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Evaluation of the International 3D Geospatial Data Models and IFC Standard for Implementing an LADM-based 3D Digital Cadastre

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Key words: LADM, CityGML, IFC, IndoorGML, LandInfra, InfraGML.

SUMMARY

Land Administration Domain Model (LADM) is an international standard for defining both semantic and spatial information connected with rights, restrictions, and responsibilities (RRRs) that affect land, water, built assets, natural resources, underground spaces, and airspaces. Since LADM is currently a conceptual land administration model, one of the main goals for the new version of this standard is to develop technical encodings. These technical encodings would be useful for adopting the LADM in different applications related to land administration. Therefore, the conceptual schema of LADM standard can be implemented in different and varying ways depending on the implementation requirements. The aim of this paper is to evaluate current standards used widely in the domains of geospatial information systems (GIS) and building information modelling (BIM) in terms of their capabilities to serve as an LADM-based technical encoding for 3D digital cadastre implementation. Some of these standards are CityGML, Industry Foundation Classes (IFC), IndoorGML, and LandInfra/InfraGML. There should be a specific use case for each implementation model or technical encoding. For example, a BIM-based implementation of the LADM standard can be useful for 3D digital lodgement of cadastral data when dealing with individual building and property subdivisions. LADM data encoded within a BIM model would be useful during planning, certification, and registration of a new complex subdivision, especially within built environments. In addition, LanInfra/InfraGML can provide another encoding option for 3D digital land registration. More specifically, LanfInfra/InfraGML supports surveying elements which are not well supported in IFC, CityGML and IndoorGML standards. Another option is CityGML technical encoding that can be effective for producing 3D digital property maps for an entire jurisdiction. Current property maps only depict 2D land parcels and ignore spatial and ownership dimensions of vertically placed assets, such as apartments, tunnels, subterranean retail malls, car parks, and utility networks. Developing a CityGML encoding for LADM would be considered a significant milestone towards realising 3D property maps that can provide a fully-integrated representation of underground and aboveground RRRs. Finally, IndoorGML is also another technical encoding which may not an appropriate option for 3D digital cadastre, but it can enable the use of LADM data for lawful indoor navigation. The main contribution of this study is to identify the possible technical encodings for the LADM standard and how various spatial and semantic entities within each encoding can be used to model the equivalent concepts defined in the LADM standard. This would provide guidelines for implementing the conceptual model of LADM using a specific 3D geospatial or BIM standard.

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1. INTRODUCTION

3D digital cadastre is a well-researched topic in the research field of land administration (van Oosterom 2018). However, from a practical perspective, 3D digital cadastral systems have not been implemented in any jurisdiction yet. The Land Administration Domain Model (LADM) provides a conceptual description of essential entities required for implementing 3D digital cadastre. The LADM standard is developed in the form of Unified Modelling Language (UML) diagrams and there is no specific technical encoding to implement the LADM standard for 3D digital cadastre. LADM provides generic entities, such as spatial units, to describe volumetric legal spaces (Paulsson and Paasch 2015; Lemmen, van Oosterom, and Bennett 2015). In reality, there are various types of legal spaces in each jurisdiction (e.g. lot, common property, and easement in Australian jurisdictions). In addition, legal spaces may have complex geometric shapes such as oblique and curved boundaries (Barzegar et al. 2021; Saeidian et al. 2021). Therefore, depending on the jurisdictional requirements, the LADM standard can be implemented variably.

On the other hand, 3D geospatial data models as well as building information models (BIM) are implemented and used for 3D physical representation of complex built and natural environments. In the geospatial domain, important 3D geospatial data models include:

- CityGML (Groger et al. 2012): It is an open 3D data standard for storing and exchanging digital 3D models of built and natural objects in cities. It includes the essential entities for describing the majority of the typical 3D physical elements and objects in urban environments (such as buildings, roads, rivers, bridges, vegetation, and city furniture), as well as their relationships. It also specifies several standard levels of detail (LoDs) for modelling 3D objects, enabling them to be used for a variety of applications and purposes such as urban planning and facility management.
- LandInfra/InfraGML (Scarponcini et al. 2016): The Land and Infrastructure (LandInfra) conceptual standard is developed for modelling civil engineering infrastructure objects, surveying data and land interests. The conceptual data elements of the LandInfra are facilities, projects, alignments, roads, railways, survey, land features, land division, and "wet" infrastructure (e.g., storm drainage, wastewater, and water distribution systems). The InfraGML standard is implemented to provide a GML-based encoding for supporting all the concepts provided in the LandInfra standard.
- IndoorGML (Lee et al. 2014): It is an Open Geospatial Consortium (OGC) standard for modelling, representing and exchanging datasets associated with indoor spaces. IndoorGML's primary use is for indoor navigation, particularly in complex built environments such as airports, shopping centres and high-rise buildings. IndoorGML

is built on two conceptual space models: the Structured Space Model (SSM) and the Multi-Layered Space Model (MLSM). SSM describes the basic structure of each space layer independently of the space model it represents, while MLSM provides a method for integrating various space structures to support indoor navigation services.

In the BIM domain, the Industry Foundation Classes (IFC) standard provides the most comprehensive standard for open exchange of building and construction data (ISO16739 2013). IFC includes different spatial and semantic elements to manage physical and functional aspects of a building over its lifecycle. The interoperability issues in exchanging BIM data can be addressed by using the IFC standard as a common and open data format among different BIM software packages. Therefore, this standard plays a key role in facilitating data management and communication in the architecture, engineering and construction industry. There is significant literature about the enrichment and use of IFC for 3D land administration (Barzegar et al. 2020; Atazadeh et al. 2019; Atazadeh, Halalkhor Mirkalaei, et al. 2021)

Previous studies have shown that there is a great opportunity to interlink the LADM standard with all the above-mentioned 3D data standards to support 3D digital cadastre (Atazadeh, Olfat, et al. 2021). However, there is no existing study to compare these standards in terms of their capability to support various conceptual data elements defined within the LADM standard.

Therefore, this paper aims to evaluate these encoding standards and their relations with the LADM standard to identify how the concepts defined in the LADM standard can be encoded using 3D geospatial data models and the IFC standard. This will help us to identify which LADM entities are supported by each encoding standard and which ones are not supported. As a result, series of recommendations will be provided for further enhancement of the current 3D geospatial data models as well as the IFC standard to support an LADM-based 3D digital cadastre.

2. LITERATURE REVIEW

In this section, we will review the existing efforts that have been done to implement the LADM standard using the common 3D data standards, including CityGML, LandInfra/InfraGML, IndoorGML and IFC. This review will provide a basis for our assessment of the technical encodings' capability in terms of supporting LADM-driven 3D digital cadastral systems.

2.1 LADM and CityGML

The proposed options for connecting CityGML with LADM primarily advocate that the Application Domain Extension (ADE) mechanism would be used to map LADM concepts into CityGML schema. Rönsdorff et al. (2014) offered two alternatives for building a LADM-based ADE for the CityGML standard. The first option is to develop a jurisdiction-specific profile of LADM and then use this profile as an ADE of CityGML. The second method is to directly implement the essential principles within LADM as an ADE of CityGML, without adapting them for a specific jurisdiction. While Rönsdorff et al. (2014) researched the latter alternative, other researchers have investigated the former in the context of other jurisdictions throughout the world (Gózdz et al. 2014; Li et al. 2016; Gürsoy Sürmeneli, Koeva, and Alkan 2021). Rönsdorff et al. (2014) presented a generic LADM-based ADE with three feature classes: "Parcel," "LegalSpace," and "LegalSpaceGroup." These subclasses were built using the LADM concepts "LA BAUnit," "LA SpatialUnit," and "LA SpatialUnitGroup". The "Parcel" class was externally connected to "LA RRR" in order to semantically specify the RRR information associated with land parcels. The benefit of connecting CityGML and LADM is that it allows us to link physical and legal objects using the CityGML extension method without changing the conceptual structure of LADM. However, there is limited research on the development of a generic approach to specify the linkages that exist between legal spaces defined in LADM and physical elements defined in CityGML (Sun et al. 2019; Kalogianni et al. 2020). Most of the existing studies have focused on a particular jurisdiction.

2.2 LADM and LandInfra/InfraGML

Open Geospatial Consortium (OGC) has recently developed LandInfra/InfraGML for 3D spatial representation of land and infrastructure objects such as highways, trains, tunnels, surveys, alignments, land subdivision, and condominium units (Scarponcini et al. 2016). The legal principles established in LandInfra (and their InfraGML counterparts) correspond to a subset of the LADM standard. LandInfra/InfraGML does not take into account the various kinds of party package provided in LADM. LandInfra/InfraGML focuses on infrastructure and cadastral surveys while minimising the required entities for managing the legal and administrative parts of property development. Stubkjær et al (2018) emphasised the need of aligning LandInfra and LADM standards for modern land administration. They developed cross-standard code lists to promote semantic harmonisation of concepts between LADM and LandInfra/InfraGML, which would result in the minimisation of interoperability issues between LADM and LandInfra/InfraGML.

More recently, Lemmen, Stubkjær, and Oukes (2021) have investigated the interoperability between LADM and LandInfra/InfraGML standards. They identified that these standards are partly complementary to each other while some functionalities are overlapped between LADM and LandInfra/InfraGML. Since LandInfra/InfraGML plays a key role in connecting BIM and GIS data environments, it can be considered as a suitable encoding for implementing the LADM standard.

2.3 LADM and IndoorGML

Zlatanova, Li, et al.. (2016) conducted one of the first studies on the relationship between LADM and IndoorGML, arguing that bridging LADM and IndoorGML would give an integrated strategy to linking physical locations and RRR information for a variety of indoor navigation use cases. Indoor spaces, such as airports, metro stations, and retail malls, have legal zones with varying right accesses and restrictions (Zlatanova, Oosterom, et al. 2016). In another study, Alattas et al. (2017) evaluated the use of LADM and IndoorGML in conjunction for indoor accessibility based on RRR information. This assists users in avoiding inaccessible locations based on the RRR information that they are authorised to. The execution of the integrated LADM-IndoorGML model for two premises demonstrated the feasibility of the suggested technique for providing RRR-based indoor navigation in a real situation.

More recently, the challenges and obstacles associated with transforming the LADM-IndoorGML model have been studied. The transformation challenges were mostly related to the right handling of primary and foreign keys, associations, cardinality of multiplicity, spatial and non-spatial data kinds, spatial data indexing, restrictions, and inheritance (Alattas, Oosterom, and Zlatanova 2018). Addressing these challenges resulted in the creation of a database for the LADM-IndoorGML model, which allows queries to be run to get accessible and inaccessible interior places based on RRR spaces (Alattas et al. 2018). The application of the LADM-IndoorGML model was investigated for indoor evacuation in complex environments and the feasibility of this model was showcased for supporting decision making when incidents occur in educational buildings (Alattas et al. 2020).

2.4 LADM and IFC

Connectivity between LADM and IFC standards has been investigated in few recent studies. Oldfield et al. (2017) conducted a preliminary investigation that identified the usage of property sets for incorporating legal information into the IFC schema. They did not, however, describe how distinct property sets based on LADM attributes can be applied to different IFC entities.

Another study was done by Atazadeh et al. (2018) who considered two theoretical methodologies for linking LADM and IFC standards in order to develop an open data model for combining 3D legal and physical data. The first methodology is extending the IFC standard with LADM data elements while the second one emphasises on the further development of LADM with IFC-based physical elements. Due to a variety of factors, the latter technique would be unfeasible. LADM is a jurisdiction-independent model, and adding physical components would complicate the standard because the method of referencing physical elements to convey legal interests varies from jurisdiction to jurisdiction. As a result, the first approach, expanding the IFC standard with LADM elements, was identified a suitable method for unifying legal and physical data in 3D. This approach has been implemented for a case study building to showcase the viability of mapping LADM concepts into the IFC standard (Atazadeh, Olfat, et al. 2021).

The above-reviewed studies have focused on a particular encoding for implementing the concepts defined within the LADM standard. However, there is no evaluation and comparison of these standards in terms of supporting LADM concepts since each encoding is limited by its capability and may not be able to fully support all the LADM concepts. Thus, in the next section, we will evaluate these encodings in terms of their capabilities for using them to develop an LADM-based 3D digital cadastre.

3. EVALUATION

The evaluation is based on LADM packages, and the main concepts defined within each package. We identified the suitable entities within each technical encoding for mapping LADM concepts. We also considered the appropriate extension mechanisms allowed by each technical encoding.

3.1 Party Package

The party package provides the concepts for modelling information related to various types of parties. In LADM, parties are defined as a person or organisation playing a role in a rights transaction. The core part of CityGML and IndoorGML standards do not provide explicit attributes or classes for encoding party package of the LADM standard. This means that the extension mechanism within standards (e.g. ADE in CityGML) need to be used for implementing LADM concepts defined in the party package. On the other hand, LandInfra/InfraGML and IFC standards include some relevant classes and attributes for implementing the party package. Both LandInfra/InfraGML and IFC standards provide the mechanism of property sets to incorporate any further user-defined attribute, which can also be used to incorporate the attributes from the LADM standard.

In the LandInfra/InfraGML standard, parties can be encoded using attributes of the “Professional” class as well as the “Signature” attribute in the “Statement” class. Another attribute is the “beneficiaryPary” attribute defined the “Easement” class, which can be used to encoding parties such as power companies. In addition, the “Ownership” class is also defined in the LandInfra/InfaGML standard to specify single or multiple owners of a property unit.

In the IFC standard, the 'IfcActor' is the main entity that can be used for encoding parties. Furthermore, several entities described in the IFC resource layer's "IfcActorResource" subschema are significant for encoding LADM concepts in the party package. These entities include IfcActorRole, IfcOrganization, IfcPerson, and IfcPersonAndOrganization. Group parties in the LADM can be encoding by considering both “IfcActor” and “IfcGroup” entities as well as the the “IfcRelAssignsToGroup” relationship entity.

3.2 Administrative Package

The administrative package of the LADM standard includes the concepts defined for modelling basic administrative units, as well as different rights, restrictions, and responsibilities defined by administrative sources. Basic administrative units are used to register multiple spatial units, which have the same right, belonging to the same party.

Since the administrative package mainly includes concepts for defining legal information, this information is not defined in the core part of the IndoorGML, CityGML, and IFC standards. However, LandInfra/InfraGML contains InterestInLand, which is a general class for defining ownership in land parcels, condominium ownerships, and easements intersecting over one or multiple land parcels. Table 1 shows some of the administrative package concepts and their equivalent classes in the LandInfra/InfraGML standard.

Table 1. Administrative package concepts and their possible encoding classes the LandInfra/InfraGML standard

LADM	LandInfra/InfraGML
LA_AdministrativeSource	Statement
LA_Restriction	Easement
LA_BAUnit	PropertyUnit
LA_RRR	InterestInLand

3.3 Spatial Unit Package

In LADM, spatial units are the core concept for defining a wide range of land parcels and legal spaces. This can include a single or multiple parcels of land and water, as well as a single volume or many volumes of space. 2.5D land parcels and 3D legal spaces are frequent types of spatial units in the setting of a 3D digital cadastre. LADM supports two types of 3D legal spaces for modelling building units (LA_LegalSpaceBuildingUnit) and utility networks (LA_LegalSpaceUtilityNetwork).

Table 2. Possible classes in the encoding standards for modelling concepts defined in the Spatial Unit package

LADM	CityGML	LandInfra /InfraGML	IndoorGML	IFC
LA_SpatialUnit	LandUse Room	LandParcel, SpatialUnit	CellSpace	IfcSite, IfcSpace, IfcExternalSpatial Element
LA_SpatialUnit Group	CityObject-Group	Administrative Division, LandProperty Unit	PrimalSpace Features	IfcZone, IfcSpatialZone
LA_Level	CityObject-Group	Administrative Division	PrimalSpace Features	IfcZone, IfcSpatialZone
LA_LegalSpace BuildingUnit	Room	BuildingPart, SpatialUnit	CellSpace	IfcSpace, IfcExternalSpatial Element
LA_LegalSpace UtilityNetwork	Room	Easement, SpatialUnit	CellSpace	IfcSpace, IfcExternalSpatial Element

Table 2 provides the relevant entities within each encoding standard, which can be used for modelling various concepts defined in the LADM Spatial Unit package. CityGML, IndoorGML and IFC standards do not provide specific entities for modelling spatial units since these standards are specifically developed for physical modelling of the built and natural environments. However, the entities identified in Table 2 provide good candidates for using these standards to implement LADM.

On the other hand, LandInfra/InfraGML includes the concept of spatial units explicitly. However, the geometrical shape of spatial units is modelled irrespective of their legal status in LandInfra. Thus, spatial units in LandInfra spatially represents land parcels, easements, and building parts of condominium units.

3.4 Surveying and Spatial Representation subpackage

This subpackage includes concepts required for modelling boundaries of the spatial units as well as the spatial data sources and transformation of coordinate systems. The encoding standards include various entities for modelling LADM concepts defined in the Surveying and Spatial Representation subpackage. Table 3 provides the relevant entities that we identified for mapping surveying and spatial representation concepts into each encoding standard.

Table 3. Entities within each 3D data standard for implementing Surveying and Spatial Representation subpackage

LADM	**CityGML**	**LandInfra/InfraGML**	**IndoorGML**	**IFC**
LA_Point	GM_Point	BEPoint	GM_Point	IfcCartesianPoint
LA_Spatial Source	PointCloud	ImageObservation, SurveyObservation, PointCloudObservation	–	–
LA_Boundary FaceString	GM_MultiCurve	BEString	GM_Curve	IfcConnection CurveGeometry
LA_Boundary Face	GM_MultiSurface	BEFace	CellSpaceBoundaryGeometry (GM_Surface)	IfcConnection SurfaceGeometry
LA_Transformation	CC_CoordinateOperation (ISO 19111:2019)	Transformation	AnchorSpace	IfcCartesianTransformationOperator

4. DISCUSSION AND CONCLUSIONS

In this study, we looked at different well-known international standards for 3D spatial data modelling in relation to their capabilities for encoding the concepts defined in the LADM standard. The conceptual essence of the LADM standard provides us with various encoding solutions. In addition, if jurisdictional profiles are considered, there would be theoretically many implementation encodings of the LADM standard (see Figure 1).

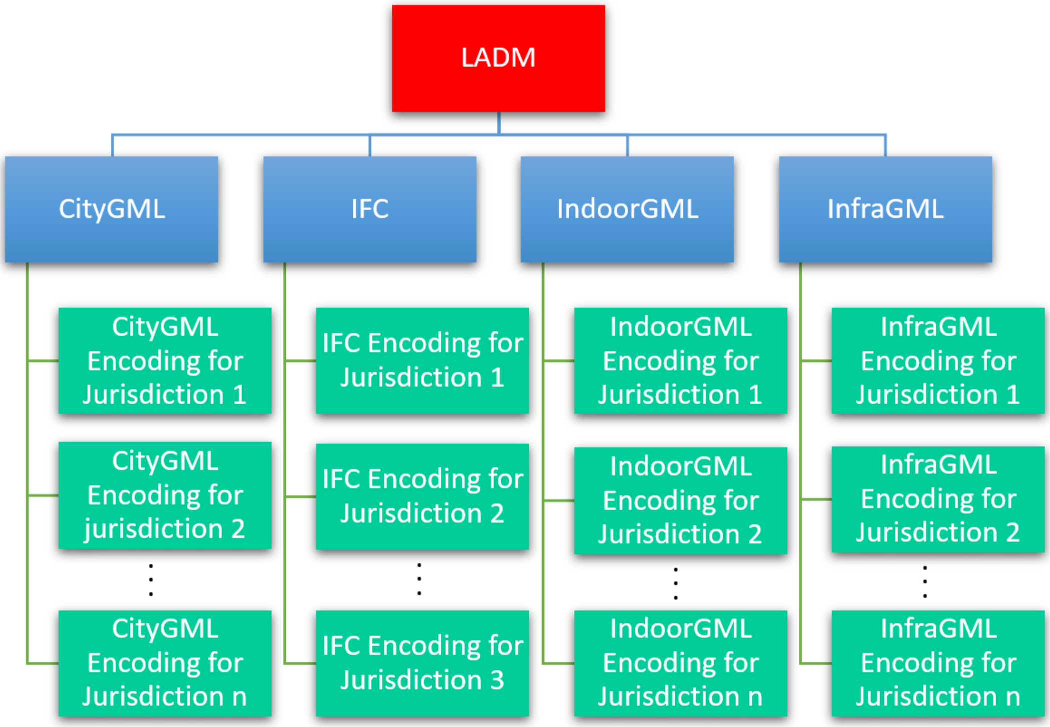

Figure 1. Technical encodings and jurisdictional implementations of the LADM standard

Each implementation model or technical encoding should have a distinct use case. When dealing with individual buildings and property subdivisions, for example, a BIM-based implementation of the LADM standard might be effective for 3D digital lodgement of cadastral data. LADM data encoded inside a BIM model would be beneficial during the design, certification, and registration of a new complicated subdivision, particularly in constructed settings. LADM data can be encoded from the early stages of the building lifecycle. The BIM model in the planning phase may not be the same as the as-built reality after the construction phase. Therefore, the LADM information also needs to be updated as the building lifecycle progresses. In fact, integration of LADM and BIM would provide a potential environment for managing the lifecycle of 3D cadastral information. It should be noted that the excessive physical information inside IFC building models may not be necessary for modelling 3D legal boundaries. Therefore, we also identified the essential IFC elements in this paper for modelling LADM concepts.

Furthermore, InfraGML can give an additional encoding option for 3D digital land registration. In particular, InfraGML offers surveying features that are not fully covered by the IFC, CityGML, or IndoorGML standards. Another encoding is to use CityGML, which might be useful for creating 3D digital property maps for a whole jurisdiction. Current property maps only show 2D land parcels and neglect the spatial and ownership dimensions of vertically stacked assets like condominiums, tunnels, underground shopping malls, car parks, and utility networks. Creating a CityGML encoding for LADM would be a key step towards realising 3D property maps with fully integrated representations of subsurface and aboveground RRRs. Therefore, CityGML standard can be considered as an appropriate data encoding for implementing an LADM-based 3D database management solution. Finally, IndoorGML is another encoding that, while not suitable for 3D digital cadastre, can enable the use of LADM data for lawful indoor navigation.

As our assessment showed, each standard can be used to partly encode the LADM concepts and the remaining LADM concepts can be added via the extension mechanism within the standard (e.g. ADE in CityGML or property sets in IFC and LandInfra/InfraGML). Integration of the BIM and GIS standards would provide a more comprehensive solution for the LADM implementation in the context of 3D digital cadastre and would address the limitations within each standard. However, this integration should also address data transformation and interoperability issues such as transforming 3D digital cadastral data from a local coordinate system to a geodetic one.

The theoretical assessment provided in this study provides a basis for us to identify a suitable encoding for implementing the LADM standard by considering the requirements and, more importantly, the specific use case for 3D digital cadastre in particular jurisdiction. Our future aim is to complement this evaluation by conducting experimental studies on the real-world case studies for 3D digital cadastre for a specific jurisdiction. Moreover, for old buildings, data back capturing methods are required for digitising the cadastral data from analogue subdivision plans for these buildings. These subdivision plans along with the 3D scanning methods can be used to create a 3D digital cadastral data for old buildings. Our assumption in this study was that the 3D digital data exists for the buildings either through back capturing of old buildings or 3D digital models for newly built assets. Therefore, the 3D data capturing methods are not considered at this stage and will be further investigated in our future work as part of the experimental studies.

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BIOGRAPHICAL NOTES

Behnam Atazadeh is a Research Fellow in the Centre for Spatial Data Infrastructures and Land Administration at the University of Melbourne. He is a leading researcher in the field of 3D land administration. His research leverages advanced scientific approaches driven from building information modelling and 3D urban modelling. He also works as a project officer in the ePlan project funded by Land Use Victoria, Victorian State Government.

Hamed Olfat is a Senior Research Fellow and Team Leader in the Centre for SDIs and Land Administration (CSDILA), The University of Melbourne, who is responsible for coordinating the ePlan project in Victoria. Hamed has over 16-years of involvement in many projects with research interests in “Smart Land Administration”, “3D Digital Cadaster”, “Spatial Data Infrastructure (SDI)”, “GIS”, and “Open Data Platforms”.

Abbas Rajabifard is Discipline Leader of Geomatics, Director of Smart Sustainable Development and Leader of the Future Infrastructure Research Program at the University of Melbourne. He is also Director of the Centre for Spatial Data Infrastructures and Land Administration. He has a strong track record in research and teaching, and academic leadership, and is internationally recognised scholar and engineer. His academic background is in Surveying and Mapping, Land Administration and Urban Systems, and has continued to maintain a high level of performance across the areas of research, teaching, supervision, and service to the surveying and spatial sciences.

Bahram Saeidian is a PhD candidate in the Centre for Spatial Data Infrastructures and Land Administration at the University of Melbourne. He is an experienced researcher with a demonstrated history of working in GIS-related industries. His research interests focus on underground land administration, 3D cadastre, 3D data modelling, spatial analysis and computational intelligence.

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