ISSN 2682-681X (Paper), ISSN 2705-4241 (Online) | http://unilorinjoger.com | https://doi.org/10.63745/joger.2025.12.30.001

JOURNAL OF GEOMATICS AND ENVIRONMENTAL RESEARCH
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RESEARCH ARTICLE

Integrating Physical and Legal Data for 3D Cadastre in Abuja, Nigeria

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Abstract

Rapid urbanization in Abuja, Nigeria, has intensified demand for multi-storey housing, exposing the limitations of conventional two-dimensional (2D) cadastral systems in representing overlapping property rights and volumetric ownership. This study develops a prototype three-dimensional (3D) cadastre by integrating Building Information Modelling (BIM) and the Land Administration Domain Model (LADM) through the Industry Foundation Classes (IFC) standard. A Design Science Research Methodology (DSRM) was employed, consisting of problem identification, requirements analysis, artifact design, demonstration, evaluation, and communication. A multi-storey apartment building in Abuja Municipal Area Council (AMAC) served as the case study. Physical ownership spaces were modelled using ArchiCAD and enriched with legal information by mapping LADM classes such as LA_Party, LA_RRR, and LA_SpatialUnit to corresponding IFC entities. Legal attributes were embedded as IFC property sets, ensuring semantic representation of rights, responsibilities, and restrictions (RRRs) within the BIM environment. The prototype was evaluated using the KIT Model Viewer, which enabled interactive visualization of integrated legal-spatial units. Results demonstrate improved boundary clarity, enhanced transparency for stakeholders, and interoperability with existing land administration standards. However, challenges remain in aligning jurisdiction specific legal requirements with standardized data models and ensuring institutional readiness for 3D cadastre adoption. The study provides a replicable framework for upgrading cadastral

ARTICLE HISTORY
Received: 11th July, 2025
Accepted: 10th September, 2025
Published: 19th October, 2025

KEYWORDS
BIM
LADM
IFC
3D Cadastre
DSRM

Citation: Muhammad B.A., Opaluwa Y.D., Zitta N., Onuigbo I.C., Eyo E.E (2025). Integrating Physical and Legal Data for 3D Cadastre in Abuja Nigeria, *Journal of Geomatics and Environmental Research, 8(2). 1-9*

1.0 INTRODUCTION

The increasing pace of urbanization in developing nations has placed unprecedented pressure on land administration systems to accommodate complex forms of property ownership. Abuja, Nigeria's Federal Capital Territory (FCT), has experienced rapid vertical expansion in response to population growth, land scarcity, and rising demand for multi-storey housing and mixed-use developments (Idris *et al*., 2021). This vertical densification has created overlapping ownership rights in 3D space, which conventional 2D cadastral systems are ill-equipped to manage. Traditional cadastral practices in Abuja rely largely on annotated subdivision plans and static PDF documents, which lack the capacity to represent volumetric ownership boundaries or to clearly communicate legal rights, restrictions, and responsibilities (RRRs) (Adu *et al*., 2020). These limitations undermine legal certainty, complicate property registration, and restrict the potential for efficient urban land governance.

Globally, 3D cadastre research has advanced as a means of capturing and representing property rights in multi-level urban environments (Stoter *et al*., 2011; van Oosterom *et al*., 2014). Two technological paradigms have played central roles in these developments: Building Information Modelling (BIM) and the Land Administration Domain Model (LADM). BIM, widely adopted in the architectural, engineering, and construction (AEC) industries, allows the creation of semantically rich 3D models that integrate geometric

and attribute data (Zlatanova *et al*., 2016). Meanwhile, the LADM (ISO 19152:2012) provides an international standard for representing land rights, restrictions, responsibilities, and parties, offering a common conceptual framework for cadastral systems (ISO, 2012; Lemmen *et al*., 2015). Recent studies have demonstrated that linking LADM concepts with BIM's open standard, Industry Foundation Classes (IFC), enables the integration of physical and legal information within a single environment, thereby supporting applications such as registration of apartment rights, urban planning, and dispute resolution (Atazadeh *et al*., 2017; Broekhuizen *et al*., 2025; Petronijević *et al*., 2021).

Despite this progress, cadastral practices in Nigeria remain predominantly 2D, with limited practical exploration of BIM–LADM integration for urban land administration. Existing initiatives have highlighted both the opportunities and challenges of transitioning toward 3D cadastre in the Nigerian context but have yet to deliver a working prototype tailored to local cadastral workflows (Adu *et al*., 2020; Emengini *et al*., 2017). Addressing this gap requires the development of a scalable framework that can integrate legal and physical data in line with international standards while being adaptable to jurisdiction-specific legal and institutional requirements.

This study aims to address these challenges by developing and demonstrating a prototype 3D cadastre for Abuja, Nigeria. The prototype integrates BIM and LADM through the IFC standard, enabling the digital representation of ownership spaces, boundaries, and legal attributes within a unified model. Using a design science research methodology (DSRM), the study models a multi-storey apartment building, embeds legal information into spatial units, and evaluates the prototype's effectiveness in improving legal-spatial integration and visualization. The contribution of this work lies in offering a replicable framework for modernizing land administration practices in Abuja and providing insights that may inform broader adoption of 3D cadastre in Nigeria and other rapidly urbanizing regions.

2. STUDY AREA

This study was conducted in the Abuja Municipal Area Council (AMAC), one of the six area councils within Nigeria's Federal Capital Territory (FCT). Abuja was designated as the capital city of Nigeria following the enactment of the Federal Capital Territory Act of 1976, which provided for its development as a planned urban center at the geographic center of the country. AMAC occupies an estimated land area of 250 km², lying between latitudes 9°0′41.234″ N and 9°6′57.474″ N, and longitudes 7°26′39.651″ E and 7°31′48.913″ E (Figure 1). It encompasses major districts such as Garki, Wuse, Maitama, and Asokoro, which represent some of the most urbanized and densely developed parts of Abuja (Idris *et al*., 2021).

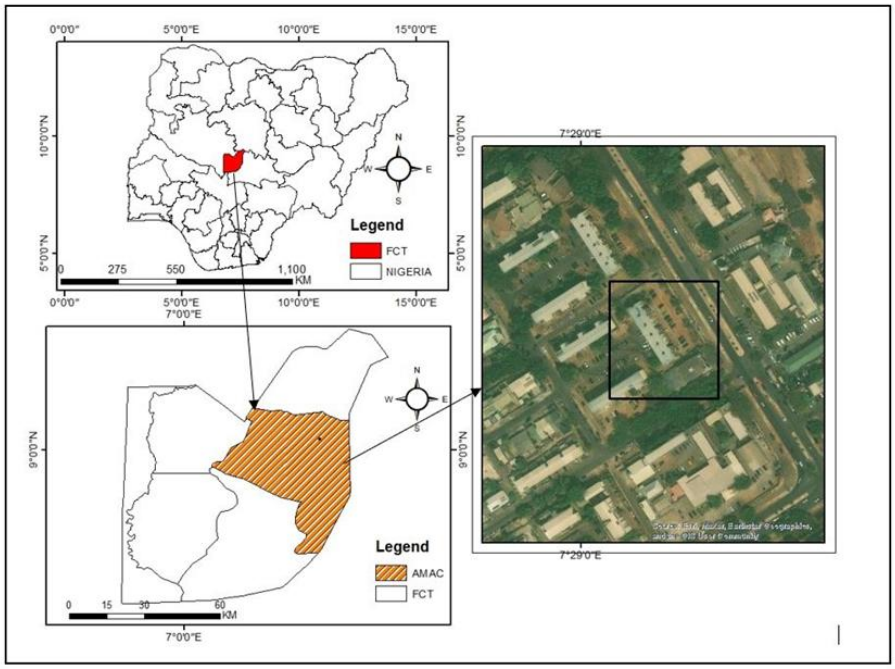

Figure 1: Study area

According to the National Population Commission (NPC, 2012), AMAC had an estimated population of 979,876 in 2012, reflecting its role as the administrative and economic hub of the FCT. Since then, the council has witnessed sustained population growth and rapid urbanization, driven by inward migration, land demand, and government-led infrastructural development. This growth has manifested in vertical expansion through multi-storey residential and mixed-use developments; a trend aimed at addressing land scarcity and the increasing demand for housing.

However, this vertical densification poses significant challenges for land administration. Conventional 2D cadastral systems currently employed in AMAC primarily rely on subdivision plans and annotated PDF documents to record property boundaries and rights (Adu *et al*., 2020). Such approaches are inadequate for representing overlapping ownership rights in multi-level buildings, often resulting in ambiguity, disputes, and reduced legal certainty. These challenges highlight the pressing need for three-dimensional (3D) cadastre solutions tailored to Abuja's rapidly evolving urban landscape.

In this study, AMAC was selected as a case study because it provides a representative environment of the challenges facing cadastral administration in Nigeria's high-density urban areas. The area's mix of land scarcity, high-rise development, and reliance on outdated cadastral practices makes it an ideal testbed for exploring the integration of Building Information Modeling (BIM) and the Land Administration Domain Model (LADM) in developing a functional 3D cadastre framework.

3. METHODOLOGY

3.1 Research Design

This study adopts the Design Science Research Methodology (DSRM) as shown in Figure 2, which is particularly suited to developing and evaluating technological solutions for complex real-world challenges (Hevner *et al*., 2004).

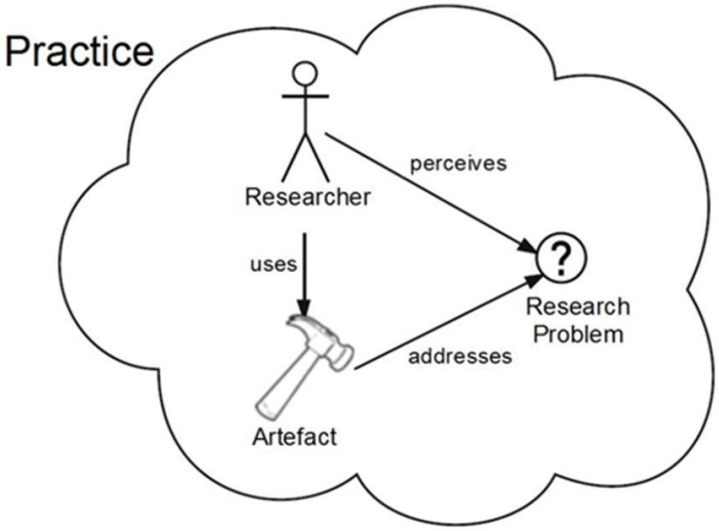

Figure 2: A general overview of design science research paradigm, adopted from (Atazadeh, 2017)

DSRM involves iterative cycles of artifact creation, evaluation, and communication, and is widely applied in land administration research to develop innovative 3D cadastral models (Adaş & Stubkjær, 2011; Atazadeh, 2017). The methodology enables the integration of physical and legal data into a unified framework by systematically progressing through six stages: (1) problem identification, (2) requirement analysis, (3) artifact design, (4) demonstration, (5) evaluation, and (6) communication.

3.2 Prototype Development

3.2.1 Problem Identification

Current land administration practices in Abuja rely predominantly on 2D cadastral representations, typically in the form of subdivision plans and annotated PDF documents (Adu *et al*., 2020). While these approaches are adequate for land parcels, they cannot accurately represent multi-storey ownership spaces, such as private apartment units and joint facilities, which are volumetrically defined within a parcel (Idris *et al*., 2021). This limitation hinders transparency, legal certainty, and efficient property registration. The problem was therefore framed as the inability of a 2D cadastre to adequately represent overlapping property rights in vertical developments.

3.2.2 Requirement Analysis

The requirements for a functional 3D cadastre were identified through a review of cadastral practices and international standards (Lemmen *et al*., 2015; Zlatanova *et al*., 2016). Four critical components were established:

1. 3D spatial representation of apartment units and joint spaces.
2. Integration of legal data such as rights, restrictions, and responsibilities (RRRs).
3. Interoperability with international standards, including LADM (ISO 19152:2012) and IFC.
4. Visualization and querying of legal and physical units within a 3D environment.

3.2.3 Artifact Design

A prototype 3D cadastre was developed using a multi-storey apartment building in Area 10, Garki, Abuja as the case study. Figure 3 depict step-wise method for designing a prototype 3D cadastre in BIM environment. Architectural plans were digitized and modelled in ArchiCAD, a BIM authoring tool compatible with IFC standards. Ownership spaces including private apartments, shared staircases, and corridors were delineated using ArchiCAD's Zone Tool, which supports volumetric and semantic attribution (Atazadeh *et al*., 2017).

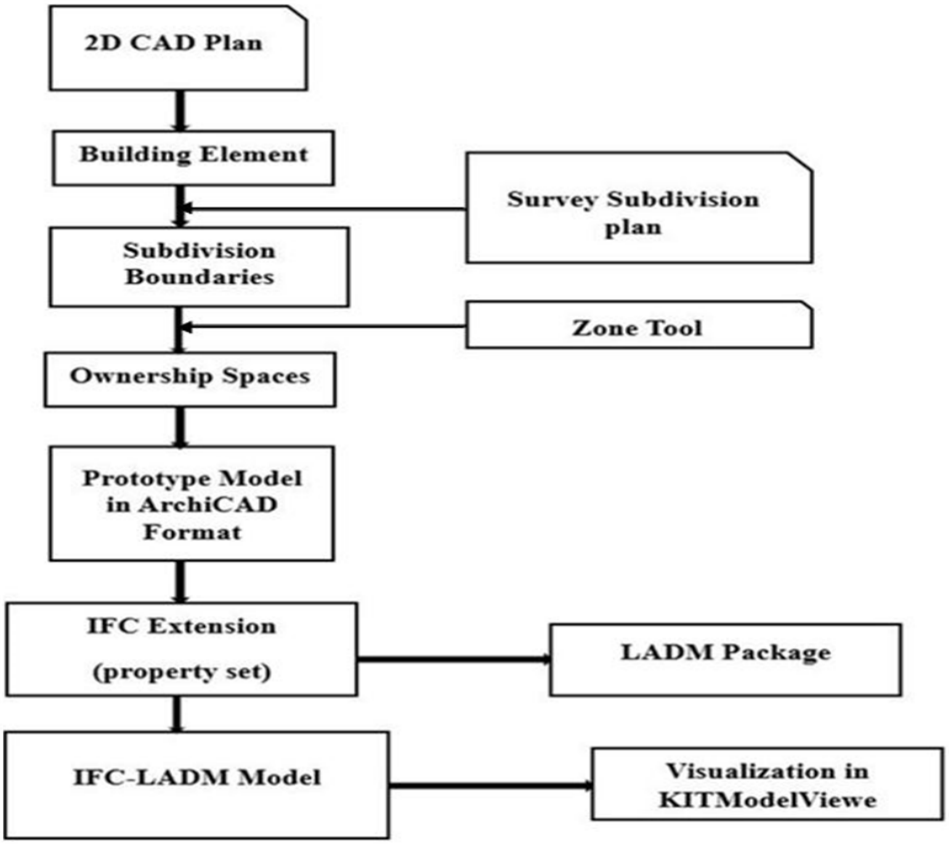

Figure 3: BIM-LADM 3D spatial representation and legal data integration process

The legal framework was modelled by mapping LADM classes (LA_Party, LA_RRR, LA_SpatialUnit, LA_BAUnit) to corresponding IFC entities (IfcActor, IfcPropertySet, IfcSpace, IfcBuilding) (Atazadeh *et al*., 2021; Broekhuizen *et al*., 2025). Legal attributes such as party identifiers, ownership type, and parcel numbers were embedded as IfcPropertySets, ensuring modularity and extensibility (Petronijević *et al*., 2021). This approach preserved the integrity of the IFC schema while enabling legal-physical integration within the BIM environment.

3.2.4 Demonstration
The prototype was demonstrated by simulating ownership scenarios within the modelled building. Apartment units were assigned to different parties, while shared facilities were classified as joint property. Rights and restrictions were linked to spatial units and visualized within the IFC model. The enriched BIM model was imported into the KIT Model Viewer, an interactive platform that enabled stakeholders to explore ownership units and their associated legal data in 3D.

3.2.5 Evaluation
The prototype was evaluated for its capacity to integrate physical and legal information in a 3D cadastre. Evaluation criteria included clarity of ownership boundaries, semantic consistency, interoperability with standards, and ease of stakeholder interpretation. The results demonstrated improved spatial representation and enhanced legal certainty compared to conventional 2D cadastral plans.

3.2.6 Communication

The findings were communicated through the development of this academic article, visual diagrams, and the prototype demonstration, highlighting the feasibility of BIM–LADM integration for supporting a functional 3D cadastre in Abuja.

4. RESULTS

4.1 Mapping of LADM Concepts to IFC Entities
A result of this study is the establishment of a mapping framework between LADM legal classes and IFC entities within the BIM environment. Table 1 summarizes the concept alignment. For example, LA_Party was mapped to IfcActor to represent owners, tenants, or organizations; LA_RRR (rights, restrictions, and responsibilities) was modeled through IfcPropertySet; while LA_SpatialUnit was represented using IfcSpace and IfcBuildingStorey to capture volumetric property units. Similarly, LA_BoundaryFace was aligned with IfcBoundaryFaceSurface to explicitly define 3D ownership boundaries (Atazadeh *et al*., 2021; Broekhuizen *et al*., 2025).

Table 1: Concept Mapping of LADM and Relevant IFC elements

LADM Concept	IFC Entity
LA_Party	IfcActor
LA_RRR	IfcPropertySet
LA_BAUnit	IfcSite / IfcBuilding
LA_SpatialUnit	IfcSpace, IfcBoundaryFaceSurface, IfcBuildingStorey
LA_BoundaryFace	IfcBoundaryFaceSurface
LA_Surveying	IfcRelContainedInSpatialStructure

4.2 Property Set Extensions for Legal Integration
The integration of legal attributes into the BIM environment was achieved through IfcPropertySet extensions. Table 2 shows Property Sets for LADM Party Entities Mapped to IFC.

Table 2: Property Sets for LADM Party Entities Mapped to IFC

Property Set Name	Attribute Name	IFC Property Type	Data Type
Pset_LA_Party	pID	IfcPropertySingleValue	IfcIdentifier
	Type	IfcPropertySingleValue	IfcIdentifier
Pset_LA_GroupParty	groupId	IfcPropertySingleValue	IfcIdentifier
	Type	IfcPropertyEnumeratedValue	IfcLabel

From the Table 2, property set Pset_LA_Party included attributes such as unique party identifiers (pID) and party type (natural person, legal entity, or public body), enabling interoperability with external land registry systems. Likewise, Pset_LA_SpatialUnit captured the geometric and functional attributes of apartment units, including area, volume, cadastral zoning code, land-use classification, and plot numbers.

4.3 Prototype Model of a Multi-Storey Building

A prototype 3D cadastre was developed for a multi-storey apartment building in Area 10, Garki, Abuja as shown in Figure 4.

The model delineated both private spaces (individual apartment units) and joint spaces (staircases, corridors, and parking areas). Each apartment was represented as an IfcSpace, enriched with legal attributes such as ownership rights, responsibilities, and restrictions.

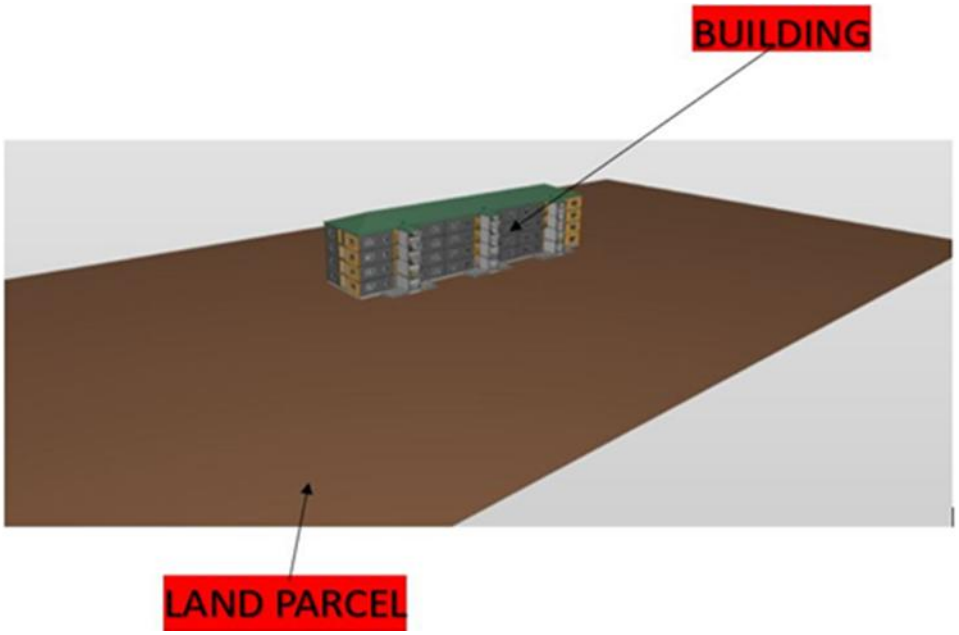

Figure 4: 3D Cadastre in BIM Environment

The hierarchical structure of IfcBuilding and IfcBuildingStorey enabled floor-by-floor organization, while IfcBoundaryFaceSurface provided explicit 3D boundaries between adjoining units.

4.4 Visualization and Querying of Legal-Spatial Units

The enriched BIM model was imported into the KITModelViewer as shown in figure 5 and 6, enabling interactive exploration of ownership units and their associated legal information.

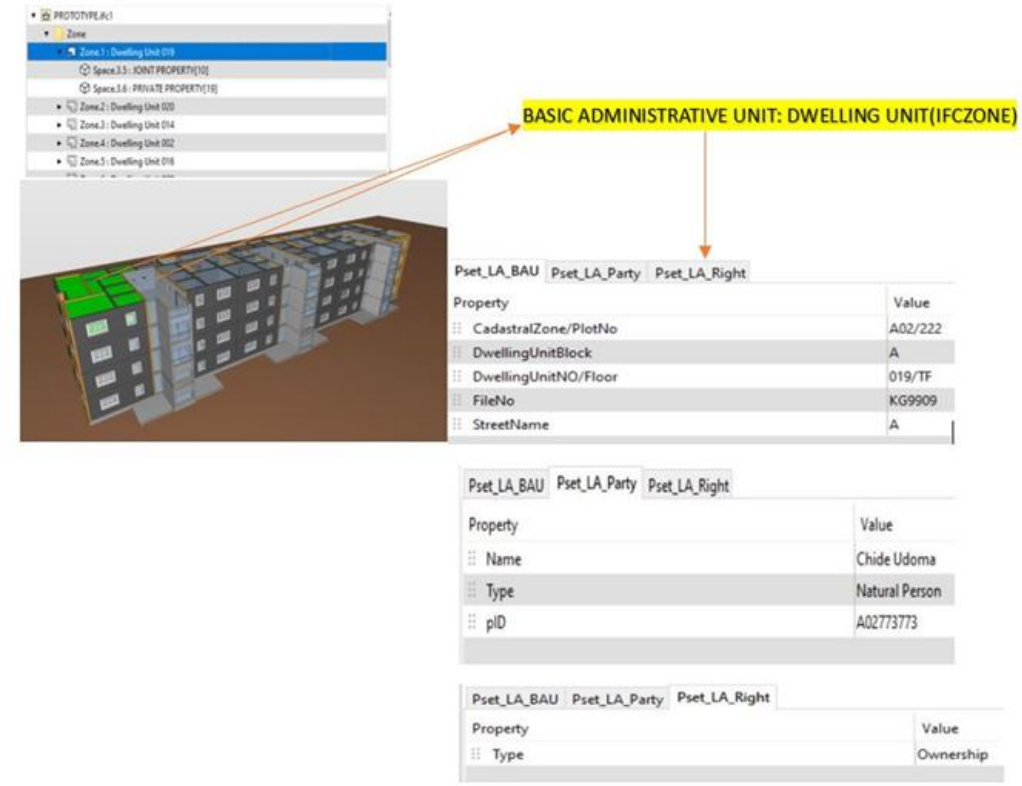

Figure 5: A 3D Cadastre with cadastral information in KITModelViewer

Users could query each spatial unit to retrieve attributes such as ownership type (Figure 5), unit, and cadastral zoning information (Figure 6). For example, as shown in Figure 6, a volumetric spatial unit was shown to have an area of 92.02 m², a volume of 248.45 m³. It was classified under a high-density land-use zone with a unique identifier (suID).

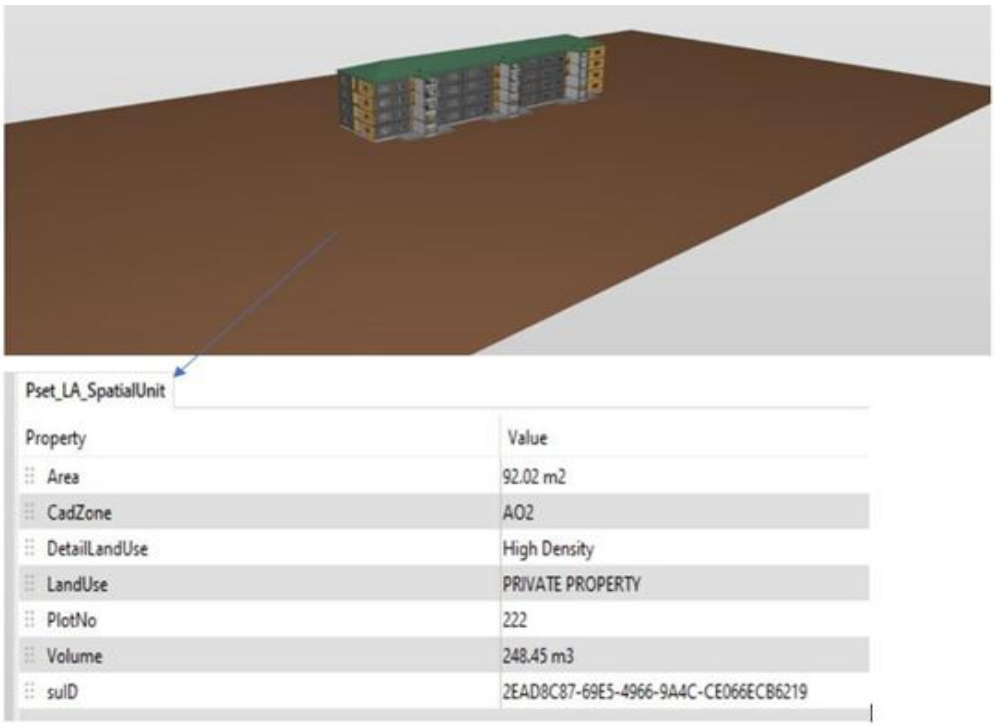

Figure 6: 3D Cadastre visualization in KITModelViewer

5. DISCUSSION

The results of this study demonstrate the feasibility of integrating BIM and LADM through IFC standards to support a functional 3D cadastre in Abuja. By embedding legal attributes directly within the BIM environment, the prototype addresses the limitations of Nigeria's conventional 2D cadastre (Adu *et al*., 2020). The ability to explicitly model volumetric ownership boundaries represent a significant advancement for land administration in Abuja, where multi-storey housing has become a dominant form of urban development (Idris *et al*., 2021).

These findings align with international research that highlights the advantages of linking LADM with BIM for 3D cadastre (Atazadeh *et al*., 2017; Broekhuizen *et al*., 2025). Studies in Malaysia (Amalina *et al*., 2021) and Greece (Gkeli *et al*., 2021) also emphasize the potential of BIM–LADM integration to enhance transparency and support legal certainty in complex urban ownership settings.

One of the notable contributions of this research is the property set extension approach, which embeds LADM concepts such as LA_Party, LA_RRR, and LA_SpatialUnit within IFC entities without altering the core schema. This approach ensures interoperability while allowing modularity and scalability for future extensions (Petronijević *et al*., 2021).

Despite these achievements, several challenges remain. First, aligning jurisdiction-specific legal frameworks with international data standards requires adaptation to Nigeria's statutory and customary tenure systems (Lemmen *et al*., 2015; van Oosterom *et al*., 2014). Second, integration into existing cadastral workflows will require institutional reforms and capacity building (Zlatanova *et al*., 2016). Finally, maintaining semantic consistency between LADM and IFC highlights the need for automated validation tools (Liu *et al*., 2023).

The implications are significant: the prototype provides a clearer, interactive representation of ownership spaces, reducing ambiguity in property registration and dispute resolution, while offering policymakers a replicable framework to support Nigeria's transition toward digital land governance.

6. CONCLUSION

This study has demonstrated the feasibility of integrating the Land Administration Domain Model (LADM) with Building Information Modelling (BIM) through the Industry Foundation Classes (IFC) standard to support a functional 3D cadastre in Abuja, Nigeria. The prototype effectively addressed the limitations of 2D cadastral systems by enabling volumetric representation of property units, embedding legal data, and enhancing ownership clarity. The results highlight the potential of 3D cadastre to modernize land administration in Abuja by supporting improved property registration, dispute resolution, and urban planning. Nevertheless, challenges remain in aligning jurisdiction-specific legal requirements with international standards and ensuring institutional readiness.

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