively new field of research that has received little attention (Kalogianni, van Oosteom, Dimopoulou, & Lemmen, 2020; Olfat et al., 2021) .

While various solutions have been developed to address technical aspects of cadastral data lifecycle in a 3D environment, the legal and institutional aspects have been identified as "invisible" constraints and fundamental barriers to shift from 2D to 3D digital environments.
To understand how current land development processes use cadastral information, researchers looked at the spectrum of regulatory, normative, and cultural factors that drive present 2D practices. As part of a study conducted in Australia, researchers found apparent obstacles to a successful transition process and offered viable methods, as well as a road map to help a shift towards 3D cadastre. Research findings from cross-case analysis and syntheses were used to build a new framework of strategic principles to guide key stakeholders in the creation of a transformation path. Development of a roadmap to enable the implementation of 3D cadastre must consider the cultivation of legitimacy as an underlying principle.

One of the earliest studies on analysing international key factors for 3D cadastre has been conducted by Paulsson (2007). Her findings revealed a number of commonalities in 3D property ownership across a variety of cadastral systems in various countries including

Australia (Victoria and New South Wales), Germany and Sweden. Legal boundaries of ownership spaces, common property definition, easement formation, forms of collaboration between units and management and regulation concerns, as well as dispute settlements and insurance solutions were identified as critically important key factors. In another study, Paulsson (2012) did a comparison between the Swedish types of 3D property and the typical types of 3D property prevalent across the world. It was preconceived that the Swedish 3D property types would be different from those used internationally. However, it was found all forms of 3D property ownership are similar in their creation even though there are differences between the legal systems. The identified key factors seem to be crucial for establishing a successful system for 3D cadastre, and these should be taken into consideration while developing new systems and comparing them to existing ones (Paulsson, 2007). More recently, Paulsson & Paasch (2013) analysed a comprehensive number of publications from 3D cadastre literature and identified four categories in this research domain, namely legal, technical, registration, and organisational. One of the main findings was that technical and registration aspects of 3D cadastre have received more attention than legal issues. Comparative studies on 3D cadastre were also found to be of limited interest. In addition, it was indicated that an increase in the number of studies comparing different cadastral systems, as well as a global perspective on the cadastral systems' strengths and drawbacks, would be useful to the scientific community.

Pouliot et al. (2011) recognised the need for comparisons between the 3D representation of vertically situated co-ownership in Quebec and Franc, which would assist to build a 3D solution for cadastral systems in these jurisdictions. The comparative analysis was partly done using Land Administration Domain Model (LADM) standard. It was shown that comparing the spatial representation of vertical co-ownership in Quebec and France may help discover better practices and, ultimately, provide advice on how best to upgrade cadastral systems. The application of LADM enhanced and clarified differences and similarities between Quebec and French jurisdictions. A clear advantage was the ability compare the two cadastral systems visually. Therefore, both systems could be compared side by side, class by class and attribute by attribute (Jacynthe Pouliot, Vasseur, & Boubehrezh, 2013). This facilitated establishing possible linkages between the two jurisdictions. The shared vocabulary provided in the LADM standard helped to identify semantic conflicts regarding the term “lot” in these jurisdictions.

In another international context, the legal foundations of 3D cadastre in fifteen jurisdictions, including Australia, have been reported in a study by Kitsakis et al. (Kitsakis et al., 2018). The study found each jurisdiction uses a distinct set of terms to define 3D legal objects, but national approaches have certain similarities. For example, although apartment ownership is based on 2D registration, it is the most common 3D legal object registered in all of the analysed jurisdiction. A 3D cadastral system requires to redefine property ownership using clear 3D language and develop appropriate legalisations to partition, consolidate, and administer vertically stratified properties in a 3D digital environment, as can be seen from the case studies that have been explored in (Kitsakis et al., 2018). For instance, according to case studies conducted in Australia (Queensland and Victoria) and Sweden, such legislations can provide a clear understanding and interpretation of complex RRR spaces above and below the earth’s surface.

In a more recent study conducted by Çağdaş et al. (2020; 2018), various jurisdictions and land administration standards have been compared regarding co-ownership shares (or common properties) in condominiums. Seven countries (Denmark, Germany, South Africa, Sweden, Switzerland, the Netherlands, and Turkey) were examined in order to evaluate techniques and processes used for the distribution of co-ownership shares in condominium systems. The study found that actors who determine the co-ownership shares differ from one jurisdiction to another. For instance, the co-ownership shares are specified by the project architect in Turkey while the cadastral authority is the actor determining co-ownership shares in Sweden. Moreover, the study found that LADM and the Land and Infrastructure (LandInfra) standards have been compared in terms of their capability to support 3D digital representation of condominiums. The comparison showed that semantically richer entities and code lists, such as condominiumMainPart, condominiumAccessoryPart, jointAccessFacility, and jointOtherFacility, are provided to describe condominium parts by LandInfra. However, LADM provides more general code list class (i.e. LA_BuildingUnitType with individual and shared values) to differentiate condominium parts (Çağdaş et al., 2018). Moreover, in a study by Pouliot et. al. (2019), LADM, LandInfra (InfraGML), and LandXML content were compared using schema matching techniques to see how well they matched.

3. METHODOLOGY

As depicted in Figure 2, the methodology of this study comprises several steps. Each step is explained in the following subsections.

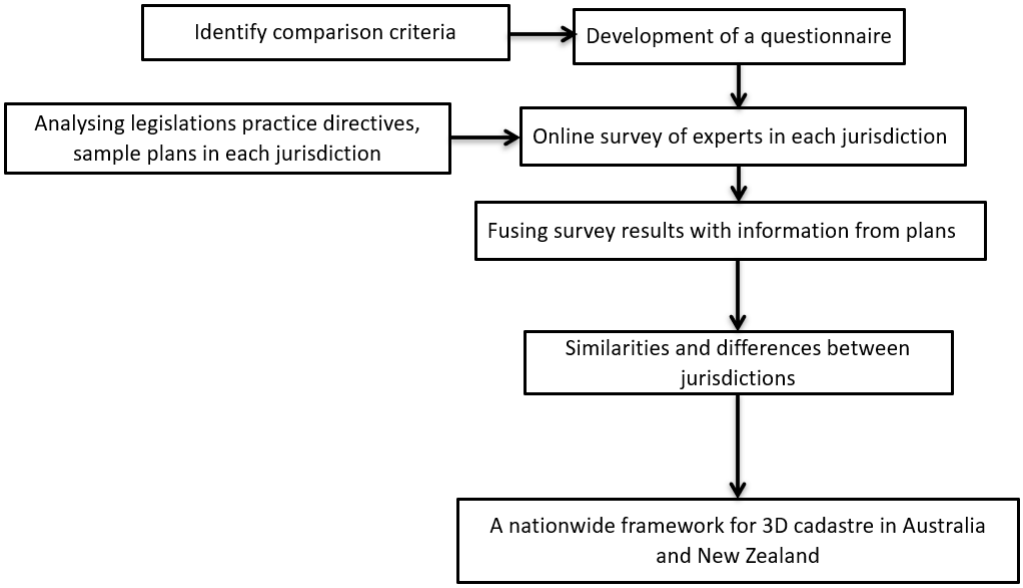

Figure 2. Research methodology adopted for studying 3D cadastre in Australia and New Zealand

3.1 Identification of comparison criteria

The first and fundamental step was development of appropriate criteria for comparing jurisdictions. Based on the current literature and our previous study in the Victorian

jurisdiction, the following criteria have been considered as critically important ones for identifying the similarities and differences between jurisdictions:

- Types of primary parcels and their shape
- Types of secondary parcels and their shape
- Spatial relationships between primary and secondary parcels
- Legal boundary types

It is important to note that the above-mentioned criteria do not provide a complete set of cadastral datasets required in each jurisdiction. Survey information such as traverse lines and survey marks may be also considered as part of cadastral datasets; however, this information has already been addressed in the current national ePlan model.

3.2 Development of a questionnaire

By considering the comparison criteria, a questionnaire was developed to seek cadastral experts' input regarding data elements of 3D cadastre in their jurisdiction. To provide a clear explanation of each question, we provided examples derived from Victoria's practices. These examples were given in line with the data elements provided in the ePlan protocol. The questionnaire comprised two parts:

- **Part One - Respondents' details:** In this part, the questions were mainly developed identify the profile of experts participating in this study. The questions of this part mainly asked about the experts' organisations, position title, expertise area and years of experience. The respondents were mainly land registry experts in each jurisdiction.
- **Part Two - Data elements of 3D cadastre:** The questions of this part asked about various questions from the respondents to identify 3D cadastral data elements in their jurisdiction. For each question, the relevant definitions and examples were given to the participant to help them better understand the purpose of the question. The questions for this part are presented in Table 1.

Table 1. Questions developed for identifying 3D cadastral data elements

Question Number	Question
1	What are the possible primary parcels defined in subdividing vertical developments?
2	What defines the 3D spatial extent (shape) of each primary parcel?
3	What are the possible secondary interests considered in vertical developments?
4	What defines the 3D spatial extent (shape) of each secondary interest?
5	How do you define relationships between a primary parcel and a secondary interest in strata developments?
6	What are the legal boundary types delineated in vertical developments?

3.3 Online survey of experts in each jurisdiction

An online survey was conducted using Survey Monkey platform. For this online survey, the following information was given to each participant:

- **The plain language statement:** This document provides a short description of study in a simple language.

- **Consent form:** In this form, it is stated that participation in this research is completely voluntary. Participants had the right to withdraw at any stage, or to withdraw any unprocessed data they have supplied, they are free to do so without prejudice. They also agree that each participant may be identifiable as a participant due to the small sample size. However, the confidentiality of the information they provided will be safeguarded, subject to any legal requirements. It was also mentioned in the consent form that responses and comments provided by each participant will be kept confidential.
- **The questionnaire form:** This form included the questions that each participant was required to answer for identifying 3D cadastral data elements.

The participants firstly read the plain language statement and signed the consent form. Subsequently, each participant was asked to complete the questionnaire.

3.4 Analysing legalisations, practice directives and sample plans in each jurisdiction

In order to enrich our understanding of 3D cadastral data elements in each jurisdiction, we investigated legislations, practice directives as well as the content of current sample cadastral plans that were used for subdividing and registering ownership in vertical developments. The plans included different types of floor plans, cross-sections, and isometric diagrams created in each jurisdiction.

3.5 Fusing survey results with information extracted from sample plans

The answers provided from participants of the online survey were investigated further by considering the information provided in the studied sample plans to provide more accurate understanding and interpretation of 3D cadastral data elements in each jurisdiction. This helped us to perform a more concrete comparison of jurisdictions.

3.6 Similarities and differences between jurisdictions

The comparison results were used to identify the similarities and differences between eight Australian jurisdictions as well as New Zealand. The comparison outcomes are presented in Section 4.

3.7 Developing a nationwide framework for 3D cadastre in Australia and New Zealand

Based on comparison outcomes, we proposed a general nationwide framework comprising differences and similarities in current practices pertaining to subdividing legal ownership of vertically stratified properties to support 3D cadastre in all jurisdictions of Australia and New Zealand. The components of this framework is detailed in Section 5.

4. SURVEY OUTCOMES AND JURISDICTIONAL COMPARISON

In this section, we will first present the survey outcomes with some tangible examples to showcase the current status of 3D cadastre practices in each jurisdiction.

4.1 Australian Capital Territory (ACT)

In ACT, the common types of primary parcels for 3D cadastre are (ACT Parliamentary Counsel, 2020):

- **Unit:** A unit represents individually owned part of a parcel which is subdivided under Unit Titles Act. There are two classes of units: Class A and Class B. Class A units are depicted as part of a whole building, with their limits established by reference to walls as well as floors and ceilings (see Figure 3). Class B units have boundaries unlimited in height except to the extent of any encroachment at, above or below ground level by another part of the parcel.
- **Unit Subsidiary:** A unit subsidiary annexed to a unit, which means it is appurtenant' to its corresponding unit. For instance, a balcony area is defined as a unit subsidiary (see Figure 3).
- **Common Property:** A common property represents a collective ownership of all parts of the parcel that are not shown as units or unit subsidiaries.

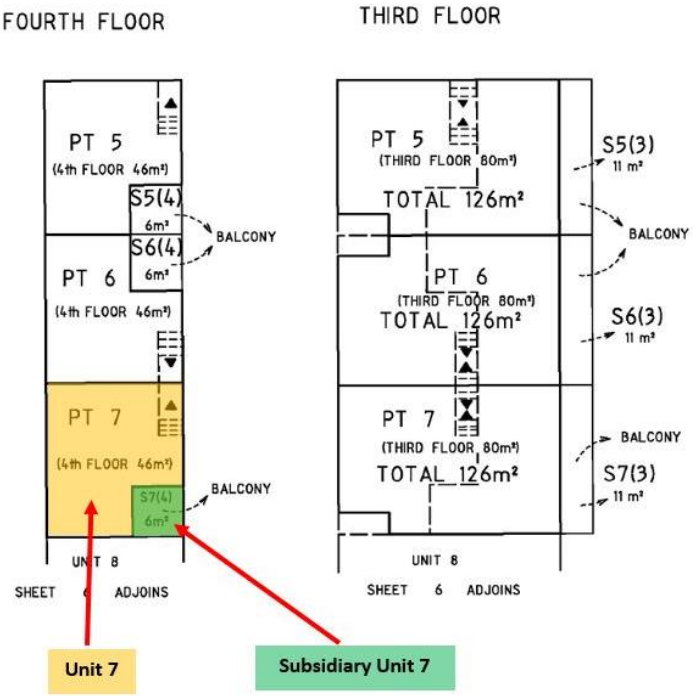

Figure 3. Examples of units and unit subsidiaries in ACT

The well-known 3D secondary parcels identified in the ACT jurisdiction are:

- Easement: Easement is defined as an interest the owner of a benefited estate (i.e., unit or common property in context of the ACT jurisdiction) may have against the owner of a burdened estate.
- Restriction: Restriction imposes a limitation or condition on the land parcel. It must clearly indicate the land which benefits from the restriction and the land which is burdened by the restriction.

The secondary interests typically overlap with the entire or part of primary parcels in the ACT jurisdiction. In the context of 3D cadastre, the legal boundaries defined in this jurisdiction include the following types (ACT Parliamentary Counsel, 2020, 2021):

- Party wall: It means a wall or structure designed for the common use of 2 or more buildings and erected, or to be erected, on a common boundary, or part of such a

boundary, between 2 parcels of land, and extending laterally into each of those parcels of land

- Common boundary: There two types of common boundaries: internal and external. The internal common boundary is typically located at the centre of a floor, wall or ceiling, when the floor, wall or ceiling separates a class A unit or a unit subsidiary from common property or another unit or unit subsidiary. It is also possible to define the internal boundary in any other location inside the floor, wall or ceiling as specified in the relevant unit title application or units plan. The external common boundary is defined by an external wall of the building containing the units. There two scenarios for external common boundaries: 1- The external boundary of the unit or unit subsidiary lies along the centre of the wall 2- The part of the wall outside the external boundary is common property.
- Measured boundary: This type of boundary is delineated using survey measurements and it is typically defined by bearing and distance values for the boundary line.

4.2 New South Wales (NSW)

Among the most prevalent types of parcels used for 3D cadastre in NSW are (NSW Parliamentary Counsel, 2016):

- Lot and part lot: It refers to one or more cubic spaces that make up part of the parcel that the strata scheme relates to, with each cubic space's base being designated as a single lot, or part of one lot (see Figure 4).
- Common property: Common property is the portion of a land that is not included in any individual lot or part lot (see Figure 4).
- Development lot: It refers to a lot in a strata plan that is identified by a strata development contract as a lot that is to be the subject of a strata plan of subdivision under the development scheme.

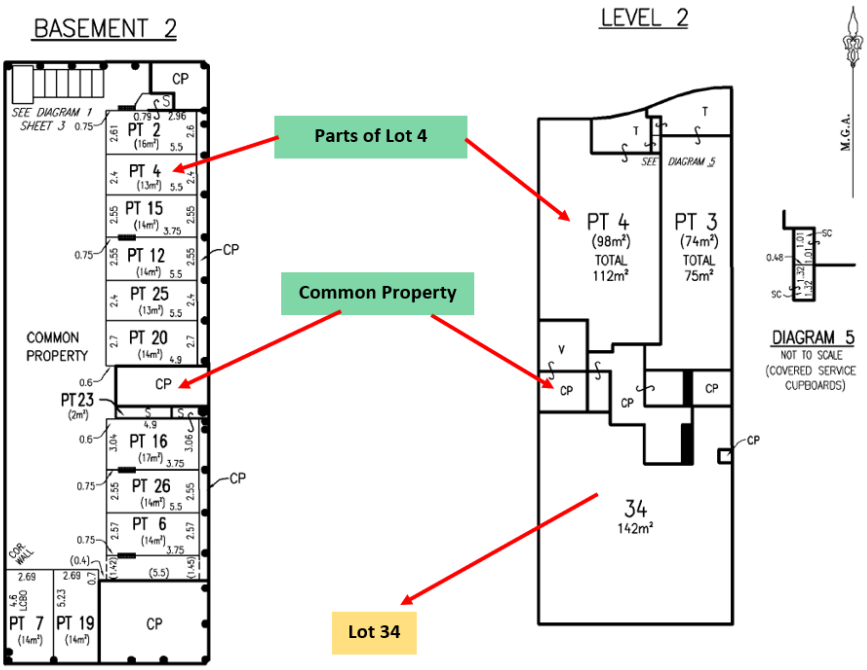

Figure 4. Examples of part lot, lot and common property in the NSW jurisdiction

The secondary interests that are important for 3D cadastre in NSW are (NSW Land Registry Services, 2020):

- Easement: It is defined as being a portion of primary parcel which gives someone (usually a third party) the right to use the parcel for a specific non-exclusive purpose.
- Restriction: It is an agreement between two or more parties that something will not be done with the land. The benefit of the restriction may be adjoining land, nearby land or the council. It is negative (restrictive) in nature and may be created to:
    1. protect a residential amenity e.g. a view.
    2. preserve the environment, e.g. preventing the lopping of trees or restricting where buildings can be erected.
    3. restrict undesirable development and preserve the character of the neighbourhood, e.g. limiting the height of buildings and/or the material of construction and/or fencing type.
- Stratum statement: Stratum statements are required if a lot is not limited in height and or depth by a structure. Lots which are within a building are generally accepted to extend from the upper surface of the floor to the lower surface of the ceiling. A stratum statement will be required for all lots outside a building which are not fully covered by a structure or do not have a structural base for their entire area.

The relationship between primary parcels and secondary interests are determined by notations on plan and Section 88B within the Conveyancing Act 1919 (NSW Parliamentary Counsel, 2021). The notations and Section 88B typically require the surveyor to provide the primary parcels that benefit from and burdened by the easements and restrictions.

Legal boundaries are defined by continuous (i.e., unbroken) lines and there are two common types: building and line boundaries. Building boundaries which are defined by a structure must be shown by thick lines. There are three categories of building boundaries: interior, median, and exterior. Boundaries which are not defined by a structure are referred to as line boundaries. Line boundaries must be dimensioned by distance only and be defined by right angled offsets and/or connections from specified points on a structural feature shown on the floor plan.

4.3 New Zealand (NZ)

In NZ jurisdiction, the following types of primary parcels are considered for 3D cadastre (Land Information New Zealand, 2021):

- Principal unit: A principal unit is a unit that is designed for use (whether in conjunction with an accessory unit or not) as a place of residence, business or otherwise (see Figure 5).
- Accessory unit: An accessory unit is a unit that is designed for use with any principal unit, such as a garden, garage, car parking space, storage space, swimming pool, laundry, stairway, or passage (see Figure 5).
- Future development unit: A future development unit is a type of unit that is shown on a stage unit plan; and is intended to be developed or subdivided into one or more units (with or without accessory units or common property) in a future stage.
- Common Property: Common property is all the land shown on a unit plan that is not: a principal unit; or an accessory unit; or a future development unit (see Figure 5).

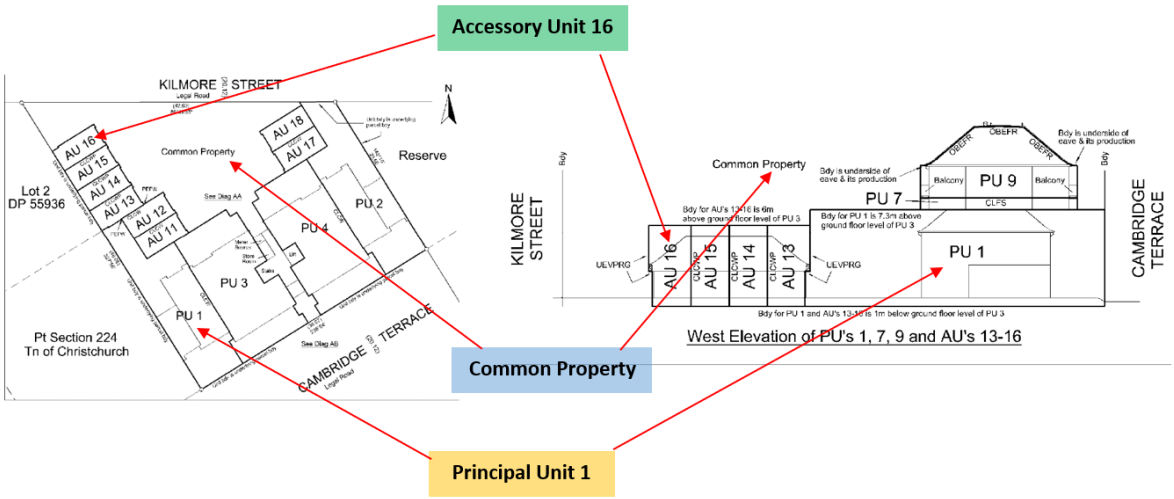

Figure 5. Examples of 3D primary parcels in the NZ jurisdiction (adopted from (Gulliver et al., 2017)

In addition, the following primary parcels are also considered in NZ jurisdiction but may be less common for 3D cadastre purposes:

- owned by the Crown, with the exception of a movable marginal strip parcel
- held in fee simple (mainly private ownership)
- Māori freehold land or Māori customary land
- part of the common marine and coastal area
- the bed of a lake or river
- road or railway,
- vested in a local authority (includes some types of reserves).

The secondary parcels that are identified in this study for 3D cadastre in NZ jurisdiction are:

- Easement: An easement is a right to use another person's land in a particular way. It cannot include any right to have possession of the land or to take any part of the soil or produce of other land.
- Covenant: A land covenant is an agreement whereby the covenantor undertakes to do (or not do) something in relation to their land that would benefit the owner or occupier of the covenantee's land.
- Movable marginal strip: A marginal strip is a strip of Crown land created along the banks of rivers and lakes, or along the foreshore. There are fixed and movable marginal strips.
- Esplanade strip: An esplanade strip is a right over a strip of land that adjoins a river, lake, or the sea.
- Lease: A lease is an instrument under which a lessor confers upon a lessee the right to the exclusive possession of the land being leased, for particular length of time.
- License: A licence to occupy is similar to a lease in that it gives the owner of the licence a right to use a flat or office; and it will have terms and conditions; however unlike a lease, a licence to occupy does not normally have a term/expiry date.

All secondary interests must be represented as a polygon or polyhedron, with the exception of:

- existing centreline easements that meet certain criteria which are allowed to be depicted as a centreline. A centreline easement is defined as an easement which is spatially represented by one or more lines along its centre.
- existing easements that have not been spatially defined previously.

The relationships between primary parcels and secondary interests are depicted spatially. Where the boundaries are defined using right-line, arc and stratum boundaries, sufficient information to enable the relationships to be determined mathematically is also required. There are six legal boundary types that may be used in NZ's 3D cadastre practices. Four are solely for use in defining the horizontal extent:

- Right-line boundary: A boundary that follows the shortest distance between two boundary points
- Water boundary: A boundary set at the landward margin of:
    1. a river bed or a stream bed,
    2. a lake bed, or
    3. the common marine and coastal area or other tidal area,
    4. and includes a natural boundary where this term is used in enactments to refer to a boundary at a water margin
- Irregular boundary: A boundary that is depicted as an irregular line but is not a water boundary
- Arc boundary: A boundary that follows part of the circumference of a circle

The fifth boundary type is solely for use in defining the vertical extent is called stratum boundary. It is a boundary, not being a permanent structure boundary, that defines the upper or lower extent of a parcel. The final boundary type can be used for both the horizontal and vertical extent, which is called permanent structure boundary. It is a boundary related to a permanent structure. Note that a permanent structure is defined as - a building or recognisable physical structure that is likely to remain undisturbed for 50 years or more.

4.4 Northern Territory (NT)

The primary parcels that are identified in this study for 3D cadastre in NT jurisdiction are (Department of the Attorney-General and Justice, 2021):

- Unit: A unit is a lot that is created on the registration of a plan of subdivision or plan of consolidation and specified as a unit in the scheme statement by reference to a cubic space, a parcel of land unlimited in its vertical dimensions, or both (see Figure 6).
- Common Property: It refers to so much of a parcel that is not within a unit. Therefore, a unit or part of a unit, or a body corporate asset, cannot be common property (see Figure 6).
- Road: It is a primary parcel that is used for the benefit of the public.
- Reserve: Similar to roads, reserves are for the benefit and use of public community. Reserves include those land parcels owned by city councils.

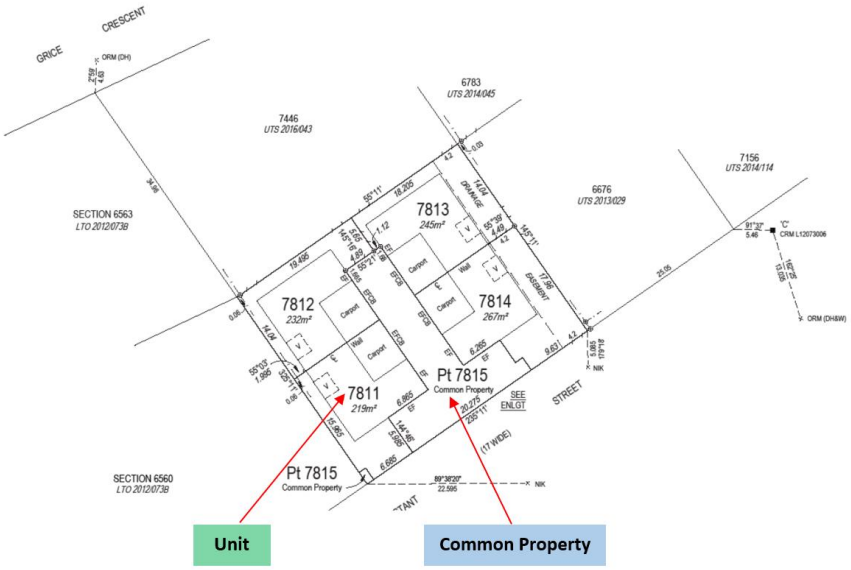

Figure 6. A unit titles subidivison in the NT jurisdiction

There are two main types of secondary interests in the NT jurisdiction for 3D Cadastre:

- Easement: It refers to a right annexed to land (the dominant land) to use other land (the servient land) in a particular manner or to prevent that other land from being used in a particular manner but does not include a right to take the soil or produce of other land. There are two easement types: general and statutory (Department of the Attorney-General and Justice, 2021).
- Covenant: It is an obligation (whether positive or negative) in respect of the use, ownership or maintenance of particular land (servient land) that is created for the benefit of other land (dominant land).

In the NT jurisdiction, the relationship between primary parcels and secondary interests is through overlay as well as annexing the secondary interests to the primary parcels. The legal boundary types in this jurisdiction include measured boundary, a physical boundary referring to a cubic space and a boundary referencing a parcel of land unlimited in its vertical dimensions.

4.5 Queensland (QLD)

In the QLD jurisdiction, the common primary parcels which are important for 3D cadastre include (Registrar of Titles Department of Resources, 2018):

- Base lots: These primary parcels are either Building Format or Community Title Scheme (CTS) standard lots or access/height limited parcels and they are defined for either building subdivision or land subdivision.
- Common property: All strata subdivision needs at least one common property which is managed by body corporate (see Figure 7).
- Road (2D as well as 3D Volumetric parcels): If road is created then land is usually surrendered to the council, however if common properties are used as access then managed by body corporate, easements can also be used for access.

- Building format lots (Units): In buildings, units/apartments are created, and can be multi-part (e.g., one lot can have ownership in multiple levels, a garage and external patio) (see Figure 7).
- Volumetric format lots: These primary parcels often created to reserve an initial envelope (see Figure 8) and further subdivided into building format lots and they also used for structural/infrastructure/utilities features, or roads.
- Private courtyard: Some apartments have private courtyards in the title shown on a plan with dimensions, which is obviously limited to the owners of the ground floor, and other floors have no access to these courtyards (see Figure 7).

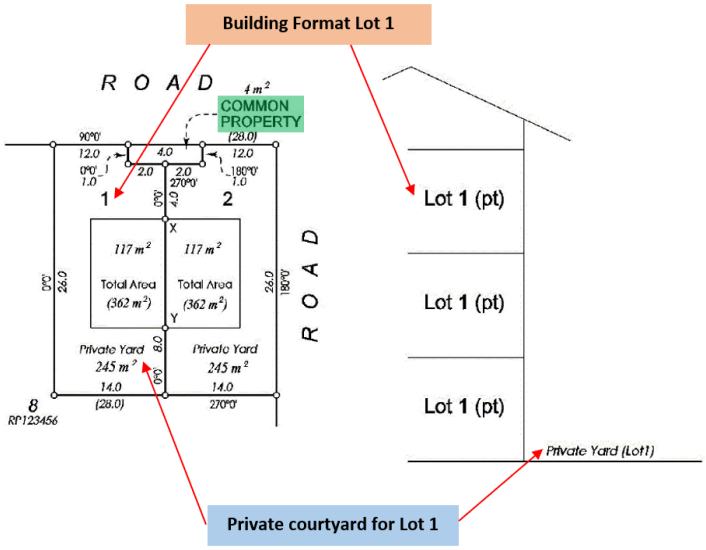

Figure 7, Examples for building format plans
(adopted from Registrar of Titles Department of Resources, 2018)

The main secondary interests in QLD jurisdiction for 3D Cadastre are:

- Permits: This includes permits over trust, road, creek, river, reserve, USL with a lot-on-plan title reference, land beyond tidal boundary (river), land beyond tidal boundary (ocean)
- Lease: In a lease, the lessor, as the registered owner, provides the lessee an estate or interest in land for a specified time in exchange for the lessee paying rent. As long as the lease is in effect, lessees maintain title to leasehold property, while lessors hold the reversion, which is the lessor's ownership interest in the land subject to lease. An asset of the lessee, the leasehold estate may be transferred during the lessee's lifetime or at his/her death.
- Easement: An easement is a right annexed to land to utilise other land in a particular manner. It does not involve the taking of any part of natural produce of the land or any part of its soil. It may, however, prevent the owner of the other land from utilising his/her land in a particular manner.
- Covenant: It is a voluntary agreement that creates an obligation by a deed entered into by the parties. Covenants may be of a positive nature in that they require the performance of an action. They may also be negative or restrictive, that is one of the parties is forbidden from undertaking or performing a specified action. Examples of using covenants include:

1. a building on the lot/land must be used for educational or residential or commercial purposes,
2. the covenant area must be used for noise attenuation purposes
3. the lot/land is to be used only for the purpose of construction of buildings used for the development of technology
4. the lot/land is to be used only for the purpose of construction of water-sensitive residential housing.

- Profit a prendre: It is an interest that arises by an agreement between two parties and relates to the right of one party to enter on the land of the other and extract or remove part of the land's substance. In simple terms, it is the right to take soil (e.g. sand, gravel) or produce (e.g. wood, turf, fish, etc.) from another's land or to graze animals on it.

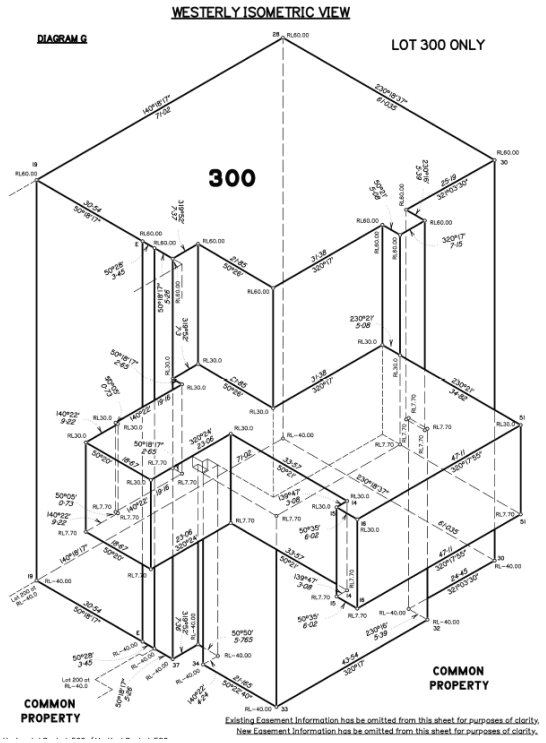

Figure 8. An example of volumetric lot in the QLD jurisdiction

In terms of the relationships between the primary parcels and secondary interests, a secondary interest is typically constrained within primary parcels. The legal boundaries of parcels are typically delineated using by using bearing and distance values alongside the boundary lines. Another common type of legal boundaries is a physical feature boundary. It is a boundary of the land whose location follows a physical feature, which can be either natural or artificial. The physical feature exists now or used to exist, and no longer exists. There are two scenarios for physical feature boundaries: ambulatory and fixed. If a dramatic change has not caused them to become permanent, the limits of water and other natural features are continually moving about, while artificial features are always fixed. It is important to note that physical feature boundaries come in many forms:

- Tidal and non-tidal water boundaries
- Other natural feature boundaries, e.g. cliffs and watersheds

- Artificial feature boundaries. For example, a constructed rock wall can be adopted as a boundary.

4.6 South Australia (SA)

In the SA jurisdiction, the common primary parcels which are important for 3D cadastre include:

- Allotment: It refers the whole of the land comprised in a certificate of title. An example of allotment is provided in Figure 9.
- Unit: The boundaries of the units are defined by reference to parts of the building, not by reference to the land. The units are defined under Strata Titles Act 1988 (South Australia Government, 2021b) (see Figure 10).
- Unit Subsidiary: The units may also include unit subsidiaries set aside for the exclusive use of a particular unit, for example carport or yard (see Figure 10).
- Community lot: It refers to an individually owned land parcel or ownership space that is created under Community Titles Act 1996 (South Australia Government, 2021a).
- Development lot: It refers to the land comprised in a development lot that will be divided during a subsequent stage or stages in accordance with a development contract.
- Lot: It refers to a community lot or a development lot
- Lot Subsidiary: It refers to an area within the building or comprising land outside the building to be used for a purpose that is ancillary to the purpose for which the rest of the lot is to be used
- Strata Lot: It refers to a community lot created by a strata plan. Strata lots are defined upper and lower boundaries as well as lateral boundaries (see Figure 9).
- Common Property: Common property is the part of the land and building in the strata plan which does not form part of any unit and is for common use by all owners, e.g. stairways, paths and driveways.
- Road: A road parcel is vested in a council or prescribed authority
- Reserve: A reserve parcel is vested in a council or prescribed authority.

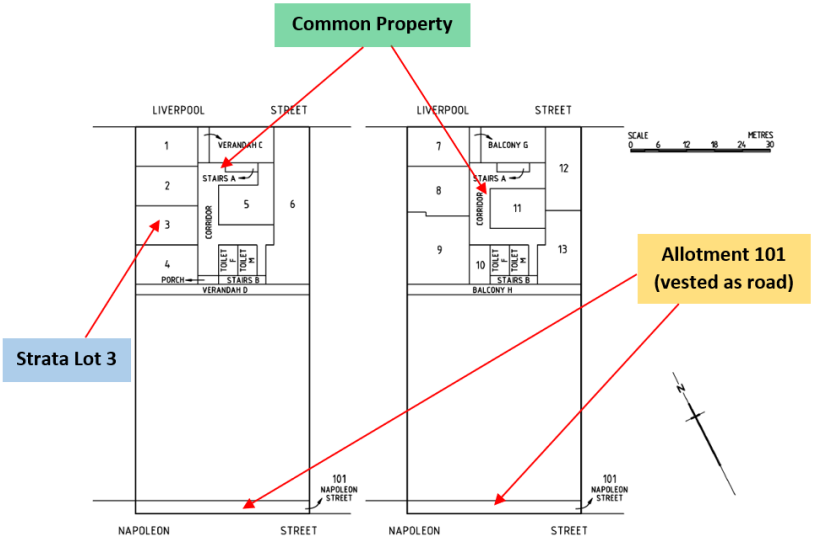

Figure 9. Floor plan diagram examples for Community Strata Plan with an allotment to vest as public road

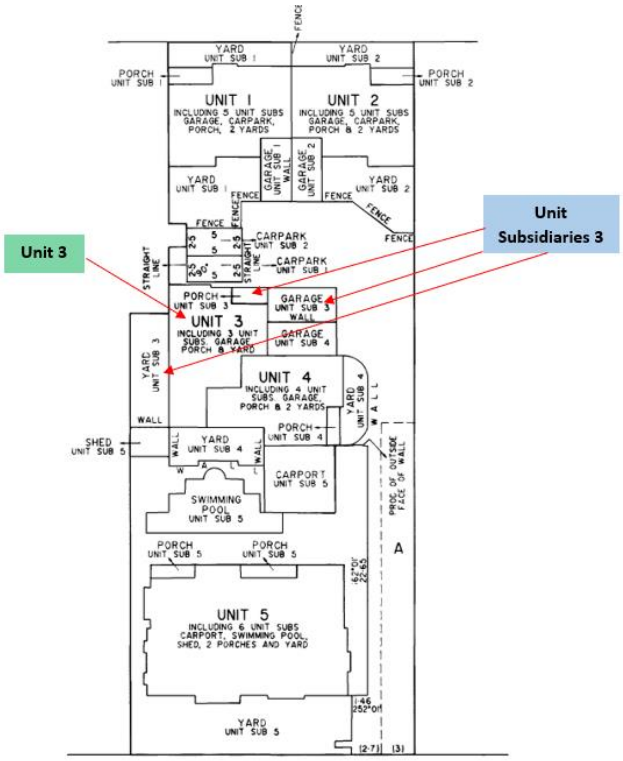

Figure 10. Floor plan diagram for a Strata Plan

The secondary interests include easements and restrictions. In strata subdivisions, the easements are used for support and shelter and allow for the establishment and maintenance of pipes, ducts, cables and other equipment. Restrictions typically apply to the appearance of community lots or buildings or other enhancements placed on community lots. In addition, as much as possible SA jurisdiction tries to apply the restriction to the common property so that it is more manageable in the future.

In regard to the relationship between primary parcels and secondary interests, any secondary interest can be defined over any primary parcel or portion of it. The legal boundaries are typically defined through the following types:

- Wall or fence boundary: When a wall or fence is used to define a boundary, the boundary is the inside surface of the wall or fence.
- Floor boundary: When a floor is used to define a boundary, the upper surface of a floor is used to define the boundary.
- Ceiling or roof boundary: When a ceiling or roof is used to define a boundary, the under surface of a ceiling or floor is used to define the boundary.
- Surveyed boundary: Boundary is defined by measuring bearing and distance of the boundary line.

4.7 Tasmania (TAS)

In TAS jurisdiction, the following primary parcels are generally defined:

- Private Parcel: Land privately owned by an individual(s), organisation, or company

- Water Area: An “arbitrary” parcel over part or whole of a lake, river, estuary for the purpose of completing a “base” layer for TAS jurisdiction.
- Authority Land: It refers to primary parcels owned or managed by a Commonwealth, State or Local Government Agency, Government Business Enterprise (GBE) or a legislated Authority.
- Casement: This primary parcel forms part of the Road, Railway or Footway network

In the context of 3D cadastre, the following two primary parcels are prevalent in strata plans:
- Lot: It refers to an area or space allocated for separate occupation by the owner of the lot or a person deriving rights of occupation from the owner.
- Common Property: It means all land within the scheme that is not within the boundaries of a lot and all other property administered by the body corporate

The secondary interests relevant for 3D cadastre are:
- Easement: It is defined as a set of legal rights and restrictions over land favouring a person or party registered on the property title.
- Covenant: It is similar to the definition provided in QLD and NSW jurisdictions
- Profit a prendre: It is similar to the definition provided in QLD and NSW jurisdictions

In terms of the relationships between primary parcels and secondary interest, a secondary interest exists over the primary parcel. For example, easements exist over the lots and common property in favour of the body corporate and the owners of lots to the extent reasonably necessary for the installation, maintenance, operation, repair, and replacement of service infrastructure.

4.8 Victoria (VIC)

The primary parcels in Victoria include (State Government of Victoria, 1988):
- Lot: A lot typically refers to a piece of land, building, airspace or any combination of these, which is assigned to an individual or a private owner (see Figure 11).
- Common property: A common property refers to parts of land and buildings that are not considered as lots, reserves, or roads. All lot owners collectively own the common property.
- Road: A road is a type of primary parcel which is for the benefit and use of public community. There are various types of road parcels such as carriageway, pavement, verge, and kerb.
- Reserve: Similar to roads, reserves are for the benefit and use of public community. Reserves include those land parcels owned by city councils. City council usually uses these parcels to establish parks or similar amenities. Reserves are typically assigned to pieces of land.
- Crown parcels: This refers to those primary parcels owned by the government. Crown land constitutes almost one-third of Victoria, and these parcels are allocated for public use, which typically includes national parks and state forest, freeways, recreation areas, hospitals and sporting facilities (DELWP 2016). There are two types of crown parcels: crown portion and crown allotment.

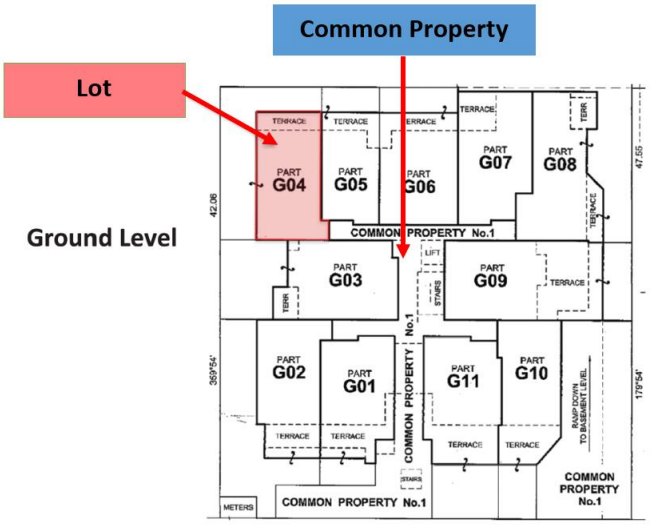

Figure 11. Lot and common property in a building subdivision plan

The secondary legal interests in Victoria include:

- Easements: Easement is part of the land or building owned by one interest holder that can be used by another interest holder or public authority.
- Restrictions: Restrictions are a type of covenant which defines the area or space on one or more lots where limitations on the use of the land apply.
- Depth limitations: Depth limitation is a form of restriction that originates from the original crown grant in Australia.

There are two common types of legal boundaries: general and fixed. General boundaries are specified and observed based on real world, tangible spatial objects. Fixed boundaries are specified based on surveying measurements such as distance, angle, and azimuth. There are three main types of general boundaries:

- Building: Building boundaries are defined and measured by considering the building structure or a part of it.
- Ambulatory: Ambulatory boundaries are defined based on observing the movement of dynamic natural features such as coastlines and river borders
- Projected: Projected boundaries are defined in balconies and terraced areas of buildings. It is mainly delineated by extending structural boundaries in both and vertical directions.

4.9 Western Australia (WA)

The primary parcels that can be considered for 3D cadastre in the WA jurisdiction are:

- Lot on Strata Plan: One or more cubic spaces forming part of the parcel to which a strata scheme and are defined by a combination of statements and dimensions depicted on the floor plan(s)(see Figure 12). Each lot is limited in height and depth.
- Common Property on Strata Plan: Any part of the scheme not labelled with a lot or part lot number is common property. This includes the airspace and land above and below the height and depth of each lot/part lot.

- Lot on Survey-Strata Plan: The lot boundaries are shown as dimensions and survey detail similar to deposited plans which depict green title lot boundaries (see Figure 13). They are usually unlimited in height and depth unless noted on the survey-strata plan.
- Common Property on Survey-Strata Plan: The areas that are common property are shown on the plan prefixed by the letters CP, e.g. CP3. (see Figure 13)
- Dedicated Road: A road or street dedicated to public use. This land is crown land under the control and management of the local government.
- Reserve: Areas of Crown Land set apart for various public purposes, such as parks, recreation, drainage or church sites.

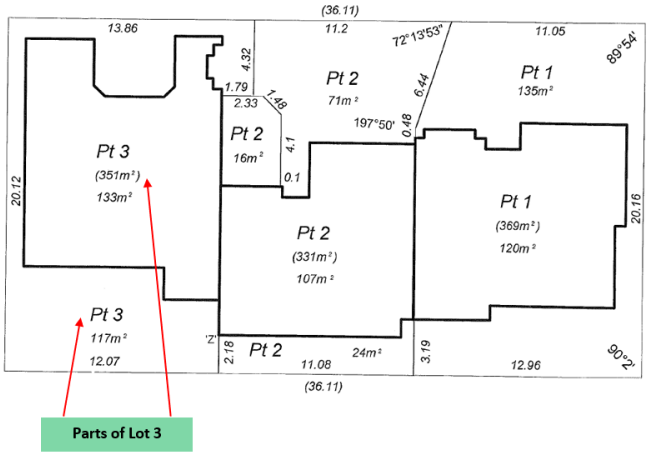

Figure 12. Example of lot on strata plan in the WA jurisdiction (adopted from Western Australia's land information authority, 2021)

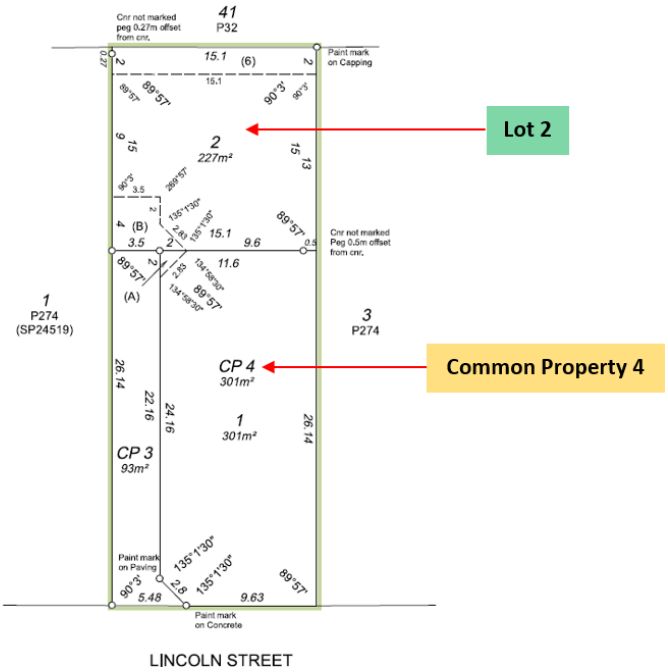

Figure 13. Example of lot and common property on survey-strata plan in the WA jurisdiction (adopted from Western Australia's land information authority, 2021)

The secondary interests identified in WA jurisdiction are similar to those in VIC jurisdiction. The relationship between these interests and primary parcels are typically identified by dimensions and comments on strata and survey-strata plans. The legal boundaries are defined through one of the following methods:

- Building boundaries
- By dimensions: This boundary type is used to define part lots external to the building and survey strata boundaries
- Stratum definitions for height and depth
- Imaging mixture of dimensions and statements, e.g. prolongation of external face of wall.

4.10 Similarities and differences between jurisdictions

The findings show that Australian and New Zealand jurisdictions have some similarity in terms of managing 3D cadastral data while there some differences between them. One main similarity is that 3D legal boundaries are typically delineated by either referencing physical structures or fixed survey measurements. Common property as a primary parcel and easement as a secondary interest have similar purposes in all Australia and New Zealand jurisdictions.

The differences mainly refer to the different types and terminologies used for primary land parcels and secondary interests in each jurisdiction. In addition, similar ownership concepts are named differently in each jurisdiction. For instance, the "Lot" primary parcel, which defines the ownership space of a private property, in Victoria is the same as "Unit" parcel in Northern Territory. All jurisdictions, except VIC, have specific legislations for 3D cadastre. For example, VIC jurisdiction considers a unified legislation, under Subdivision Act 1988, for dealing with any type of land and property ownership. Table 2 shows the summary of different 3D cadastral data elements in Australian and New Zealand jurisdictions.

Table 2. Important 3D cadastral data elements in Australian and New Zealand jurisdictions

Jurisdiction	Primary parcels	Secondary interests	Spatial relationships	Legal boundaries
ACT	Unit, Unit Subsidiary, Common Property	Easement, Restriction	Secondary interests overlap with the entire or part of primary parcels	Party wall, common boundary (internal and external), measured boundary
NSW	Lot, Part lot, Common Property, Development Lot	Easement, Restriction, Stratum Statement	Notations on plan, Section 88B instrument of the Conveyancing Act 1919	Building boundary (interior, exterior, median), ambulatory boundary, line boundary
NZ	Principal Unit, Accessory Unit, Future Development Unit, Common Property	Easement, Covenant, Movable marginal strip, Esplanade strip, Lease, License,	The relationships are depicted spatially. Where the boundaries are defined using right-line, arc and stratum boundaries, sufficient information to enable the relationships to	Right-line boundary, water boundary, irregular boundary, arc boundary, stratum boundary, permanent structure boundary

			be determined mathematically is also required.	
NT	Unit, Common Property, Road, Reserve	Easement (general, statutory), Covenant	Secondary interests overlay on the base primary parcels.	Measured boundary, Boundary referring to a cubic space, Boundary referencing a parcel of land unlimited in its vertical dimensions
QLD	Base Lots, Common Property, Road, Building format Lots (Units), Volumetric format lots, Private Courtyard	Permits over: Trust, Road, Creek, River, Reserve, Land beyond tidal boundary (river), Land beyond tidal boundary (ocean), Lease, Easement, Covenant, Profit a prendre	Strata development constrained within primary parcel	Bearing and distance, physical feature boundary (Tidal and non-tidal water boundaries, Other natural feature boundaries, Artificial feature boundaries)
SA	Allotment, Unit, Unit Subsidiary, Lot (Community or Development Lot), Lot Subsidiary, Strata Lot, Common Property, Road, Reserve	Easements, Restrictions	An interest can be defined over any primary parcel or portion of it.	Wall or fence boundary, Floor boundary, Ceiling or roof boundary, Surveyed boundary
TAS	Lot, Common Property, Private Parcel, Water Area, Authority Land, Casement	Easement, Covenant, Profit a prendre	Secondary interests exist over the primary parcels	boundary structure (Centre of the structure or other specified location), Measured bearing and distance
VIC	Lot, Common Property, Road, Reserve, Crown Portion, Crown	Easement, Restriction, Depth Limitation, Crown Land Service	Secondary interests are spatially related to the primary parcels	Building boundary (interior, exterior, median, other), ambulatory boundary, projection, fixed boundary

	Allotment,			
WA	Lot on Strata Plan, Common Property on Strata Plan, Lot on Survey-Strata Plan, Common Property on Survey-Strata Plan, Dedicated Road, Reserve	Easement, Restriction, Depth Limitation	Dimensions and comments on strata and survey Strata plans	Building boundaries, By dimensions for part lots external to the building and survey strata boundaries, Stratum definitions for height and depth, Imaging mixture of dimensions and statements (e.g. prolongation of external face of wall)

5. PROPOSED FRAMEWORK

By considering the differences and similarities outlined in Section 4, we proposed a new framework to support 3D cadastral data elements in all of the studied jurisdictions. As shown in Figure 14, there are four tiers for the proposed framework:

- **Definition tier:** This tier includes the definition elements that are fundamental to the developed framework for 3D cadastre in Australia and New Zealand. These elements provide a set of basic and generic entities related to geometric and topologic representations as well as various semantic definitions. Modelling 3D cadastral elements' geometric or spatial shape is described using a number of different geometric representation techniques such as solid models (e.g., Boundary representation, Constructive Solid Geometry), multi-surface and tessellated models. Topological elements can include vertex, edge, and face. In addition to geometry and topology concepts, a range of semantic definitions of basic concepts related to 3D cadastre are considered in this part of the framework. For instance, an agreed definition of 3D land parcel can be included. These definition and concepts provided here can be used in core, interoperability, and jurisdictional elements.
- **Core abstract tier:** This tier includes abstract and general data elements. Primary parcel, secondary interest, legal boundary, survey element, and physical element are the most common types of items in this category. All subsequent specialisations in interoperability and jurisdiction elements are defined based on data elements considered in this section of the framework. The abstract elements considered are not instantiated in the real-world cases. However, the fundamental structures, essential relationships, and broad concepts established by these elements can then be reused and refined by classes in the interoperability and jurisdictional tiers.
- **Interoperability tier:** In this tier, data elements that are shared across all jurisdictions based on their similarities are defined. This tier is significantly important for supporting data exchange and semantic interoperability between Australian and New Zealand jurisdictions. Among primary parcels, lot and common property are similar data elements among all jurisdictions while easement is considered as a secondary interest in all

jurisdictions. More specialised concepts of physical elements include wall, floor, ceiling, and roof which are mainly used for defining building boundaries in the studied jurisdictions. In addition, these physical elements can be used as part of the entire spatial structure of common property parcels. In terms of survey elements, all jurisdictions generally consider survey marks and observations to define survey network and measure legal boundaries. In general, interoperability data elements can be used to communicate and share 3D cadastral information between jurisdictions.

- **Jurisdictional tier:** The most specific data elements for each jurisdiction are defined within this tier. The jurisdictional data elements are self-contained, and there is no possibility to further specialize or reference them in other tiers. This tier includes a set of specific data elements for nine jurisdictions, namely ACT, NSW, NZ, NT, QLD, SA, TAS, VIC, and WA. These data elements may include specific elements, attributes, relationships, and code lists that are used in a particular jurisdiction. For instance, in VIC jurisdiction, the median boundary can be defined as a specific type of physical boundary.

6. DICUSSION AND CONCLUSIONS

In this research, we studied the current practice of 3D cadastre in all Australian states and territories as well as New Zealand jurisdictions. By using a questionnaire, we have used the land administration experts' input to identify different types of primary parcels, secondary interest, legal boundaries as well as the relationships between the primary parcels and secondary interests. Out investigation of sample cadastral plans, the relevant land and property legislations as well as guidelines and survey practice directives helped us to better consolidate our findings and obtain a more concrete understanding of 3D cadastral data elements in the studied jurisdictions. Our study helped us to identify the similarities and differences between these elements across the jurisdictions. In addition, we developed a new generic nationwide framework to describe how specific jurisdictional practices can be harmonised. Theoretically, our proposed framework would provide a starting point for developing a nationally connected digital data ecosystem for 3D cadastre in Australia and New Zealand.

Moving towards 3D digital cadastre can be considered through three common lenses: technical, legal, and institutional. From a technical point of view, developing a new 3D data model for is fundamentally important for implementing 3D digital cadastre. The data model provides the basis for the lifecycle of 3D digital data including data capturing, validation, visualisation, storage, query and analysis. Currently, the 3D Cadastral Survey Data Model and Exchange (3D CSDM) is being developed to provide a standard for transferring digital cadastral survey information between the survey industry and government land administration agencies in Australia and New Zealand. This data model should be able to support 3D cadastral data elements in various jurisdictions that we studied in this investigation.

The implementation of the conceptual data model for 3D cadastre is done through developing appropriate technical encodings. In our view, building information modelling (BIM) and its IFC standard can be considered as an appropriate encoding for exchanging 3D digital cadastral data during subdivision processes including planning permit, certification, and registration. This is due the fact that BIM models provide rich 3D digital data sharing space

during the building lifecycle. It would also facilitate 3D data re-use, share and exchange with other stakeholders such as architects and engineers. However, BIM cannot be a good solution for upgrading the current 2D property map base into 3D digital environment. In this case, a technical encoding based on CityGML or InfraGML standards would provide a suitable approach for storing all 3D cadastral and survey information within a 3D digital cadastral database (3D DCDB).

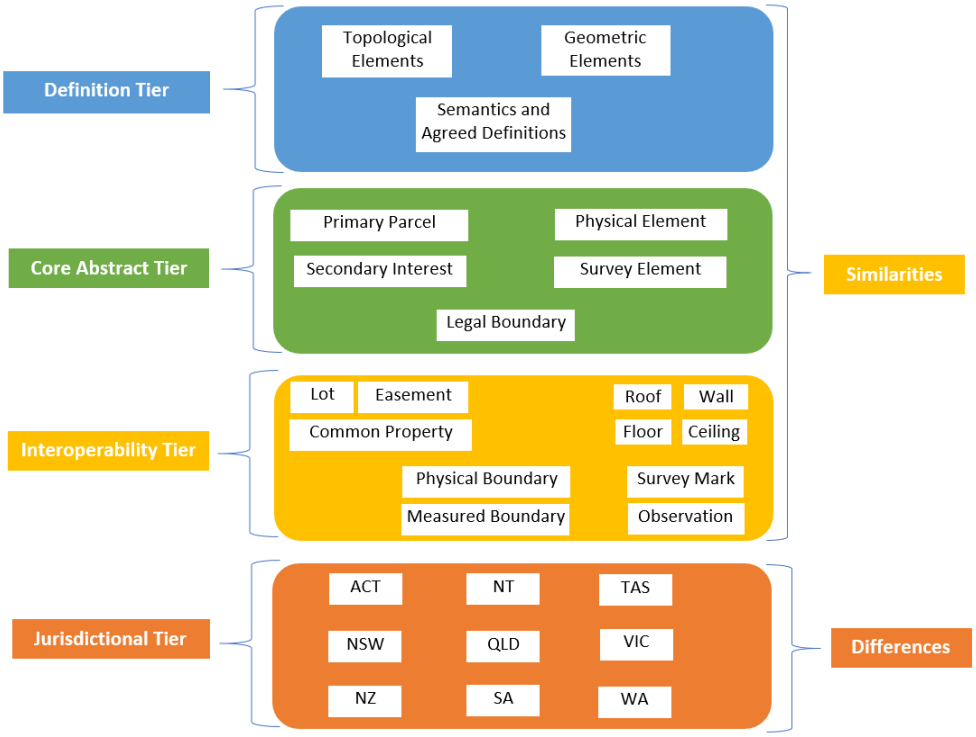

Figure 14. Proposed framework for 3D cadastre in Australian and New Zealand jurisdictions

In terms of legal aspects, the required changes in legislation relevant to supporting 3D digital cadastre implementation should identified. Rules and regulations need to fully support lodging 3D models for cadastral registration. This includes looking closely at the existing Acts and regulations and proposes the required changes for facilitating the change process for 3D digital cadastre implementation. To address the legal challenges, the following key questions are expected to be answered:

- Does the current legislation allow for the registration of vertically stratified ownership rights using 3D digital models?
- What are the required changes to the existing legislation to enable the use of 3D digital data?
- What would be the potential format of 3D digital models as the legal instrument?

Finally, some institutional changes are also expected. This includes changes to the processes and activities at land registries, surveying industry as well as other key land administration stakeholders including councils and referral authorities. This includes looking closely at the existing land administration processes and stakeholders' interaction and proposing the required modifications for facilitating the change process for 3D digital cadastre implementation. The following questions are important for institutional changes:

- What is the appropriate solution for incorporating 3D digital models into the land approval processes undertaken by councils and referral authorities and the government land authorities' registration processes?
- How will plan information be incorporated into the contract of sale for transferring legal ownership, and supplementing real estate marketing?
- How will the surveying and property industries align their systems to read, interpret and make administrative decisions to cadastral information represented in a 3D digital environment?
- Will 3D digital models replace or supplement 2D cadastral plans/ images or data files?

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BIOGRAPHICAL NOTES

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