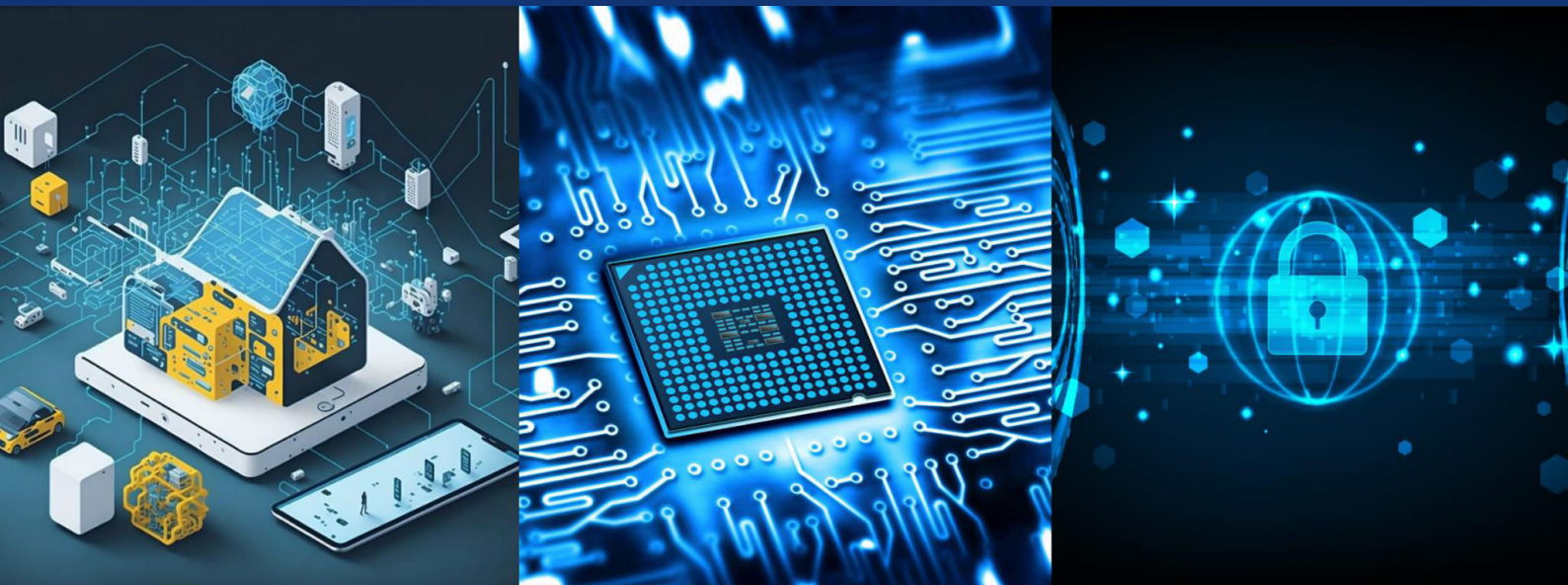
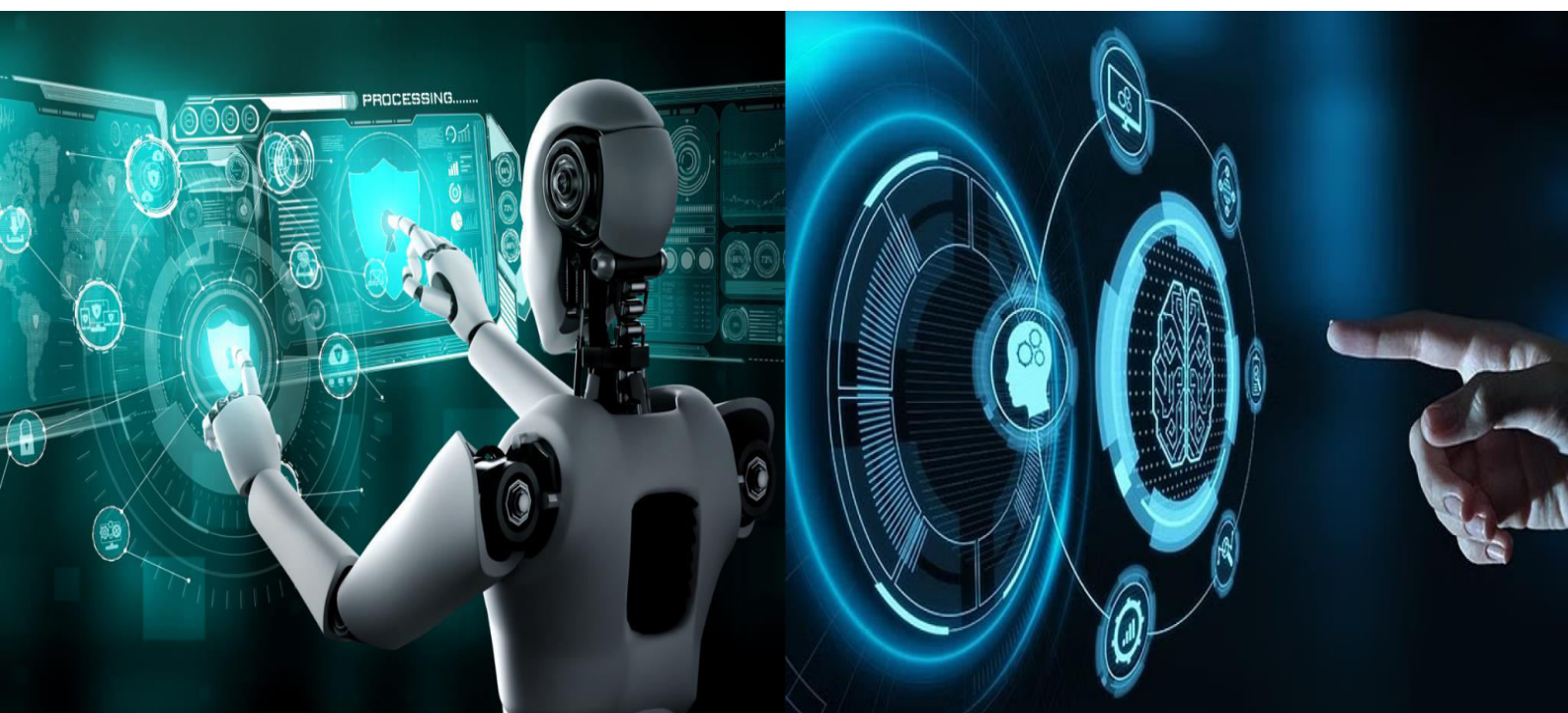




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3D ULPIN Generation and Vertical Property Mapping System using AI and Geospatial 3D

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ABSTRACT: Conventional property identification is primarily plot-oriented and does not adequately represent vertical property units such as individual flats, floors, basements and underground spaces. This paper proposes a 3D ULPIN Generation and Vertical Property Mapping System that extends the existing 14-character ULPIN with a vertical property identity and a geometry-based integrity fingerprint. The proposed system integrates GIS parcel records, SVAMITVA/drone imagery, LiDAR point clouds and floor plans in CAD, PDF or IFC formats to construct a three-dimensional cadastral representation. Artificial intelligence is proposed for automated floor-plan extraction, point-cloud segmentation and boundary validation, while PostGIS with SFCGAL provides three-dimensional geometry and topology validation. GNSS/CORS is used for accurate outdoor georeferencing, and CesiumJS with 3D Tiles supports interactive visualization. The proposed identity contains the base plot ULPIN, a vertical tag, a registry-issued unit serial and a six-character SHA-256-derived integrity fingerprint computed from canonicalized geometry. The design retains existing two-dimensional records while adding a three-dimensional extension for vertical property management. The paper presents the architecture, generation workflow, validation strategy and potential impact of the proposed system.

KEYWORDS: 3D ULPIN; vertical property mapping; 3D cadastre; GIS; LiDAR; CesiumJS; PostGIS; spatial fingerprint; AI; smart automation

I. INTRODUCTION

Property records traditionally focus on parcels represented in two dimensions. Such a representation becomes insufficient when a single plot contains multiple vertically separated property units, including apartments, commercial units, basements and underground infrastructure. The Smart India Hackathon 2026 problem statement addressed in this work is SIH26011, titled "3D ULPIN Generation and Vertical Property Mapping System," under the Smart Automation theme. The proposed solution aims to transform existing land information into an intelligent three-dimensional property map.

The SIH proposal identifies a multi-source integration approach in which GIS parcels, SVAMITVA/drone imagery, LiDAR point clouds and floor plans are combined into a 3D cadastral model. Each parcel, building, floor and unit is represented as a closed 3D volume, while an extended 3D ULPIN is associated with each unit. The design keeps the existing 14-character ULPIN unchanged and adds a three-dimensional identity layer [1].

A major objective is to provide a consistent digital identity for vertical property units while enabling spatial verification. The proposed platform supports floor-by-floor visualization, unit search, officer verification and audit history. AI-assisted extraction and boundary validation are included to reduce the manual effort involved in converting heterogeneous property data into structured 3D objects [1].

The remainder of this paper describes the related standards and data sources, the proposed 3D ULPIN architecture, the identity-generation process, the technical implementation, the validation framework, and the expected benefits and future enhancements.



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II. RELATED WORK AND TECHNOLOGICAL BACKGROUND

The proposed system is positioned at the intersection of land administration, geospatial information systems, 3D city modelling and artificial intelligence. The Department of Land Resources provides the ULPIN/Bhu-Aadhaar framework, while the DILRMP portal supports digitized land-record activities. The SVAMITVA scheme provides drone-survey data relevant to rural property mapping, and NGDRS provides a national framework for document registration [1].

For interoperability, the SIH proposal identifies CityGML, IFC and ISO 19152 Land Administration Domain Model (LADM) as relevant standards. CityGML supports interoperable 3D city information, IFC supports building information exchange, and LADM provides a conceptual basis for land-administration entities and relationships [1].

From the computational perspective, the proposed stack combines PostGIS and SFCGAL for 3D solids, spatial indexing and topology validation; Python and PyTorch for AI-based floor-plan and point-cloud processing; PDAL and Open3D for LiDAR filtering and tiling; GNSS/CORS for outdoor georeferencing; and CesiumJS with 3D Tiles for streaming large 3D models [1].

The distinctive contribution of the proposed work is the integration of these components around a property identity rather than treating visualization, land records and 3D geometry as independent systems. The system therefore addresses both spatial representation and identity management in a single workflow.

III. PROPOSED SYSTEM

A. System Objectives

- Convert 2D parcel and building information into a structured 3D cadastral representation.
- Represent land, buildings, floors, units and underground spaces as spatially identifiable 3D entities.
- Extend the existing ULPIN without replacing the original 2D identifier.
- Generate a deterministic geometry-based integrity fingerprint to support uniqueness and conflict detection.
- Provide AI-assisted extraction and boundary validation while keeping officer verification in the workflow.
- Provide interactive floor-by-floor visualization, search, verification and audit history.

B. Data Integration Layer

The system accepts multiple data sources. Existing GIS parcel information forms the base cadastral layer. SVAMITVA/drone imagery contributes survey information, while LiDAR point clouds provide three-dimensional surface and structural information. Floor plans in CAD, PDF or IFC formats provide detailed building and unit layouts. The data are normalized, georeferenced and transformed into a common spatial reference before 3D entity generation [1].

C. 3D Cadastre Model

Each parcel, building, floor and property unit is represented as a closed 3D volume. The model maintains relationships between the base plot and its vertical components. This enables a single building to contain multiple independently searchable units while preserving their relationship with the underlying parcel.

D. 3D ULPIN Generation

The proposed identifier extends the existing 14-character ULPIN with four logical components: (i) the unchanged base plot ULPIN, (ii) a vertical tag indicating above-ground or basement location and floor, (iii) a registry-issued unit serial number, and (iv) an integrity fingerprint derived from canonicalized X, Y and Z geometry. The SIH example illustrates a base ULPIN followed by a vertical tag, unit serial and six hexadecimal characters derived from SHA-256 [1].

$$\text{3D-ULPIN} = \text{Base ULPIN} + \text{Vertical Tag} + \text{Unit Serial} + \text{Geometry Fingerprint}$$

The geometry fingerprint is calculated only after canonicalization of the spatial representation. Canonicalization is important because equivalent geometries should produce the same representation before hashing. A database uniqueness constraint and 3D topology checks are then used to detect duplicate or conflicting identities [1].



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IV. TECHNICAL ARCHITECTURE

The technical architecture is organized into five layers: data acquisition, preprocessing and AI extraction, 3D spatial database, identity and validation services, and visualization/application services.

A. Data Acquisition and Preprocessing

The input layer collects GIS parcel records, drone imagery, LiDAR point clouds and floor plans. PDAL and Open3D are proposed for LiDAR filtering and tiling. GNSS/CORS-based georeferencing is proposed to improve the spatial alignment of outdoor datasets. Incomplete or inconsistent source records are identified during preprocessing rather than silently treated as authoritative.

B. AI-Assisted Extraction

Python and PyTorch are proposed for extracting building and floor information from floor plans and point clouds. Candidate models mentioned in the SIH proposal include U-Net or Mask R-CNN for floor-plan parsing and PointNet++ or KPConv for point-cloud segmentation. AI-generated floors remain unverified until an authorized officer completes the verification step [1].

C. Spatial Database and Validation

PostGIS with SFCGAL provides storage and processing for 3D solids, topology validation and spatial indexing. Validation includes geometry closure, spatial consistency, duplicate detection and conflict checks. The SIH design also proposes limiting spatial-index searches to a building's neighborhood instead of scanning the entire city, improving scalability [1].

D. API and Access Control

FastAPI with PostgreSQL is proposed for REST services and role-based access. The intended roles are surveyor, officer and citizen, with different permissions for data creation, verification and public viewing [1].

E. Visualization

Cesium.JS and 3D Tiles provide the interactive visualization layer. Users can inspect a building floor by floor, search for a unit and review verification information. The approach is intended to support streaming of large 3D datasets without requiring the complete model to be loaded at once [1].

V. 3D ULPIN GENERATION ALGORITHM

The proposed workflow generates a unit identity only after the spatial entity passes the required geometric and administrative checks:

- Step 1: Obtain the base 14-character ULPIN associated with the parent plot.
- Step 2: Extract or construct the building, floor and unit geometry from available GIS, imagery, LiDAR and floor-plan sources.
- Step 3: Georeference and normalize the geometry into the common coordinate reference system.
- Step 4: Validate the unit as a closed 3D volume and perform 3D topology and spatial-conflict checks.
- Step 5: Assign the vertical tag representing the above-ground or basement position and floor.
- Step 6: Assign a registry-controlled unit serial number for the relevant floor.
- Step 7: Canonicalize the X, Y and Z geometry and compute SHA-256.
- Step 8: Store the first six hexadecimal characters of the hash as the integrity fingerprint.
- Step 9: Apply database uniqueness constraints and verify that the new 3D identity does not conflict with an existing identity.
- Step 10: Keep the AI-generated result in an unverified state until officer approval is completed.

The workflow separates automated spatial processing from administrative authorization. This is important because AI extraction is treated as an assistive mechanism rather than the final authority for property identity.



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VI. PSEUDOCODE

Input: Base ULPIN, parcel data, building data, floor plan, LiDAR/imagery

1. Generate candidate 3D building and unit geometries.
2. Georeference and normalize all candidate geometries.
3. For each candidate unit:
 - a. Validate closed 3D geometry.
 - b. Check topology and spatial conflicts.
 - c. If validation fails: mark unit as invalid and continue.
 - d. Generate vertical tag.
 - e. Assign registry-controlled unit serial.
 - f. Canonicalize X, Y, Z geometry.
 - g. Compute SHA-256 fingerprint.
 - h. Form 3D ULPIN from base ULPIN, vertical tag, serial and fingerprint.
 - i. Check uniqueness in the spatial database.
 - j. If unique: mark as unverified and send for officer verification.
4. After officer approval: publish verified unit identity and audit event.

VII. IMPLEMENTATION AND EVALUATION FRAMEWORK

The SIH document defines the proposed technology stack and expected impact, but it does not provide numerical experimental measurements such as processing time, segmentation accuracy, topology-error rates or scalability benchmarks. Therefore, this paper does not claim numerical performance results that are not present in the source proposal.

A prototype evaluation should be conducted using representative parcel, building, floor-plan and LiDAR datasets. The first evaluation dimension should measure geometric validity, including the percentage of generated units that form valid closed 3D solids and the number of topology conflicts detected. The second should evaluate identity integrity by checking duplicate and conflicting 3D ULPIN generation under repeated or modified geometries.

The third dimension should evaluate AI-assisted extraction using precision, recall and intersection-over-union for floor or unit boundary extraction where labelled ground truth is available. The fourth should measure system scalability by varying the number of buildings, floors, units and LiDAR points. Finally, user-oriented evaluation should measure the time required by an authorized officer to inspect, verify and audit a generated unit.

The SIH proposal identifies incomplete property data, large and complex LiDAR datasets, and difficulty in accurately mapping floors and property boundaries as key risks. Its corresponding strategies include multi-source data integration, AI-based processing and filtering, and GNSS/CORS-based georeferencing [1].

VIII. EXPECTED RESULTS AND BENEFITS

The proposed system is intended to provide a property model in which every flat, basement and relevant vertical unit can receive an independently identifiable record while remaining linked to the parent plot. The SIH proposal identifies clear property identification, reduced property disputes, improved urban planning, efficient infrastructure management, improved transparency and scalability as major benefits [1].

At the operational level, a building can be inspected floor by floor through a single dashboard. Utility or infrastructure conflicts can potentially be detected before construction rather than only after disputes occur. The system also provides a foundation for a digital twin of built properties and can support more transparent government approval and property-management workflows [1].



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These benefits should be validated through a future prototype evaluation rather than treated as measured outcomes at the current proposal stage.

IX. CHALLENGES AND FUTURE ENHANCEMENTS

The principal challenges are data completeness, heterogeneous formats, large-scale 3D processing, accurate floor extraction, property-boundary ambiguity and administrative verification. A robust deployment should therefore retain provenance information for every generated geometry and record the source data, processing version, AI model version and officer action associated with an identity.

Future work can include larger-area experiments, more extensive labelled datasets for AI extraction, automated change detection between successive surveys, improved underground-structure modelling, integration with additional land and registration services, and benchmarking against alternative 3D cadastral identity schemes. The system can also be extended to support temporal digital twins in which property geometry and verification history are maintained across multiple survey dates.

X. CONCLUSION

This paper presented a 3D ULPIN Generation and Vertical Property Mapping System based on the SIH26011 problem statement. The proposed approach combines existing 2D ULPIN records with 3D property geometry, vertical tags, registry-issued unit serials and a geometry-derived integrity fingerprint. GIS, drone/SVAMITVA imagery, LiDAR and floor plans are integrated to create a 3D cadastral representation, while AI, PostGIS/SFCGAL, GNSS/CORS, FastAPI and CesiumJS provide the computational and visualization framework [1].

The key design principle is to preserve the existing land identity while adding a verified vertical dimension. AI is used to assist extraction, but generated property units remain subject to officer verification. This provides a practical path from 2D plot-centric records toward intelligent 3D property mapping. Quantitative accuracy, scalability and performance remain subjects for prototype implementation and experimental validation.

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