Development of a Cutting-Edge 3D Cadastral Management System

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SUMMARY

This article outlines the creation and implementation of a groundbreaking 3D Cadastral Management System in alignment with Israel's new 3D land registration law. In 2018, the State of Israel enacted a pioneering 3D land registration law as an amendment to the Real Estate Law. Consequently, The Survey of Israel awarded a contract to Sivan Design (www.sivandesign.com) for the creation of a cutting-edge 3D Cadastral Management System.

The input to the new system are 3D Cadastral Subdivision Plans which are submitted in accordance with the new Israeli 3D CAD Standard. This 3D CAD Standard uses 3D Points, that construct 3D Parcels, which defines Subtractions.

The development of the 3D Cadastral System consisted of the design, development and implementation of the following components:

1. The design and configuration of a 3D Cadastral Database.
2. The development of a quality control engine.
3. The development of a CAD to GIS migration engine.
4. The installation and configuration of the 3D viewing and querying environment.
5. The development of a web-based management system.

The article concludes with a demonstration of a few practical cases of loading, analyzing and integrating of 3D Cadastral Plans into the 3D Cadastral System.

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1. Introduction

1.1 The Development of 3D Cadaster in Israel

In the fast-paced world of urban development and land management, traditional cadastral systems are inadequate to meet the demands of modern societies. As cities grow and infrastructure becomes more complex, the need for a sophisticated, accurate, and efficient land management system has become paramount. In this context, 3D cadastral management systems emerge as innovative solutions, revolutionizing land administration and resource management (Felus et al 2014).

In Israel, the development and implementation of a 3D cadaster has been driven by the need to efficiently utilize land in a country with a high population density and limited available land for residence, especially in central and northern areas. This situation has necessitated innovative solutions for urban development, including effective use of space both above and below ground level.

The development of Israel's 3D cadaster includes several key elements:

- Initial development and R&D Projects started by the Survey of Israel (SOI) in 2002 when a multi-layer 3D cadaster research has begun. This project involved experts from various disciplines, aiming to find geodetic, cadastral, planning, engineering, and legal solutions for utilizing space above and below the surface (Benhamu and Doytsher, 2003, Shoshani et al. 2005 and Peres and Benhamu, 2009).
- In 2016, Israel adopted new survey regulations that laid the foundation for a Coordinate Based Cadaster (CBC). In this CBC system, each parcel corner point is ranked based on its accuracy and definition clarity. A rank 1 parcel corner is defined by its coordinates alone. A definition of a corner point by its coordinates is the basis for the 3D- Cadaster where a point is defined by 3D coordinates (Fishbein et al., 2017 and Barazani and Felus, 2017).
- At the end of 2018, Israel's Real Estate Law was amended to permit vertical division of land into distinct spatial levels, introducing the concept of a three-dimensional parcel in legislation. Subsequently, by the end of 2020, Israel approved its first three-dimensional subdivision plan leading to the registration of the first three-dimensional parcel in the country (Khasanshina et al. 2021).
- At the end of 2021, the Survey of Israel initiated a rigorous selection process and eventually awarded the contract to Sivan Design (www.sivandesign.com) for the

creation of a cutting-edge 3D Cadastral database and a 3D spatial analysis and validation system. The systems with its main modules are depicted in Figure 1.

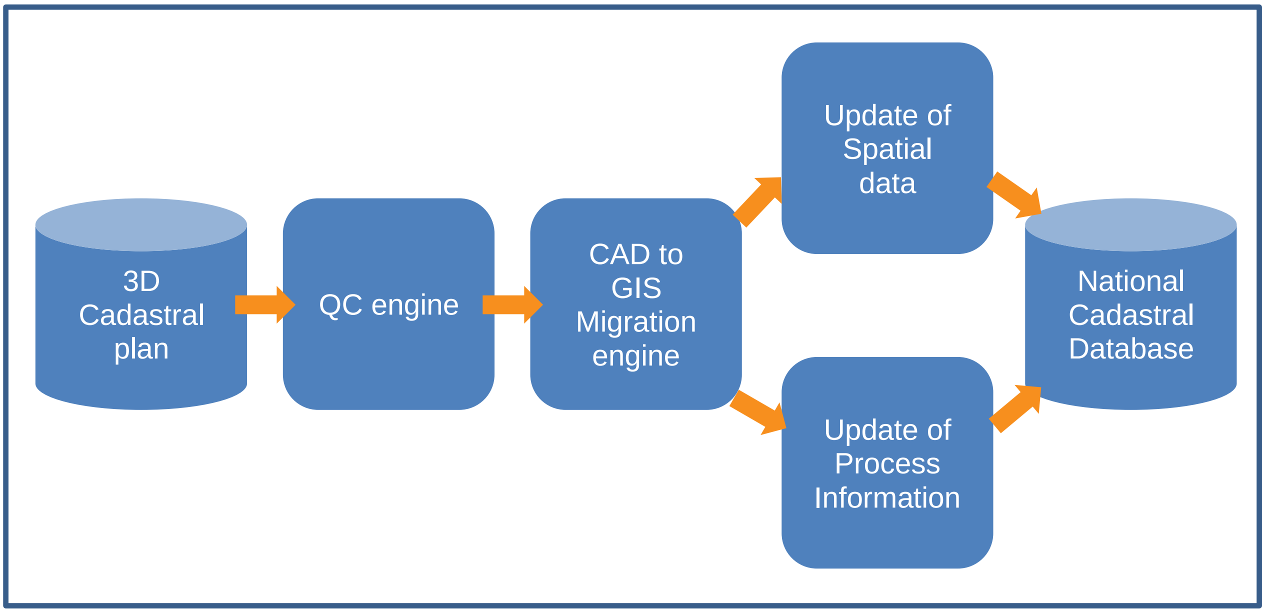

Figure 1: The main modules of the 3D Cadastral Management System.

The system with its development stages will be described after a brief introduction to the 3D subdivision plan, the foundational input for the system.

1.2 How to Prepare a 3D Subdivision Plan?

The submission of a subdivision plan, in either 2D or 3D format, initiates updates to the National Cadastral Database (NCDB). Specifically, a 3D subdivision plan leads to the addition, alteration, or removal of 3D parcels and subtractions in the NCDB. The subdivision plan encompasses not only the spatial layers of information, such as corner points, land boundaries, and parcels, but also details pertaining to the cadastral process and calculations, including the surveyor's name and number, date, area tables, and more.

The technical guidelines for preparing the three-dimensional subdivision plan were published in 2018 as part of the updated "National Mapping Specification" (Adi, Shnaidmann, and Barazani 2018). To comprehend the 3D cadaster process, it's crucial to understand the following key concepts:

- Parcel (2D, on the ground) - The Israeli Cadaster predominantly consists of 2D parcels surveyed on the ground and delineated by 2D border points. These parcels are defined from the center of the earth to the infinite sky (for instance, parcel 56 in Figure 2).
- 3D Border Point – This refers to a vertex characterized by X, Y, and Z coordinates, which delineate the three-dimensional boundaries of a 3D parcel. The point coordinates are the sole evidence for the corner location.
- Subtraction - a volumetric unit which inherits the 2D horizontal boundaries of a parcel but has vertical boundaries which are delineated by 3D Corner Points. For example, subtraction 56-1 inherits the 2D boundaries of parcel 56 in Figure 2.

- A three-dimensional parcel - a volumetric unit which its boundaries are registered in three-dimensions and can be located below or above the ground surface. An example is parcel 89 in Figure 2, which Substraction 56-1 was created out of it

The 3D subdivision plan consists of a CAD file with three distinct sheets:

- Main Sheet: This sheet includes the 3D model of the parcels, surface details, comprehensive information about the general subdivision plan, and various calculation tables.
- Profile Sheet: This sheet presents vertical views of the 3D parcel and its subtractions, showing their dimensions in length and width.
- Top View Sheet: It displays the overhead projection of the 3D parcel in relation to the 2D cadastral boundaries.

The subtractions and 3D Parcels are constructed in CAD in a multi-step process: Initially, a 3D polygon is drawn, connecting the 3D corner points. Subsequently, surfaces are formed from these polygons using the 'SURFPATCH' command in AutoCAD. Finally, these surfaces are merged to create 3D solids, employing the 'SURFSCULPT' command in AutoCAD.

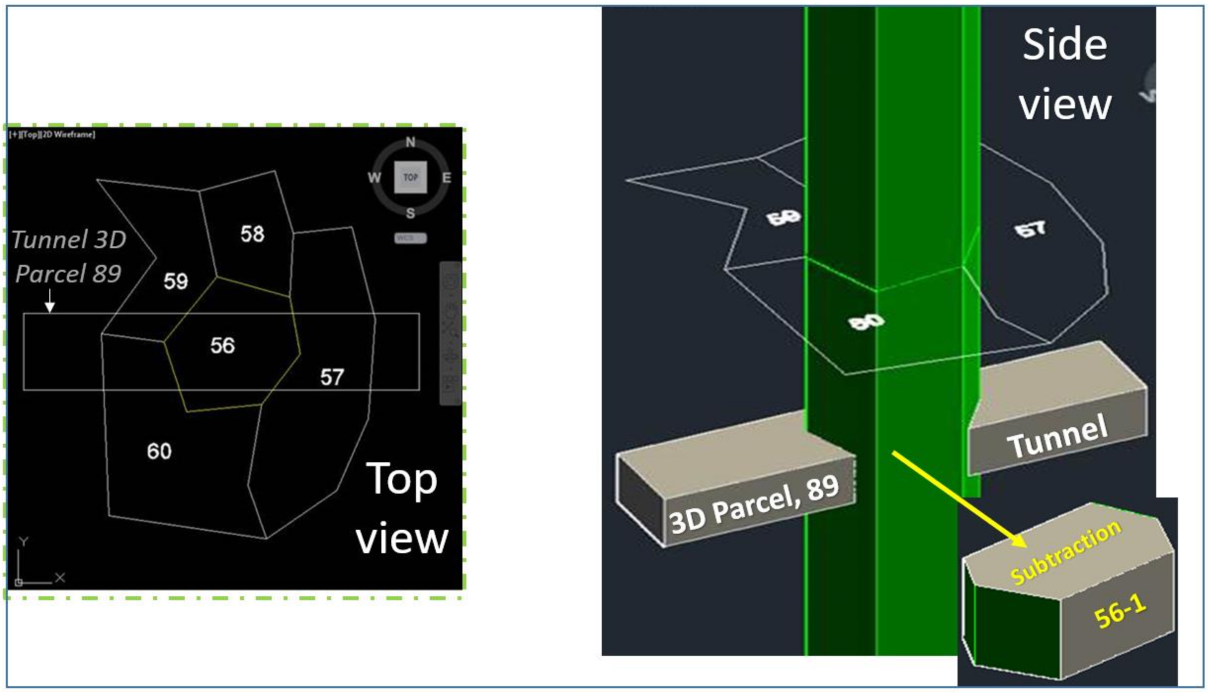

Figure 2: On the left, a top-down view presents five parcels (56, 57, 58, 59, 60) along with the projection of a 3D parcel, 89 (representing a tunnel). On the right, a side view of parcel 56, extending from the earth's center to the infinite sky, except for the area designated as subtraction 56-1.

In the subsequent sections, we will detail the development of a 3D cadastral management system. Section 2 outlines the database design principals, while section 3 delves into the evolution of a quality control engine and a CAD to GIS migration engine. Section 4 describes the 3D viewing and querying environment, and Section 5 the management system. Lastly, section 6 offers concluding remarks.

2. Three-Dimensional Database Design

The purpose of the cadastral database (2D and 3D) is to keep a comprehensive record of land boundaries and associated details. This includes information about the land parcellation process, specifics of parcels (such as area, volume, and type), parcel history, measurements, monuments, the year of survey, surveyor identification, and more. Additionally, the database facilitates data quality and topology verification during updates. It also enables rapid and efficient querying and analysis of data.

The national cadastral database is comprised of three distinct categories of tables:

1. Spatial Data: This category includes the 2D Parcels layer, 2D Blocks layer, 3D Parcels layer, Subtraction layers, and Border points. These datasets represent the delineation of cadastral boundaries of parcels in both 2D and 3D formats.
2. Cadastral Process Information: This section contains comprehensive details about the cadastral process. It includes historical modifications of borders, such as divisions and unifications of parcels, the surveyors responsible for these modifications, relevant dates, and subdivision numbers.
3. Supplementary Data: This category encompasses tables detailing surveyors, types of geodetic networks, land registration status, and other related information.

Both the Cadastral Process Information tables and the Supplementary Data tables are consistent across the 2D and 3D databases. Therefore, these categories of tables will not be further discussed. The following guidelines were adhered to during the development of the 3D Cadastral database:

1. The database should be structured to minimize redundancies and eliminate inconsistent dependencies.
2. Each parcel, whether 2D or 3D, within a block is assigned a unique number, serving as its index.
3. Certain redundancies are intentionally retained to ensure data consistency and facilitate quality checks. This includes assigning a unique identifier to each parcel and subtraction, encompassing both block and parcel numbers.
4. The Israeli database predominantly operates in 2D but includes distinct 'islands' of 3D parcels. As a result, land is indexed and referenced solely by its 2D parcel number, with links to any existing 3D subtractions and 3D parcels.
5. The AutoCAD file of the 3D subdivision plan encapsulates all the data that needs to be stored in the database.
6. Some layers, such as the topographic layer, will not be incorporated into the cadastral database. Instead, they will be included in the Israeli National Spatial Database (NSDB), which falls outside the scope of the 3D cadaster project.

7. In general, most of the attributes are extracted from the CAD file (of the 3D subdivision plan) but some attributes are added to the database in order to support the cadastral management system such as uploading date, QC verification date, etc.

The following relationship are set between the tables:

1. **Table Parcels 2D**: This is the national index for the cadastral layer, featuring a unique block and parcel number for each entry. It provides complete and seamless coverage of the country. Each parcel, represented as a closed polygon in the geometry field, has a defined legal area and registration status. Each parcel has a one-to-many relationship with the CadasterProcess3D Table, which details the cadastral processes or approved subdivision plans that have created or modified the parcel.
2. **Table Substraction**: This table stores Multipatches in the Geometry field. Each Substraction maintains a one-to-many relationship with a parcel, meaning one Substraction is linked to one 2D parcel, but a single 2D parcel may be associated with multiple Substractions. The Substraction table records information such as volume, the projected horizontal area of the parcel, and elevations at both upper and lower levels of the Substraction, as well as a relationship with the Parcel3D table (each Substraction corresponds to one 3D parcel, but a single 3D parcel is composed out of many Substractions)
3. **Table Parcels 3D:** This table contains information about 3D parcels. Each 3D parcel includes data on volume, projected horizontal area, and elevations at both upper and lower levels of the 3D parcel. It also maintains a relationship with the CadastterProcess3D table, which keeps records of the subdivision plans that created or modified the 3D parcels (each 3D Parcel is linked to a single cadastral process, but each process can create or modify multiple parcels).
4. **Table Border Points:** This table documents information about the vertices or corner points of parcels. While these points are often physically marked on the ground, in the case of 3D points, numerical coordinates are the sole evidence of their location. Each record includes geodetic information along with point identification data.
5. **Table CadasterProcess3D:** It stores comprehensive information about the 3D subdivision plan and its approval process, including details about the surveyor, date, scale, registration status, and more. Each process in this table is associated with multiple parcels, either 2D or 3D.

Figure 3 presents the relationships between the spatial data tables of the 3D cadastral database.

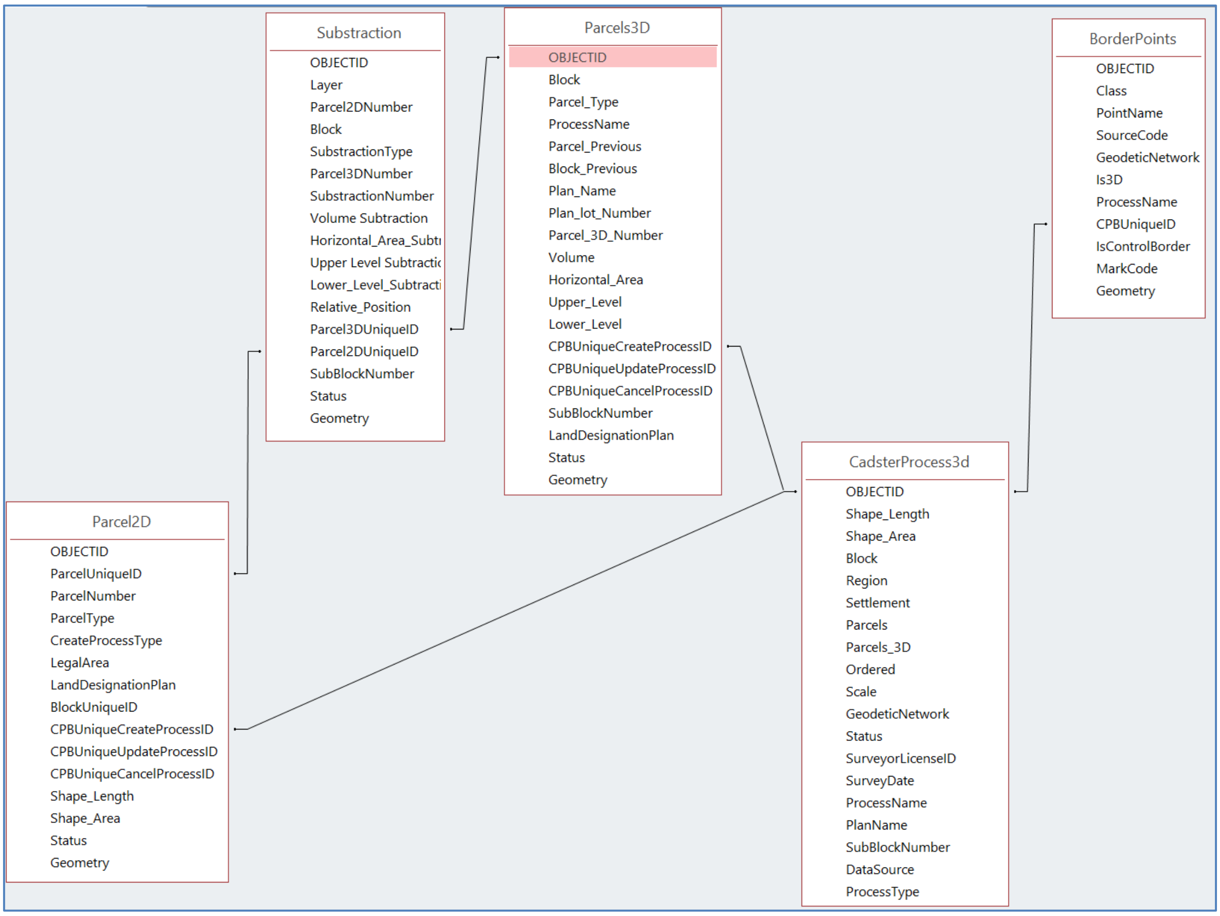

Figure 3: ERD (entity relationship diagram) of the key tables is the 3D cadastral database.

3. Quality Control and CAD to GIS Migration Engine for 3D Subdivisions Plans

The 3D Cadastral Management System was designed utilizing a microservices architecture. ArcGIS was chosen as the foundational GIS platform, and AutoCAD served as the primary CAD platform. As can be seen in Figure 4 the system utilizes both CAD and GIS tools in the quality verification and data migration process.

Tests-engine was designed and developed and includes more than 120 different types of automated compliance tests. Each test is conducted either in a CAD (Computer-Aided Design) or GIS (Geographic Information System) environment. It's important to note that the choice between CAD and GIS is not based on the test's logical context, but rather on factors such as the ease of development, the speed and accuracy of execution, and the potential for parallel processing (scalability). Additionally, it should be highlighted that the preference is to initially develop the test in the CAD environment, and only if that is unfeasible, to implement it in GIS.

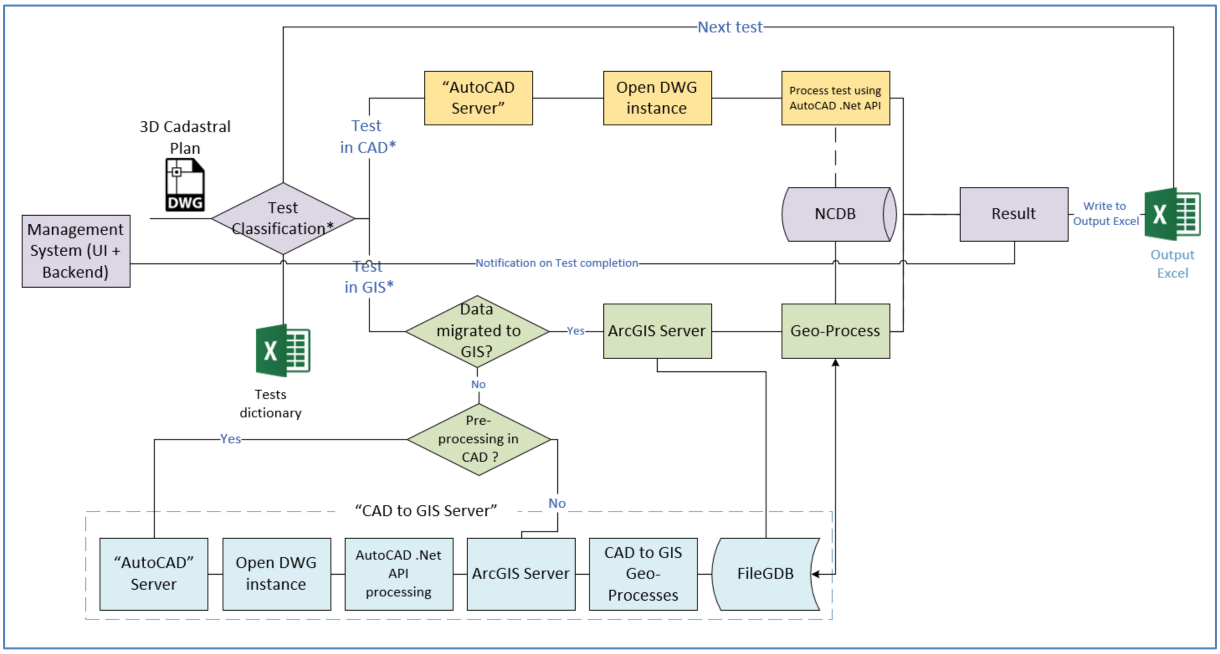

Figure 4: system architecture which employs CAD and GIS tool interchangeably to provide most appropriate solution.

Data migration from the 3D CAD Subdivision Plans to the GIS NCDB was executed following a comprehensive series of quality control tests within the CAD environment. The data migration engine processes three-dimensional CAD entities by removing superfluous fields, creating new fields in line with the required specifications, and transferring essential data in accordance with the data conversion dictionary. Figure 5 illustrates the process, showcasing key CAD layers and their subsequent conversion into corresponding tables. For instance, CAD Layer C1718 contains the geometry of 3D parcels (3D Solids), and Layer C1703 includes a block of information about these 3D parcels. Both layers are converted into the Table Parcels3D (Multipatches). Similarly, CAD Layers C1710-C1712, which contain the geometry of existing and new border points (Blocks), are converted into the Table Borderpoints (Points). Additionally, CAD Layers C1740, C1742 and C1743, which contain blocks of map information, are converted into the Table CadsterProcess3D, and so forth.

Let's examine the 4 primary categories of quality control in the 3D Cadastral Management System.

1. Syntax and format: This refer to compliance with the prescribed data formats of the national mapping standard. It involves 25 checks, for example, verifying that each geometry layer has a corresponding block with attribute data.
2. Geometry: This include 15 test which focus on accurately representing the shapes, sizes, and volumes of parcels and Substractions. It includes confirming that the geometry of border point parcels and Substractions in the 3D subdivision plan aligns correctly. Additionally, it involves ensuring that the geometry of these features matches that of adjacent elements in the National Cadastral Database (NCDB).

3. Topology: This include 15 tests that ensures that the spatial relationships among parcels, Substractions and border points the are accurately depicted. For example: making sure that boundaries don't overlap inappropriately, parcels are properly adjacent to each other, 3D parcels integrate all the Substractions and there are no gaps between parcels.
4. Logic and entities relationship: This consist of 60 tests for the coherence of the data and the relationships between different entities on the map. Examples include checking for logical consistency in attribute data, such as ensuring that parcel numbers begin with one and increment sequentially, the upper level elevation is higher than the lower level elevation, and the calculated parcel volume matches the one in the block.

In summary, this section has outlined the implementation of a comprehensive quality control process for the 3D subdivision plan. Such a process ensures the maps are not only accurate but also meaningful, facilitating their seamless integration into the National Cadastral Database.

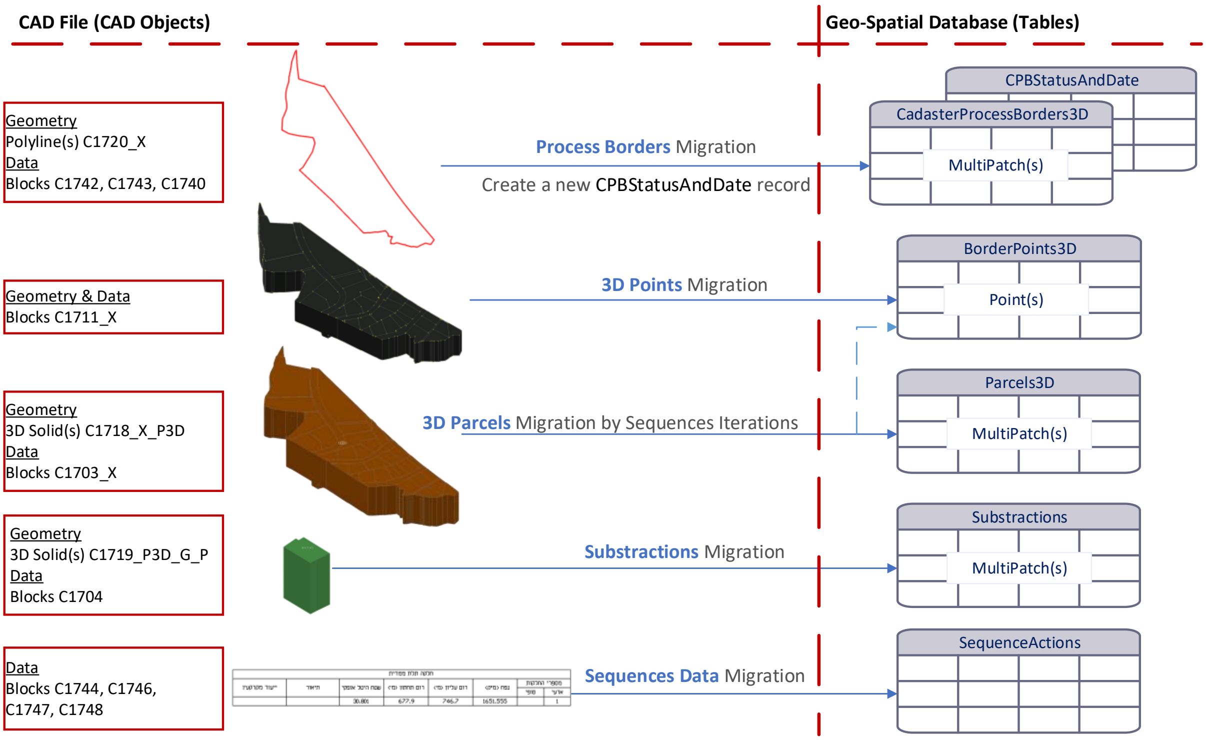

Figure 5: CAD layers to database tables conversion process

4. Interactive Environment for Viewing and Querying the 3D Cadaster

This system component allows none expert GIS users to easily view and query the 3D Cadaster data. It is based on ArcGIS out-of-the-box technology with some minor configurations. The component allows to browse through the 3D Cadaster data in a simple web browser without any installation. The data compiles 2D and 3D Cadastral information. Figure 6 shows 3D registered parcels in conjunction with the 2D Parcels above them.

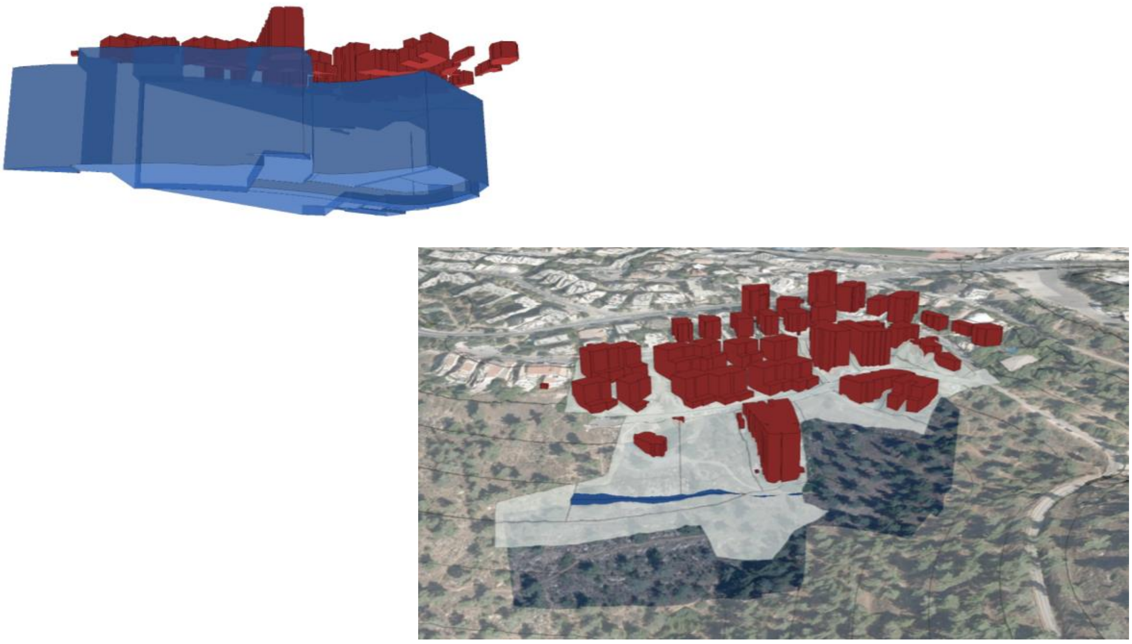

Figure 6: Underground 3D Parcels with the 2D Parcels above them

5. The Management System

This section outlines the design of the management system which was developed to manage the process of intaking 3D Subdivision Plan, running the QC check, and finally populating and/or updating the 3D Cadastral data in the NCDB.

The management system encompasses two primary entities:

1. Project: This entity consolidates all pertinent details of a project, such as the surveyor, date, purpose, and associated 3D Subdivision Plan actions.
2. 3D Subdivision Plan Actions: These are linked to a project and encompass three major types:
   a. Migration Tests
   b. Quality Control Tests and Comparisons
   c. Importing 3D Subdivision Plans into the Database

Additionally, the 3D Cadaster system workflow operates under two scenarios:

1. Default Scenario: This involves the automatic and seamless execution of tests, followed by data loading into the database, unless a critical or stopping error occurs.
2. Sequential Action Scenario: Actions are executed consecutively, with pauses allowing user intervention to decide whether to proceed to the next action.

In the event of a critical error, the system prohibits the loading of the subdivision into the database.

6. Conclusions

The successful development of a cutting-edge 3D cadastral management system in Israel marks a significant milestone in the evolution of land administration and management.

The adoption of 3D cadastral systems addresses numerous challenges faced by traditional 2D systems, particularly in densely populated and rapidly urbanizing areas. By incorporating the third dimension, it allows for a more precise representation of property boundaries and rights, especially in complex infrastructure facilities like underground train station, aerial lift transportation facilities, underground shopping center etc.

Furthermore, the developed system significantly streamlines the entire cadastral process. It automates every step, from uploading a 3D subdivision plan and conducting its quality control examination, to transferring the information to the GIS and updating the National Cadastral Database (NCDB).

This pioneering project lays the foundation for more advanced methods of land resource management in the 21st century. These may include utilizing Building Information Modeling (BIM) files as system inputs, employing Artificial Intelligence (AI) for quality control assessments, and leveraging Virtual Reality (VR) technologies for data visualization.

Looking forward, the 3D cadastral system in Israel, showcases the potential of modern technology in enhancing the transparency, reliability, and efficiency of land administration systems, which is essential for sustainable urban development and effective governance. It is hoped that the article will help other nations in adopting a similar strategy for the effective management of their scarce land resources.

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8. BIOGRAPHICAL NOTES

Shlomi Sivan holds a BS from the Tel-Aviv University, Israel (Mathematic and Computer Sciences) and has been the CEO of Sivan Design D.S Ltd for more than 25 years. Under his leadership the company is becoming a leading provider of systems for national land management, comprehensive GIS solution integrating with ERP capabilities, 3D GIS application and holistic user-friendly civil engineering CAD products.

Yaron Felus holds a BS from Ben-Gurion University, Israel (Electrical and Computer Engineering), a MS from the International Institute for Geo-Information Science and Earth Observation, Netherlands (Geomatics), and both MS and PhD from the Ohio State University (geodetic science). He is a Professional Surveyor in Michigan, USA and in Israel.

Currently, He is a professor in the Surveying and Geo-Information track at the Civil Engineering Department in Ariel University.

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