Representing and Querying 3D Cadastral Data Using GeoSPARQL: Compatibilities and Gaps in Australia

Pavan Sai Goud Goddu[1], Shokoufeh Farhadi Zangabad[1], Jihye Shin[2], Hamed Olfat[2], Ashleigh Foreman[3], Sisi Zlatanova[4], Mohsen Kalantari[1]*

[1] School of Civil and Environmental Engineering, University of New South Wales (UNSW), Sydney, Australia - goddupavansaigoud@gmail.com; s.farhadi_zangabad@unsw.edu.au; mohsen.kalantari@unsw.edu.au
[2] Department of Transport and Planning, Victoria, Australia - jihye.shin@transport.vic.gov.au; hamed.olfat@transport.vic.gov.au
[3] Spatial Services, NSW Government, Bathurst, Australia - ashleigh.foreman@customerservice.nsw.gov.au
[4] School of Built Environment, University of New South Wales (UNSW), Sydney, Australia - s.zlatanova@unsw.edu.au

Keywords: GeoSPARQL; 3D cadastre; 3D CSDM; compatibility assessment; IFC; semantic interoperability.

Abstract

Three-dimensional cadastral representation requires more than explicit 3D geometry, yet it remains unclear whether limitations arise from the published standard, evolving model, or source data. This study addresses that gap by assessing two real industry datasets, a GeoPackage exported to GeoJSON and an IFC2X3 building model, against the 3D Cadastral Survey Data Model (3D CSDM) reference target built on GeoSPARQL 1.1 as its semantic-spatial base. The specific contribution is the classification of standard-, model-, and source-data gaps so findings can be directed to the appropriate community. Across 70 assessed elements, one mapping was clean, 36 were partial, and 33 were absent, showing that neither dataset, in its delivered form, is directly representable in the target without significant transformation or augmentation. GeoSPARQL 1.1 geometric functions ignore Z values in spatial calculations, while the standard lacks solid-geometry classes and three-dimensional topology functions, limiting volumetric representation and 3D spatial querying. The 3D CSDM retains open or profile-dependent points, while both datasets lack survey observation evidence, cadastral survey provenance, and complete structured legal-interest records. Their strengths are complementary: GeoJSON provides clearer parcel-part identifiers and cadastral attributes but only implied 3D geometry, whereas IFC provides explicit 3D geometry but no formal georeferencing and limited cadastral parcel structure. The findings provide criteria for future GeoSPARQL 3D capability, priorities for 3D CSDM refinement, and a practical data-enrichment roadmap for industry.

1. Introduction

The increasing complexity of ownership patterns in high-rise buildings and subsurface spaces has exposed the limitations of conventional cadastral registration and surveying systems. Many cadastral databases remain based on two-dimensional (2D) or 2.5D representations, even where some form of 3D registration is implemented, and therefore struggle to represent contemporary urban environments accurately (FIG, 2022; Shahidinejad et al., 2024; Wu et al., 2019; Nacar, 2021; Kalogianni et al., 2020). In 2.5D models, Z-coordinates may be stored but are not fully incorporated into spatial analyses and computations, preventing true 3D relationships from being represented or analysed and motivating research into volumetric 3D cadastral systems (van Oosterom, 2013; Aien et al., 2013).

GeoSPARQL, a formal Open Geospatial Consortium (OGC) standard for representing and querying spatial data within the Semantic Web, provides an RDF vocabulary for geographic features and geometries and extends SPARQL with spatial functions and relationships (Car et al., 2024). However, GeoSPARQL 1.1 is based on Simple Features and remains 2.5D: although Z-coordinates can be stored, spatial computations disregard them and project geometry onto a 2D plane. It therefore lacks solid geometry classes and three-dimensional topology functions and cannot alone fully address 3D cadastral representation requirements.

In this context, the Intergovernmental Committee on Surveying and Mapping (ICSM) launched the 3D Cadastral Survey Data Model and Information Exchange (3D CSDM) project in Australia and New Zealand. The initiative aims to establish a standardized mechanism for digitally exchanging cadastral survey data and supports candidate implementation encodings, including JSON-based formats. Developed using OWL-based ontological modelling, the 3D CSDM enables coherent mapping across conceptual, logical, and implementation levels. It builds upon the semantic-spatial foundation of GeoSPARQL and extends it toward 3D cadastral representation, facilitating explicit representation and reliable data exchange between jurisdictions and systems (ICSM, 2022).

IFC and GeoPackage/GeoJSON were selected as input exchange representations because they reflect two complementary environments relevant to 3D urban and cadastral data. IFC, the dominant BIM standard, carries design and construction data and supports the physical and semantic representation of built elements (Liu et al., 2021; Alattas et al., 2021), whereas GeoPackage, an OGC standard used in GIS and cadastral systems, supports the storage, management, and exchange of registry and spatial data (OGC, 2021). Assessing real industry datasets from these environments, rather than synthetic samples, exposes practical compatibility limitations in the source data, GeoSPARQL 1.1, and the 3D CSDM (Shahidinejad et al., 2025).

This study presents a systematic mapping and compatibility assessment of real-world IFC and GeoPackage/GeoJSON representations against the 3D CSDM reference target built on GeoSPARQL 1.1 as its semantic-spatial base. The framework identifies mappable portions of data and distinguishes limitations in the published GeoSPARQL 1.1 standard, the evolving 3D CSDM, and the source datasets. Aligning these heterogeneous representations with the target remains challenging, making the framework valuable for practical 3D cadastre applications.

Specifically, this study addresses three questions: first, which elements of real industry IFC and GeoPackage/GeoJSON datasets can be mapped, completely or partially, to the 3D CSDM target built on GeoSPARQL 1.1; second, where do the published standards themselves stop short of what 3D cadastral representation requires; and third, where do the source datasets lack target-relevant information for complete 3D cadastral representation. The findings provide actionable guidance for GeoSPARQL standards development, 3D CSDM refinement, and industry data capture improvement.

2. Related work

2.1 From 2D to 3D Cadastre

Most cadastral databases remain based on two-dimensional models and lack the technical, legal, and data infrastructure for fully volumetric registration (Harper, 2024; van Oosterom, 2013). The 2.5D approach typically adds upper and lower height bounds to planar parcels, allowing vertical information to be introduced without representing true volumes (Rebong et al., 2025; Ghawana et al., 2021). Because these Z-values are not fully incorporated into spatial computation, genuine three-dimensional relationships still cannot be analysed (Aien et al., 2013). Full 3D implementation remains difficult because multi-storey and subsurface boundaries require high-precision data, solid geometric modelling, and standards for defining, storing, and exchanging 3D data (Kalogianni et al., 2020). Within the broader transition toward integrated land management, this study focuses on the compatibility of real industry data with an emerging 3D cadastral semantic target (Paasch and Paulsson, 2023; Shahidinejad et al., 2024).

2.2 GeoSPARQL and Semantic Web Standards

GeoSPARQL, the OGC standard for representing and querying geospatial data in RDF, provides a vocabulary for geographic features and geometries and extends SPARQL with spatial functions and relationships (Car et al., 2024). Its relevance to land administration has been demonstrated by Vilches-Blázquez and Saavedra (2022), who integrated distributed cadastral datasets into a knowledge graph containing spatial relationships and property-right information. GeoSPARQL 1.1 expanded spatial functions, improved geometry-type support, and strengthened alignment with related Semantic Web standards (Car and Homburg, 2022).

However, its geometric capabilities remain fundamentally two-dimensional. Although GeoSPARQL 1.1 permits Z-coordinate storage, its geometric functions ignore Z values and project geometries onto the Z=0 plane (Car et al., 2024, Section 10.2). It therefore provides no volumetric solid-geometry classes, no three-dimensional topology functions, and no full 3D computational framework. Candidate solid-geometry and spatial-relationship extensions are documented in the OGC GeoSPARQL 3D White Paper (Open Geospatial Consortium, 2025).

2.3 3D CSDM and Its Relationship to GeoSPARQL 1.1

In 2022, the Intergovernmental Committee on Surveying and Mapping (ICSM) introduced the 3D Cadastral Survey Data Model and Information Exchange (3D CSDM) for Australia and New Zealand as a standardized mechanism for exchanging cadastral survey data (ICSM, 2022). Developed using OWL-based ontological modelling and with reference to current and emerging standards, including the Land Administration Domain Model (LADM, ISO 19152), it enables mapping across conceptual, logical, and implementation levels and supports the representation of volumetric parcels and multi-level property rights (ISO, 2012). This technical development forms part of a broader 3D cadastre transition that also requires legal and institutional components beyond data modelling (Saeidian et al., 2024).

The relationship between GeoSPARQL 1.1 and the 3D CSDM is layered rather than parallel. The 3D CSDM does not replace GeoSPARQL; it adopts GeoSPARQL 1.1 as its semantic-spatial base, reusing the feature-geometry chain, topology vocabulary, and serialization formats while extending them with cadastral-specific concepts for parcels, survey observations, and provenance. Solid-geometry and 3D-topology concepts are organised under a GeoSPARQL 1.2 extension-candidate 3D profile. Accordingly, the assessment target in this study is the 3D CSDM built on GeoSPARQL 1.1, not two independent models compared side by side.

2.4 IFC and GeoPackage in Cadastral Contexts

IFC, the dominant BIM standard, supports the physical and semantic representation of built elements, while GeoPackage, an OGC standard based on SQLite, stores vector features, attribute tables, and spatial metadata in a portable GIS container (Liu et al., 2021; OGC, 2021). Aditya et al. (2021) demonstrated the use of GeoPackage as a local repository in an LADM-compliant cadastral field-collection workflow. BIM has also been used to construct and validate three-dimensional cadastral boundaries, including volumetric format plans and formative and summative validation of BIM-based cadastral data (Bryant et al., 2025; Asghari et al., 2021).

Previous IFC/BIM studies have mainly focused on LADM-based representation. They have mapped private, common, and exclusive common building spaces from IFC to LADM, extended IFC to support LADM geometry, applied BIM to high-rise land administration, and implemented a 3D cadastral database using LADM Edition II and IFC (Alattas et al., 2021; Petronijević et al., 2021; Atazadeh et al., 2017; Shahidinejad et al., 2025). This study differs by assessing real industry IFC and GeoPackage/GeoJSON datasets against the 3D CSDM reference target built on GeoSPARQL 1.1. It distinguishes limitations in the published standard, the evolving model, and the source data so that findings can be directed to the appropriate community. This classification of standard-, model-, and source-data gaps against the GeoSPARQL/3D CSDM stack is the specific contribution of the study.

3. Methodology

This study adopts a systematic mapping and compatibility assessment to evaluate how well two real industry datasets can be represented within the 3D CSDM reference target built on GeoSPARQL 1.1. Rather than attempting to convert the data into a fully operational semantic system, it identifies what can be expressed, what falls short, and whether each limitation lies in the source datasets, GeoSPARQL 1.1, or the evolving 3D CSDM. Figure 1 summarises the overall assessment framework.

GeoSPARQL 1.1 provides the published semantic-spatial base, including the feature-geometry chain, topology vocabulary, serialization formats, and SPARQL extension functions (Car et al., 2024). The 3D CSDM builds on this base as the 3D cadastral extension used in the study, with solid-geometry and 3D-topology concepts organised under a GeoSPARQL 1.2 extension-candidate 3D profile (ICSM, 2022). Its container vocabulary defines this profile as an extension candidate, while the implementation specifications identify GeoSPARQL 1.2 as a proposed extension for describing 3D topological relationships between features with solid geometries. The datasets are assessed in their delivered encodings: an IFC2X3 building model and a GeoPackage exported to GeoJSON with an EPSG:3857 CRS declaration.

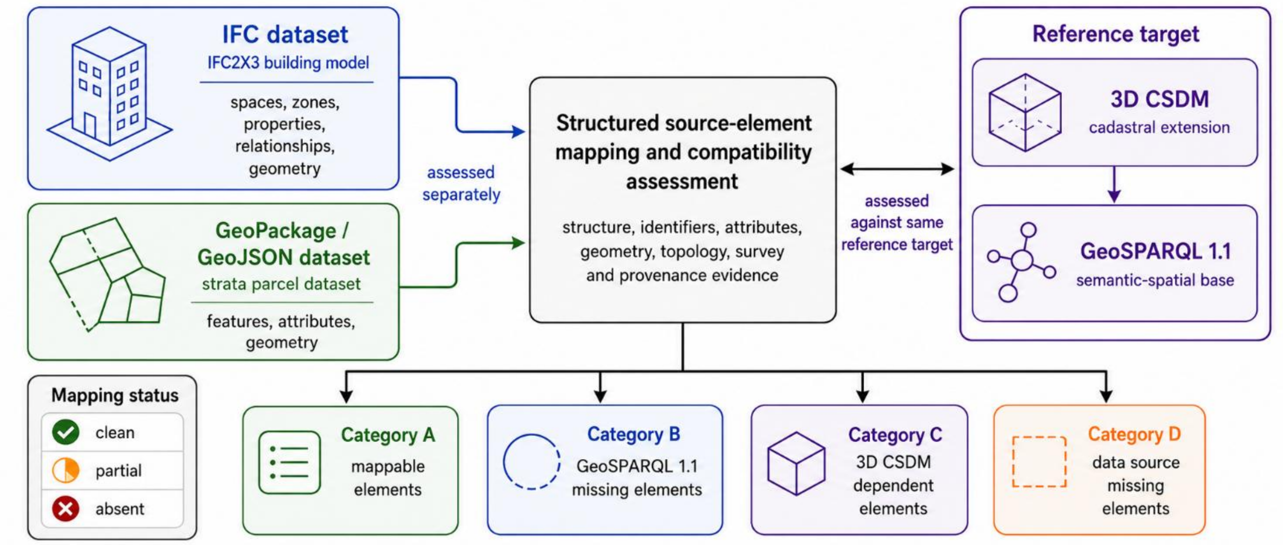

Figure 1. Assessment framework. Each dataset (GeoPackage/GeoJSON and IFC) is analysed independently against the 3D CSDM reference target built on GeoSPARQL 1.1, and its elements are classified into the four assessment categories; the two datasets are not merged.

3.1 Dataset Selection

Two complementary industry datasets were selected; Table 1 summarises their formats, content, geometry, georeferencing, and key present and absent information.

The GeoPackage dataset (OGC, 2021), provided by a New South Wales cadastral authority and exported to GeoJSON, contains 101 lot-part features across five building levels. These resolve to 13 lots and one common property by grouping lot parts through lot number and part suffix. Its two-dimensional MultiPolygon geometries use an EPSG:3857 CRS declaration, with vertical extent implied by BASE_Z values of −3.0, 0.0, 3.0, 6.0, and 9.0 m and a HEIGHT value of 3.0 m rather than explicit 3D geometry.

Attribute	GeoJSON/GPKG	IFC
Source format	GPKG, exported to GeoJSON with EPSG:3857 CRS declaration	IFC2X3, Autodesk Revit 2016
Jurisdiction	New South Wales	Victoria
Content	NSW strata plan (residential + basement)	Multi-storey residential building
Primary units	101 lot-part features (13 lots + 1 common property, all multipart)	146 IfcSpace instances
Levels / storeys	5 building levels (1 basement + 4 floors)	9 building storeys
Cadastral grouping	Lot number + part suffix per feature	4 IfcZone groupings (3 cadastral-labelled groupings: LOT 211, LOT 212, CP No. 1 = 14 spaces; 132 spaces in Default)
Geometry	2D MultiPolygon; implicit 3D via BASE_Z + HEIGHT	Explicit 3D solids (3,171 IfcExtrudedAreaSolid; 778 IfcFacetedBrep)
CRS / georeferencing	EPSG:3857 horizontal CRS declaration; no vertical datum	No formal CRS/georeferencing (local coordinate system in millimetres; no IfcProjectedCRS/IfcMapConversion)
Key present	Parcel-part identifiers and class attributes; parcel form/type; vertical-extent attributes	Explicit 3D geometry; limited cadastral-labelled IfcZone grouping; BIM unit and authoring metadata
Key absent	Explicit 3D geometry; survey observations/provenance; vertical datum; structured legal-interest records	Formal georeferencing; complete cadastral grouping; survey observations/provenance; structured legal-interest records

Table 1. Description of the two assessed datasets.

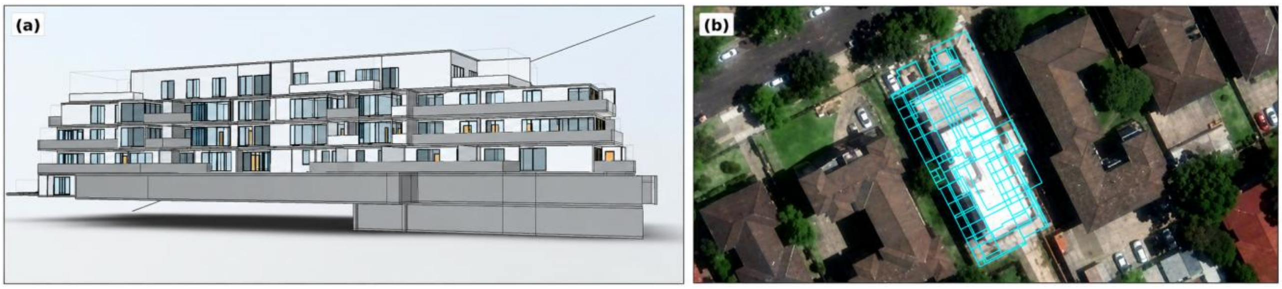

Figure 2. Snapshots of the two assessed datasets: (a) the IFC building model viewed in an IFC viewer; (b) the GeoJSON strata plan rendered in QGIS.

The IFC2X3 model (buildingSMART International, 2006), produced in Autodesk Revit 2016 for a multi-storey residential building in Victoria, contains 146 IfcSpace instances across nine storeys and four IfcZone groupings. LOT 211, LOT 212, and Common Property No. 1 cover 14 spaces; the remaining 132 are in Default. The model contains 3,171 IfcExtrudedAreaSolid and 778 IfcFacetedBrep instances. Lengths are expressed in millimetres and areas in square metres through IfcUnitAssignment, while space areas are BIM-derived gross-space-area quantities rather than authoritative cadastral areas. The model uses a local coordinate system and contains neither IfcProjectedCRS nor IfcMapConversion, consistent with IFC2X3 predating the georeferencing support introduced in IFC4. Figure 2 shows the two assessed datasets: the IFC building model (a) and the GeoJSON strata plan rendered in QGIS (b).

3.2 Mapping Framework

Each dataset was mapped independently against the 3D CSDM reference target built on GeoSPARQL 1.1 using a structured mapping table. Neither IFC nor GeoJSON was developed as a complete 3D cadastral survey encoding. The mapping therefore relies on interpretive alignment based on the cadastral, spatial, geometric, and structural support in each delivered dataset rather than direct element-to-element equivalence.

Each source element was compared at one of five levels: the feature or entity level, such as a lot-part feature or IfcSpace; the attribute or property level, such as a lot number or floor elevation; the geometry level, such as a MultiPolygon or extruded solid; the relationship level, including objectified IFC relationships such as IfcRelAssignsToGroup and IfcRelSpaceBoundary; and the conceptual level, covering survey observation or provenance concepts not explicitly present in the source. Internal file-header metadata and software artefacts without a cadastral or spatial-semantic role were treated as dataset description rather than mapping rows. Identifiers were retained only where they supported feature identity or target attachment. For each element, the analysis recorded the GeoSPARQL 1.1 target, the 3D CSDM target, a mapping status, and one or more assessment categories.

The four categories locate where each limitation sits so that findings can be directed to the appropriate community:

1. **Category A (mappable):** a valid target class or property exists in GeoSPARQL 1.1 or the 3D CSDM; where a property is involved, it is used in the correct direction. The element is achievable today, although it may remain partial because of source-quality or implementation caveats.

2. **Category B (GeoSPARQL 1.1 missing):** the published GeoSPARQL 1.1 standard stops short, including solid geometry classes, three-dimensional topology functions, and capabilities beyond the 2.5D limitation stated in GeoSPARQL 1.1 Section 10.2.

3. **Category C (3D CSDM dependent):** a 3D CSDM target exists but is incomplete or implementation-dependent, including classes whose TTL descriptions state “Definition not yet provided” and fields whose scope notes state that interpretation is “implementation and context dependent”.

4. **Category D (data source missing):** target-relevant information is absent, null, unstructured, or unusable in the assessed source dataset. Category D is dataset-specific and does not imply that every listed element is mandatory in every jurisdiction. For each element, the analysis records where the missing information would attach within the target as guidance for data enrichment.

Mapping status was assigned conservatively:

1. **Clean:** the source element maps directly and completely to the target class or property, with no substantive transformation or interpretive assumption beyond normal encoding.

2. **Partial:** the element is present but requires transformation, reprojection, or interpretation, for example where a source field provides a string label for a concept represented in the target through a structured class or codelist IRI.

3. **Absent:** the element has no usable direct mapping in the present source-target combination because the source lacks usable target-relevant information, GeoSPARQL 1.1 has no corresponding published construct, or the 3D CSDM construct is not sufficiently defined for direct implementation.

Where a class assignment cannot be established from the source value alone, such as mapping parcel class “Lot” to parcel:PrimaryParcel, it is recorded as interpretive rather than clean. The study assesses the published GeoSPARQL 1.1 documents and 3D CSDM TTL reference files rather than jurisdiction-specific instance encodings; instance-level validation is therefore outside its scope.

3.3 Implementation and Reproducible Outputs

For transparency and reproducibility, the complete outputs for both datasets are published as an open deposit (see Data Availability): an interactive HTML mapping table and a flat CSV file for each dataset, with a README documenting the expected input structure. The IFC input exposes IfcSpace, IfcZone, IfcElementQuantity, IfcRelAssignsToGroup, and IfcRelSpaceBoundary entities; the GeoJSON input carries lot-part attributes, including lot number, part suffix, parcel class, BASE_Z, HEIGHT and derived area/length. The deposit also includes assess.py, mapping_rules.json and sample.geojson, demonstrating rule execution, RDF/SPARQL querying using GeoSPARQL vocabulary, and CSV-total checking. Together, these materials make the assessment repeatable, not an automated converter.

4. Results

4.1 Overview of Mapping Outcomes

The GeoJSON/GPKG dataset yielded 45 assessed elements (1 clean, 22 partial, and 22 absent), while the IFC dataset yielded 25 (0 clean, 14 partial, and 11 absent). Across both datasets, 70 elements were assessed: 1 clean, 36 partial, and 33 absent. IfcRelAssignsToGroup is reported separately as uncounted structural evidence because it has no 3D CSDM target of its own. The single clean mapping shows that neither dataset, in its delivered form, is directly representable in the 3D CSDM reference target built on GeoSPARQL 1.1 without significant transformation or augmentation. Table 2 summarises the category distribution; rows may carry more than one assessment category. Tables 3–6 present representative examples, while the complete HTML and CSV outputs are available through the Figshare link in the Data Availability section.

Assessment Category	GeoJSON/GPKG	IFC
A: Mappable elements	3 (1 clean, 2 partial)	2 (partial)
B: GeoSPARQL 1.1 missing elements	9	5
C: 3D CSDM dependent elements	21	12
D: Data source missing elements	24	15

Table 2. Assessment category distribution across both datasets.

Note: Rows may carry more than one assessment category. Category A count reflects category assignment, not clean status.

4.2 Mappable Elements (Category A)

Three elements in the GeoJSON dataset were assigned to Category A, indicating that their target properties are valid in direction within the reference target. Only geo:hasDefaultGeometry constitutes a clean mapping (Car et al., 2024, Section 8.4.2), linking each feature to its single spatial representation and supporting GeoSPARQL query rewriting. The shape_area and shape_leng mappings remain partial: although geo:hasMetricArea and geo:hasMetricPerimeterLength are correct in direction, the source values are GIS-computed in EPSG:3857 and are geometry-derived estimates rather than authoritative cadastral measurements. Both apply to individual parcel parts. For a reconstructed multipart parcel, shape_area requires interpretation or aggregation, while shape_leng remains a part-level geometry-derived estimate. The IFC dataset produced two Category A elements and no clean mappings.

DS	Source Element	GeoSPARQL 1.1 Target	3D CSDM Target	Status
GeoJSON	GeoJSON geometry member, single geometry per feature	geo:hasDefaultGeometry (Sec. 8.4.2); subproperty of geo:hasGeometry, used by query rewriting	Inherited from GeoSPARQL; no additional 3D CSDM constraint	Clean
GeoJSON	shape_area (GIS-computed in EPSG:3857)	geo:hasMetricArea (Sec. 8.3.8); correct in direction	parcel:area; partial: value applies to an individual parcel part, so the reconstructed multipart parcel requires interpretation or aggregation	Partial
GeoJSON	shape_leng (GIS-computed in EPSG:3857)	geo:hasMetricPerimeterLength (Sec. 8.3.6); correct in direction	Inherited from GeoSPARQL; no separate 3D CSDM target is required	Partial
IFC	GSA Space Areas (IfcQuantityArea)	geo:hasMetricArea (Sec. 8.3.8); correct in direction	parcel:area; partial: quantities attach to individual IfcSpace instances, so an interpreted multipart parcel requires selection or aggregation of member-space areas	Partial

Table 3. Category A — Mappable elements. DS = dataset source.

The GSA Space Areas (IfcQuantityArea) map correctly to geo:hasMetricArea but remain partial because the quantities attach to individual IfcSpace instances, while an interpreted multipart parcel requires selection or aggregation of member-space areas. IfcProject aligns partially with container:CSD as the dataset's top-level container; the cadastral survey metadata that a CSD additionally requires is recorded separately under Category D.

4.3 GeoSPARQL 1.1 Missing Elements (Category B)

Nine Category B elements were identified in the GeoJSON dataset and five in the IFC dataset. Together, they point to two structural limitations in the published GeoSPARQL 1.1 standard: the absence of solid-geometry classes and three-dimensional topology functions.

DS	Source Element	GeoSPARQL 1.1 Target	3D CSDM Target	Status
GeoJSON	Implied volume from 2D footprint + BASE_Z/HEIGHT	geo:Solid not defined in published GeoSPARQL 1.1; no solid geometry classes (Sec. 10.2)	geometry:ExtrudedSurface ⊂ geometry:ExtrudedGeometry ⊂ geometry:AbstractSolidGeometry; extension candidate	Absent
IFC	IfcExtrudedAreaSolid (3,171 instances): explicit 3D solid	geo:Geometry present, but geo:Solid not defined in published GeoSPARQL 1.1 (Sec. 10.2)	geometry:AbstractSolidGeometry (candidate class)	Partial
IFC	IfcRelSpaceBoundary: space-to-boundary evidence	No 3D topology predicates in published GeoSPARQL 1.1; touchesInward/touchesOutward are 3D CSDM extensions	geometry:BoundaryFace with geo:touchesInward / geo:touchesOutward	Partial

Table 4. Category B — GeoSPARQL 1.1 missing elements. DS = dataset source.

GeoSPARQL 1.1 Section 10.2 states that geometric functions ignore Z values and project geometry onto the Z=0 plane (Car et al., 2024). Published GeoSPARQL 1.1 defines no geo:Solid, geo:Shell, or geo:MultiSolid; although geo:hasMetricVolume provides a scalar volume value, it does not provide a volumetric geometry model or full 3D computational framework. The two datasets expose this gap from opposite directions. The GeoJSON dataset carries only an implied volume through a 2D footprint with BASE_Z and HEIGHT, while the IFC dataset contains 3,171 IfcExtrudedAreaSolid and 778 IfcFacetedBrep instances but has no GeoSPARQL solid target.

GeoSPARQL 1.1 also lacks explicit three-dimensional boundary-topology support. In the GeoJSON dataset, boundary faces, edges, nodes, and GML topology serialization are absent. The IFC dataset contains IfcRelSpaceBoundary records that provide space-to-boundary evidence, including links from spaces to physical bounding elements or virtual boundaries, but they do not directly represent two-space or legal cadastral boundaries; adjacency and a legal geometry:BoundaryFace require interpretation and topology extraction. GeoSPARQL 1.1 provides geo:sfTouches only as a two-dimensional predicate and has no orientation-aware boundary-face model or inward and outward adjacency semantics for volumetric neighbours. The geo:touchesInward and geo:touchesOutward predicates are 3D CSDM extension candidates rather than published GeoSPARQL 1.1 constructs.

4.4 3D CSDM Dependent Elements (Category C)

Category C included 21 elements in the GeoJSON dataset and 12 in the IFC dataset, reflecting open or profile-dependent points in the published 3D CSDM TTL files.

DS	Source Element	GeoSPARQL 1.1 Target	3D CSDM Target	Status
GeoJSON	BASE_Z: floor base elevation (−3.0/0/3/6/9 m)	No GeoSPARQL equivalent for vertical-extent scalar	parcel:zmin; defined in parcels.ttl, but scope note: interpretation is "implementation and context dependent"	Partial
IFC	IfcZone "LOT 211" / "LOT 212": cadastral-labelled space grouping	No GeoSPARQL equivalent for lot-level grouping	Interpretive candidate: lot-labelled IfcZone groupings may support parcel:PrimaryParcel representation, but IfcZone is a BIM grouping mechanism, not a formal cadastral class	Partial
IFC	IfcOwnerHistory model creation timestamp	No GeoSPARQL equivalent	Weak BIM authoring provenance: the entity may carry prov:generatedAtTime and, where an activity is constructed, link through prov:wasGeneratedBy to survprov:SurveyActivity; interpretive evidence only, not cadastral survey provenance; also Category D.	Partial

Table 5. Category C — 3D CSDM dependent elements. DS = dataset source.

The GeoJSON coordinate reference system illustrates a profile-dependent issue rather than a GeoSPARQL 1.1 missing-construct gap. GeoSPARQL 1.1 Requirement 26 specifies that geo:geoJSONLiteral must use WGS84 longitude-latitude (CRS84), so the dataset's EPSG:3857 declaration is not directly usable in that serialization (Car et al., 2024). The geometry can instead be represented through geo:wktLiteral with an explicit CRS IRI. Within the 3D CSDM, the source CRS attaches to container:horizontalCRS, while the choice between reprojection to CRS84 and WKT serialization is left to the implementing profile; the vertical datum remains absent.

The vertical-extent properties parcel:zmin and parcel:zmax, corresponding to BASE_Z and the derived ceiling elevation, are defined in the 3D CSDM but their interpretation is stated to be "implementation and context dependent". This creates interoperability risk where different profiles interpret the same fields differently.

The IFC-related Category C findings concern IfcOwnerHistory, the 3D CSDM IFCRef class, and parcel-class interpretation. IfcOwnerHistory provides only weak BIM authoring provenance, not cadastral survey provenance. IFCRef, intended to link a survey observation to an IFC design model, remains under-defined, while IFC 4.3 integration is marked "Under development"; consequently, a formal reference from a FeatureOccupationObservation to the IFC model cannot yet be implemented unambiguously. Similarly, source labels pointing toward parcel:PrimaryParcel or parcel:SecondaryParcel remain interpretive because neither dataset contains the full legal-right structure needed to confirm those assignments, and the published TTL files do not provide jurisdiction-specific mapping rules.

4.5 Data Source Missing Elements (Category D)

Category D included 24 elements in the GeoJSON dataset and 15 in the IFC dataset. These findings identify target-relevant information that is absent, null, unstructured, or unusable in the assessed source dataset. They are specific to these two datasets and do not imply that every listed element is mandatory in every jurisdiction. Cases where source content is present but GeoSPARQL 1.1 has no corresponding published construct, or the 3D CSDM construct is not sufficiently defined for direct implementation, are treated under Category B or C rather than Category D; IFC solid geometry is one such example.

The GeoJSON dataset contains no survey evidence layer: survey points, boundary marks, vector observations, and VectorDetermination records are absent. The 3D CSDM represents surveyobs:SurveyVectorObservation with qualified vector results linked to surv:BoundaryMark, anchoring parcel boundaries to measured positions (ICSM, 2022). Without this evidence, the source coordinates have no traceable measurement origin. Formal cadastral survey provenance is also absent from both datasets. The 3D CSDM cadastral survey dataset requires a survey provenance bundle and survey type and also models survey purpose; none of this metadata is present. In the GeoJSON dataset, UnitEntitl, which could contribute to legal-interest or entitlement representation, is null across all 101 features.

The IFC dataset lacks formal georeferencing and complete cadastral parcel structure. Without a formal CRS declaration, its 3D solid geometry cannot be anchored to an external cadastral reference system. IfcZone names and the IfcPropertySingleValue Zone property provide only ad-hoc text labelling rather than the structured parcel identity represented through parcel:appellation; Pset_SpaceCommon is likewise a BIM-authoring convention rather than cadastral semantics.

The identified attachment paths provide guidance for data enrichment. Survey vector observations would attach through container:CSD, container:vectorObservations, and a sosa:ObservationCollection containing surveyobs:SurveyVectorObservation, with sosa:hasResult carrying a surveyobs:QualifiedVector. Where required, a terrain intersection curve would attach through parcel:Parcel and parcel:terrainIntersectionCurve to a gml:LinearRing. Legal-interest or entitlement evidence would attach through parcel:Parcel → parcel:interest → parcel:Estate, where parcel:Estate is a subclass of parcel:LandInterest.

DS	Source Element	GeoSPARQL 1.1 Target	3D CSDM Target	Status
GeoJSON	Survey vector observations: absent from source	No GeoSPARQL equivalent for field observations	surveyobs:SurveyVectorObservation → sosa:hasResult → surveyobs:QualifiedVector; anchors boundaries to measured positions	Absent
GeoJSON	UnitEntitl: present as field but entirely null across 101 features	No GeoSPARQL equivalent	Potential legal-interest or entitlement evidence; no usable value is present for a parcel:Parcel → parcel:interest → parcel:Estate mapping	Absent
IFC	Survey points / boundary marks: absent from source	No GeoSPARQL equivalent for field observations	surv:BoundaryMark → geo:hasGeometry → geo:Point; anchors boundaries to measured positions	Absent
IFC	Zone property value on each IfcSpace: present but unstructured naming-convention text	No GeoSPARQL equivalent	Interpretive analogue to parcel:appellation; IFC value is unstructured text, not a structured compound name	Partial

Table 6. Category D — Data source missing elements. DS = dataset source.

4.6 Comparative Observations

The two datasets show complementary limitations. GeoJSON provides clearer parcel-part identifiers and cadastral attributes but only implied 3D geometry and no survey evidence, whereas IFC provides explicit 3D solids but limited cadastral structure, no formal georeferencing, and weak legal-interest encoding. These IFC findings are consistent with earlier studies showing that IFC can support 3D cadastral geometry and legal-space representation but requires extension, enrichment, or preprocessing for cadastral registration (Atazadeh et al., 2017; Alattas et al., 2021; Petronijević et al., 2021; Shahidinejad et al., 2025). This study extends that work by locating each limitation in GeoSPARQL 1.1, the 3D CSDM, or the source data. Neither dataset alone provides a complete 3D CSDM representation, and the findings should not be generalised to all IFC or GeoPackage/GeoJSON files.

5. Conclusions

This paper presented a systematic compatibility assessment of two real industry datasets, a GeoPackage exported to GeoJSON from a New South Wales cadastral authority and an IFC2X3 building model from a Victorian project, against the 3D CSDM reference target built on GeoSPARQL 1.1 (OGC, 2021; buildingSMART International, 2006; ICSM, 2022; Car et al., 2024). The findings distinguish limitations across three fronts. GeoSPARQL 1.1 provides a robust semantic-spatial foundation but lacks solid-geometry classes and three-dimensional topology functions; although geo:hasMetricVolume provides a scalar volume value, it does not provide a volumetric geometry model or full 3D computational framework, consistent with the 2.5D treatment in GeoSPARQL 1.1 Section 10.2. The published 3D CSDM TTL files retain open or profile-dependent points, including the interpretation of parcel:zmin and parcel:zmax, the under-defined IFCRef class, and codelist or encoding decisions delegated to implementing profiles. The assessed datasets also lack survey observation evidence, cadastral survey provenance, and structured legal-interest records, while the IFC dataset additionally lacks formal georeferencing.

The Category B findings provide concrete criteria for assessing future GeoSPARQL 3D capability. The absence of solid-geometry classes and three-dimensional topology functions corresponds to the solid-geometry and 3D-topology concepts organised in the 3D CSDM under a GeoSPARQL 1.2 extension-candidate 3D profile. If future GeoSPARQL development adopts these capabilities, including orientation-aware boundary-face predicates such as geo:touchesInward and geo:touchesOutward, the identified standard-level gaps would be reduced. The remaining limitations would then lie mainly in 3D CSDM profile definition, source-data capture, and implementation practice.

The findings provide separate guidance for each community. For GeoSPARQL standards development, Category B identifies the missing published capabilities. For 3D CSDM development, Category C identifies the open points most important to interoperability, including IFCRef, parcel:zmin and parcel:zmax, and jurisdictional codelist and parcel-class mappings. For industry and government data providers, Category D and the identified attachment paths provide a practical enrichment roadmap showing what target-relevant information is absent, null, unstructured, or unusable and where it would connect within the target.

The transferability of the findings varies by category. Category B is jurisdiction-independent because it concerns the published GeoSPARQL 1.1 standard; Category C is specific to the 3D CSDM reference target; and Category D is specific to the two assessed datasets. The broader diagnostic pattern may nevertheless recur where BIM and GIS exchange representations were not designed as complete cadastral survey encodings. Within Australia, jurisdictional requirements and implementation profiles may differ, so the 3D CSDM is treated here as a reference target rather than a uniformly implemented operational schema. Future work should assess additional datasets and jurisdictions, validate interpretive legal-class mappings against cadastral legal frameworks (ISO, 2012; Lemmen et al., 2015), evaluate GeoSPARQL 1.2 once published, and investigate cadastral-specific BIM property sets. The structured mapping tables and reproducible assessment outputs are provided through the Data Availability section to support future comparative analysis.

Data availability

The mapping outputs are available at Figshare: https://doi.org/10.6084/m9.figshare.31937493. The deposit contains the HTML/CSV mapping tables, README, rule file, companion script, and synthetic GeoJSON sample described in Section 3.3.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

This work was supported by the Australian Research Council under Grant LP22020090.

References

Aditya, T., Sucaya, I.K.G.A., Nugroho Adi, F., 2021. LADM-compliant field data collector for cadastral surveyors. Land Use Policy, 104, 105356. https://doi.org/10.1016/j.landusepol.2021.105356

Aien, A., Kalantari, M., Rajabifard, A., Williamson, I., Wallace, J., 2013. Towards integration of 3D legal and physical objects in cadastral data models. Land Use Policy, 35, 140–154. https://doi.org/10.1016/j.landusepol.2013.05.014

Alattas, A., Kalogianni, E., Alzahrani, T., Zlatanova, S., van Oosterom, P., 2021. Mapping private, common, and exclusive common spaces in buildings from BIM/IFC to LADM. A case study from Saudi Arabia. Land Use Policy, 104, 105355. https://doi.org/10.1016/j.landusepol.2021.105355

Asghari, A., Kalantari, M., Rajabifard, A., 2021. Formative and Summative Validation of Building Information Model-Based Cadastral Data. Land, 10(8), 822. https://doi.org/10.3390/land10080822

Atazadeh, B., Kalantari, M., Rajabifard, A., Ho, S., Ngo, T., 2017. Building Information Modelling for High-Rise Land Administration. Transactions in GIS, 21(1), 91–113. https://doi.org/10.1111/tgis.12199

Bryant, B., Agha Karimi, A., Atazadeh, B., Rajabifard, A., 2025. Modelling 3-Dimensional cadastral boundaries in a BIM environment: a case study using volumetric format plans in Queensland, Australia. International Journal of Digital Earth, 18(1), 2518578. https://doi.org/10.1080/17538947.2025.2518578

buildingSMART International, 2006. Industry Foundation Classes (IFC) 2x3 Final Release. buildingSMART International. https://standards.buildingsmart.org/IFC/RELEASE/IFC2x3/FINAL/HTML/

Car, N.J., Homburg, T., 2022. GeoSPARQL 1.1: Motivations, Details and Applications of the Decadal Update to the Most Important Geospatial LOD Standard. ISPRS International Journal of Geo-Information, 11(2), 117. https://doi.org/10.3390/ijgi11020117

Car, N., Homburg, T., Perry, M., Knibbe, F., Cox, S.J.D., Abhayaratna, J., Bonduel, M., Cripps, P., Janowicz, K., 2024. OGC GeoSPARQL – A Geographic Query Language for RDF Data, version 1.1. OGC Standard 22-047r1. Open Geospatial Consortium. http://www.opengis.net/doc/IS/geosparql/1.1

FIG, 2022. Joint Commission 3 and 7 Working Group on 3D Cadastres. International Federation of Surveyors. https://www.fig.net/organisation/comm/wg/2022_joint3_7.asp

Ghawana, T., Janečka, K., Zlatanova, S., 2021. Development of 3D Spatial Database Enabled IT Framework for Land Agencies: Case Studies of Delhi, India and Prague, Czech Republic. Land, 10(3), 248. https://doi.org/10.3390/land10030248

Harper, I., 2024. Fit for Purpose 2D Cadastres as the Foundation for 3D Cadastral Modelling and Digital Twins: Comparing Different Solutions from Australia and Indonesia. In: Proceedings of the FIG Working Week 2024, Accra, Ghana, 19–24 May 2024. International Federation of Surveyors (FIG).

ICSM, 2022. 3D Cadastral Survey Data Model and Exchange (3D CSDM): Conceptual Model and OWL/TTL Implementation. Intergovernmental Committee on Surveying and Mapping. https://linked.data.gov.au/def/csdm

ISO, 2012. ISO 19152:2012 Geographic information — Land Administration Domain Model (LADM). International Organization for Standardization, Geneva, Switzerland.

Kalogianni, E., van Oosterom, P., Dimopoulou, E., Lemmen, C., 2020. 3D Land Administration: A Review and a Future Vision in the Context of the Spatial Development Lifecycle. ISPRS International Journal of Geo-Information, 9(2), 107. https://doi.org/10.3390/ijgi9020107

Lemmen, C., van Oosterom, P., Bennett, R., 2015. The Land Administration Domain Model. Land Use Policy, 49, 535–545. https://doi.org/10.1016/j.landusepol.2015.01.014

Liu, L., Li, B., Zlatanova, S., van Oosterom, P., 2021. Indoor navigation supported by the Industry Foundation Classes (IFC): A survey. Automation in Construction, 121, 103436. https://doi.org/10.1016/j.autcon.2020.103436

Nacar, F., 2021. The need for 4D in Turkish cadastre. Arabian Journal of Geosciences, 14, 542. https://doi.org/10.1007/s12517-021-06809-w

OGC, 2021. OGC GeoPackage Encoding Standard. OGC 12-128r18, Version 1.3.1. Open Geospatial Consortium. https://www.geopackage.org/spec131/index.html

Open Geospatial Consortium, 2025. GeoSPARQL 3D White Paper (OGC Technical Paper, Candidate SWG Draft). Available at: https://opengeospatial.github.io/geosparql3dwhitepaper/documents/document/document.html

Paasch, J.M., Paulsson, J., 2023. Trends in 3D cadastre – A literature survey. Land Use Policy, 131, 106716. https://doi.org/10.1016/j.landusepol.2023.106716

Petronijević, M., Višnjevac, N., Praščević, N., Bajat, B., 2021. The Extension of IFC For Supporting 3D Cadastre LADM Geometry. ISPRS International Journal of Geo-Information, 10(5), 297. https://doi.org/10.3390/ijgi10050297

Rebong, F.R., Meilano, I., Sadarviana, V., Hernandi, A., Abdulharis, R., Meilani, R., 2025. Strategy for the Conversion of 2D to 3D Cadastral Maps by Standardizing the Height Limit of Land Rights Space Based on Land Use/Land Cover. Land, 14(4), 763. https://doi.org/10.3390/land14040763

Saeidian, B., Rajabifard, A., Atazadeh, B., Kalantari, M., 2024. Managing underground legal boundaries in 3D – extending the CityGML standard. Underground Space, 14(1), 239–262. https://doi.org/10.1016/j.undsp.2023.08.002

Shahidinejad, J., Kalantari, M., Rajabifard, A., 2024. 3D Cadastral Database Systems—A Systematic Literature Review. ISPRS International Journal of Geo-Information, 13(1), 30. https://doi.org/10.3390/ijgi13010030

Shahidinejad, J., Kalantari, M., Rajabifard, A., 2025. 3D Cadastral database implementation based on LADM edition II and IFC. Survey Review, 57(405), 621–633. https://doi.org/10.1080/00396265.2025.2544404

van Oosterom, P., 2013. Research and development in 3D cadastres. Computers, Environment and Urban Systems, 40, 1–6. https://doi.org/10.1016/j.compenvurbsys.2013.01.002

Vilches-Blázquez, L.M., Saavedra, J., 2022. A graph-based representation of knowledge for managing land administration data from distributed agencies – A case study of Colombia. Geo-spatial Information Science, 25(2), 259–277. https://doi.org/10.1080/10095020.2021.2015250

Wu, C., Ding, Y., Zhou, X., 2019. Three-dimensional data modeling of real estate objects in China. Journal of Geographical Systems, 21(3), 433–450. https://doi.org/10.1007/s10109-019-00295-1