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BIM-GIS Integration for Interactive, Open and Low-Cost 3D Land Use Registration and Urban Neighbourhood Management

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Abstract: This paper is part of an on-going research study on developing a low-cost and approachable methodology for f-f-p, transparent and future inclusive 3D land use management for an urban neighbourhood by constructing a homogenous, open, cloud-based and free-to-use virtual BIM-GIS geospatial infrastructure. The proposed platform is structured for registering, classifying and visualizing volumetric land use prisms, distributing conceptual and geometric information, conducting statistical analyses and data exchange aiming for optimal decision making, urban neighbourhood management and land use tracking. The proposal aspires to aid the successful and timely achievement of the UN Sustainable Agenda 2030, in particular SDGs 1,9 and 11. The methodology includes: 1) the creation of approximate BIMs by utilizing open and available data and platforms, 2) modelling of land uses as 3D volumetric prisms, 3) registering semantic and geometrical land use information and 4) crafting statistical graphs, emphasising on data compilation and BIM-GIS standards implementation.

Keywords: BIM; Crowd-Enabling Urban Neighbourhood Management; Data Integration; Fit-For-Purpose; GIS; Open 3D Land Use Registry

1 INTRODUCTION

1.1 Objective of the Research

The complexity of modern urban environments is characterized by overlapping facilities, vertical extensions of property rights, superimposed legal spaces or operational systems, conflicting benefits and the constant need for utilizing land. Consequently, proper and constant land management, land use tracking, 3D cadastral registration policies, crowd-enabling incentives and digitization of neighbourhoods are needed for optimal, inclusive, fair, transparent and modernized urban governance and planning. The SDGs of the United Nations (UN) Agenda can pave the way for the implementation of all the above, tailored to each country's distinct needs and problems, creating a homogenous conceptual background between different countries and administrative systems with fit-for-purpose solutions.

3D representation and distribution of key urban instances such as land uses and property boundaries can reform the 2D static establishment of contemporary cadastral and land administration systems. 3D visualization of land use spaces can contribute to interactive, dynamic, personalized and fit-for-purpose (f-f-p) urban management procedures with many outlets to future smart applications, real-time facility management, digitization of old neighborhoods, parking spaces planning, sustainability, optimal urban segmentation, etc.

3D land use registration and management applications are favored to start at a neighborhood-scale extent as neighbourhoods represent a small-scaled indicative simulation of the entirety of an urban environment, serving as a possible stepping-ground for crowdsourcing, tracking and registration applications.

An open, low-cost and interactive 3D land use registry could contribute in the optimal deployment, usage and distribution of parcels and urban space while it could aid the establishment of permanent crowdsourcing urban incentives, inclusive policies and transparent urban management procedures. One important factor is the protection of personal and sensitive data. Various 2D data portals around the globe follow data protection rules and the same has to be applied to 3D portals. Open and available data dictate transparency, citizen-engagement and incentives leaving no one behind but not at the expense of privacy and safety standards.

Building Information Modelling (BIM) and Geographic Information Systems (GIS) technologies and standards are leading the trends of 3D representation, data compilation, urban management, chartography, urban planning, decision-making and digitization while they contribute in the merge of static 2D geospatial instances with dynamic 3D models. BIM serves as a proper host for volumetric land use modelling, registration, classification and representation while GIS possess an array of tools, platforms and programs for disposing, querying and analyzing both semantic and geometric information.

Proper, accurate and thorough synthesizing of the above-mentioned standards is a major research theme across the global academic and technical community as the BIM extraction format, the Industry Foundation Class (IFC), is not fully compatible with GIS-based interfaces. IFC also tends to not transfer important textural information across platforms while BIM data are more frequently adjustable to GIS-based programs through rigorous and demanding programming transformations i.e. JSON format.

The paper proposes the construction of a low-cost, cloud-based, open and interactive platform called "LAURET" for the compilation of approximate BIMs, GIS tools, 3D spatial and semantic data, embedded sites, pop-up windows and statistical graphs for creating a seamless, quick and accessible 3D land use registry of an urban neighbourhood for future crowd-enabling applications. The interface proposes the simultaneous visualization of 3D BIMs, categorization of volumetric land uses both semantically and visually, a 2D land use registry and graphical analyses. The proposed “LAURET” platform contains all the needed tools and official pages for registering 3D urban neighbourhood land use prisms while it utilizes open and available data aspiring to aid 3D land use registration purposes, reform 2D procedures, back up digitization incentives and push forward future crowdsourced policies for inclusive urban neighbourhood management.

The contribution highlights the importance of BIM-GIS integration in aiding optimal neighbourhood decision-making and digitization procedures while establishing modernized urban functionality, social equality and fostering the cooperation between experts and citizens regarding urban planning and tracking. The proposed platform can support crowdsourced urban neighbourhood management, proposes a f-f-p and approachable solution for the creation of approximate yet detailed BIMs, emphasizes the importance of data reproducibility and interoperability while being in terms with SDG 9 (Industry, Innovation and Infrastructure), 10 (Reduced Inequalities) and 11 (Sustainable Cities and Communities).

1.2 State of the Art

One of the most important factors of the contribution is researching, implementing and highlighting the merge of BIM data with GIS standards for the betterment of urban planning and land use registering. BIM is translated as IFC format containing the various modelled structural and architectural elements as classes and subclasses. IFC is a highly interoperable dataset that can boost interconnectivity and multisectoral workflows.

The research field has developed various methodologies based on the interconnection of BIM and GIS technologies by utilizing the IFC schema for cadastral, urban planning and city functionality tracking purposes. BIM and GIS integration is a recently advancing trend with many researches focusing mostly on interoperability and merging methods rather than consequent analyses [1]. The combination of BIM and GIS can be helpful for public administration and 3D cadastral issues [1]. BIM and GIS synthesization is a possible supportive factor for sustainable urban management as it fosters capabilities regarding data interoperability, exchange, analyses and technologies [2].

BIM hosts vast information regarding a built construction throughout its lifecycle [3] while GIS technologies are characterized by multiple analytical and visualization tools that enable geospatial decision-making [4]. IFC is one of the two most prominent data formats that is used for BIM-GIS compilation [5] with City-GML taking the other spot. In the last decade, BIM-GIS merge has been utilized for urban energy management [6] and ecological assessments [7] while applications on emergency and unexpected factor handling have also been developed [8].

Theoretically, BIM-GIS compilation has been split into two categories, one being the geometric and the other the semantic, leading to continuous research that revolves around FM (Facility Management) and AEC (Architecture, Engineering and Construction) sectors. [9]. For instance, the ArcGIS Pro platform has been used to host 3D BIMs of complex buildings, 3D volumetric rights and a semantic cadastral database following the LADM (Land Administration Domain Model) standard [10]. Other paradigms entail the development of a crowdsourced application by utilizing GIS toolboxes for a cost-effective, quick and approachable 3D cadastral registration [11] while a BIM and 3D GIS-empowered cadastral system has been created for the 3D visualization of cadastral entities [12]. Through BIM-GIS compilation it has been researched that spatial planning can take place before the construction, enabling the possibility to solve upcoming problems ahead of time [13]. Regarding the construction domain, supply chains and material sequences can be visualized by using complex BIM-GIS systems [14].

Further applications regarding optimal and sustainable building energy management and tracking have been developed under the prism of BIM-GIS implementation such as energy mapping which makes possible the visualization and monitoring of spatial motifs of energy consumption across a multi-storey building [15]. Sustainable management, especially in real-time, consists a key-factor for Smart City establishment. Consequently, research regarding the merge of IoT (Internet of Things) devices, GIS meteorological and weather systems with BIM models has been carried out [16].

Regarding urban management and optimization, GIS has been incorporated with BIM datasets to digitally present flood-jeopardized urban areas [17] while applications about tunnel creation have also been made [18]. GIS-BIM systems can support the constant flow and interconnection of indoor building data with urban facility information resulting in possible future Smart City solutions [19]. BIM-GIS complied systems, enriched with GPS technologies, can host various important urban data such as construction costs or rentable areas which play a lead role to urban are development [20].

3D Cadastral applications around the theme of GIS-BIM integration have focused on creating a homogenous 3D cadastral data model which follows both GIS standards and BIM storage capabilities [21]. A BIM-GIS integrated platform enriched with 3D BIM data and cadastral information has also been developed [22]. In 3D cadastral applications that regard BIM and GIS, georeference plays a major role as it hosts all the important geospatial and coordinate data for the correct and proper location of the properties under study. Research showcasing the automated georeference by utilizing building footprints by merging GIS with BIM has been developed [23].

A highly integrated model that entails information about varying building and construction phases alongside data regarding economic, environmental and operational factors has been proposed in [24]. In China, a case study concerning the application of BIM-GIS compiled methods for underground piping management has been developed and tested [25].

BIM terminology and technologies have also been researched considering green and sustainable purposes such as the evaluation of the sustainability score in existing buildings as well as green retrofitting [26]. The need for maintaining and tracking green building components throughout the construction phases is also another sector that calls for BIM implementation [27]. Certification procedures for safeguarding green building complexes can have also been extensively studied in literature [28].

BIM has furtherly been implemented in preventive, risk-management and security applications which is a key-instrument for future Smart City and interconnected building complexes. A BIM Risk Identification Expert System has been developed, for instance, regarding tunnel construction procedures compiling BIM models [29]. Many times, mistakes and mis happenings during construction competition lead to revealing foundings. A framework concerning empirical safety risk data and BIM datasets has been proposed in [30]. Automation safety excavation modelling has also been presented by merging BIM, safety regulations, visual programming and automatic rule checking [31]. A more universal research regarding validating the performance of BIM-based applications has been shaped [32].

Scheduling toolsets have been mingled with BIM technologies both for railroad tracking [33] and bridge construction procedures [34]. Clash detection and mistake finding utilizing BIM has been developed regarding large construction projects, equipment bump and machinery failures due to inadequate time schedule structuring or deficient site management [35].

An open, communicative and online virtual hub has been developed which stores the approximate crowdsourced BIMs of an entire neighbourhood enriched with street furniture, environmental elements and various mechanical, electrical and pluming (MEP) devices [36]. The developed cloud-based and all-in-one platform of this proposal, LAURET, has been based on previous conducted research which covers the low-cost, fast and engaging 3D registration of property units by utilizing embedded sites and official open portals [37].

2 METHODOLOGY

2.1 Overview of the Methodology

The presented methodology is based on creating the approximate yet highly detailed BIM of an urban neighbourhood while modelling land use boundaries as 3D volumetric prisms for their collective distribution in a holistic and multifaceted interactive platform named LAURET. LAURET stands for "land use registry" and it is a cloud-based 3D land use and urban neighbourhood analysis as well as visualization platform. The methodology, in general, depends on the availability of floor and architectural plans as well as the open distribution of 2D data and portals.

The technical part is relying on the utilization of low-cost techniques, open platforms and available data such as the National Cadastral Portal or Google Earth Pro. The delineation of the 3D volumetric land use prisms is mainly based on floor and topographical plans. The methodology is largely leaning on the previously developed contributions of the authors [36] and [37] that thoroughly cover the creation of f-f-p and low-cost BIMs and the modelling of land use prisms.

Fig. 1 showcases the proposed methodology for the compilation of the LAURET platform. According to the graph:

- Firstly, the BIMs of the urban neighbourhood under study are going to be modelled, following the f-f-p and low-cost methods proposed in [36] and [37].
- The spatial extent of the land use prisms is going to be modelled by delineating the 2D plans and categorized.
- Statistical and analytical graphs as well as a semantic registry in the form of a queried table are going to be constructed.
- All the elements are going to be compilated in the online ArcGIS Experience interface for the final synthesization of LAURET.

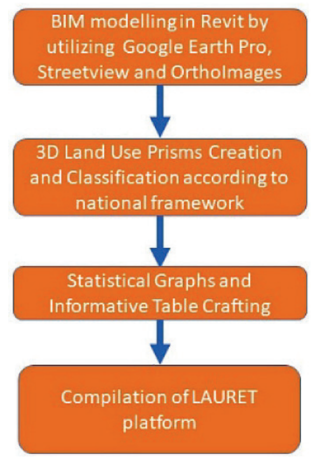

Figure 1 The followed methodology for the creation of LAURET platform

The entire methodology is a paradigm for modelling, registering, visualising, categorising, analysing, quiring and openly distributing 3D land use data in Greece under the prism of a homogenous, available, communicative and cloud-based interface.

2.2 Compilation of the BIM of the Urban Neighbourhood

As it is stated, the current contribution follows precisely the previously developed methodologies that are analyzed in [36] and [37] for the creation of the BIMs which cover thoroughly:

- The construction of BIMs of existing buildings in an urban neighbourhood by utilizing 2D data such as Orthophotos from the Official Cadastral Portal for the delineation of boundaries.
- Obtaining textural information for the coating and materials of the buildings from Streetview.
- Approximate elevation data and measurements deriving from Google Earth Pro.
- Collection of appropriate 2D and 3D information for constructing the outer shell and the surrounding area of each building in Autodesk Revit.
- Insertion of BIMs in the online, open and communicative platform of Autodesk Tandem for their semantic and visual classification and management.

Figure 2 Compilation of 3D BIM of the neighbourhood

Fig. 2 presents the approximate, f-f-p, low-cost and detailed BIMs of the urban neighbourhood under study that consist of a reliable and satisfactory 3D geospatial infrastructure. The BIMs in Fig. 3 consist of thorough rendition of the real structure and geometric configuration of the buildings while entailing information about the surrounding area and urban elements.

Figure 3 Cross sections of the 3D model of the neighbourhood

The BIMs serve as the modelling and presentation basis for the creation of the land use prisms and the platform.

2.3 Creation and Classification of 3D Land Use Prisms

Important information about each land use prism is obtained through the platform of StreetView. The spatial extent of each land use is approximately modelled and visualized following the boundaries of the 2D architectural and topographical plans. The geometric information and the structural layout of the plans serves as the guideline for the creation of the 3D land use volumes. Height information for each volume is either deriving from the height diagrams or vertical measurements conducted in Google Earth Pro. The digitization of the volumetric prisms is based on the Greek legislation while it follows the external wall boundaries and inwards.

The online platform of Tandem is utilized for the presentation, management and categorization of the 3D land use volumes according to their different class as shown in Fig. 4. Tandem enables the insertion, selection, management, editing, configuration, colorization, classification, display and storing of the volumetric prisms.

The classification of the volumetric land use prisms is in full accordance with the Greek legal framework, presenting the following categories which entail different types:

- Residential: which entails housing, lofts and detached houses
- Repository which includes storages and stockrooms.
- Retail-Store which covers shops and stores i.e. pet shops, bakeries, mechanical or computer parts, comic stores, DVD rental stores, etc.
- Services which entail offices and associations i.e. technical, engineer and doctors' office, technical companies, neighborhood associations, etc.

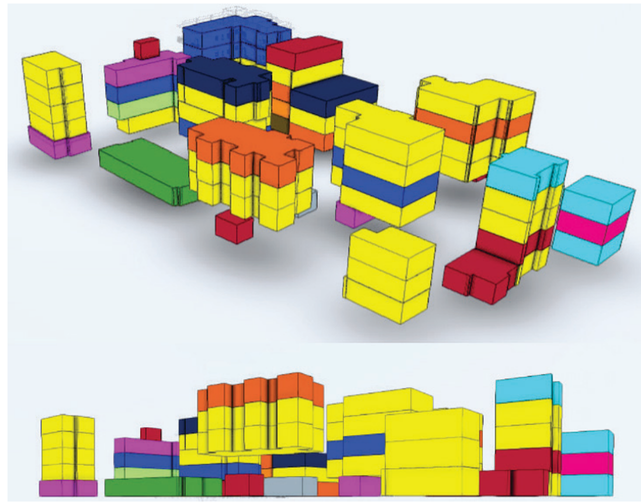

Figure 4 The different categories of land use prisms

The various 3D land use prisms can be both visually and semantically classified according to different filters such as "type" as shown in Fig. 5 (i.e. pet shop, technical office, doctors' office, bakery, neighborhood association, loft, detached house, etc.) and "category" as analyzed previously (i.e. Residential, Storage Room, Retail – Store and Service), while important information such as area (in m^2), perimeter (m) and volume (m^3) is stored.

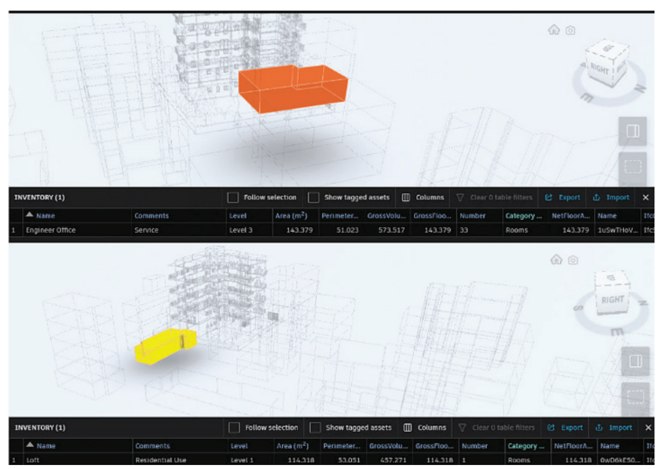

Figure 5 Classification according the "Type", an engineer office (above) and a loft (below)

Fig. 6 presents classification according to the categories of the land uses that are present in the neighborhood.

By selecting one land use prism, an interactive table is presented with all the needed information about it as shown in Fig. 7.

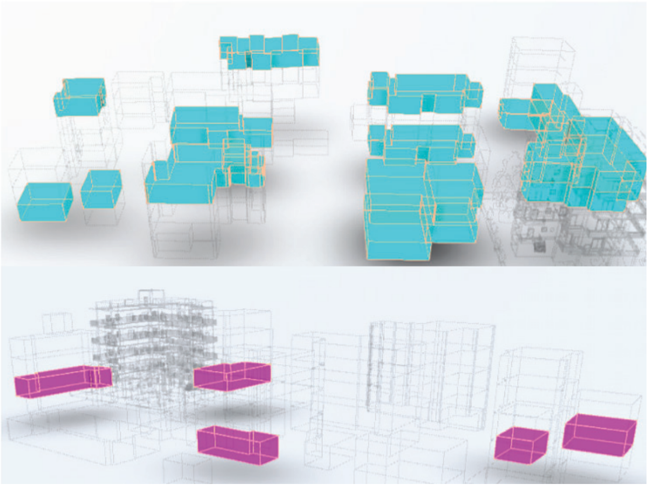

Figure 6 Classification according the "Category", services (above) and retail (below)

Figure 7 Selection of a prism and the distribution of information

Land use prisms that belong to the same category are depicted with similar colorations. By example, Tab. 1 presents the different colour schemes for each land use category making them easy to stand out, differentiate and spot.

Table 1 Colours for each Category

Category	Colour
Residential	yellow
Repository	burgundy
Retail	magenta
Services	azure

3 TECHNICAL APPLICATION - THE LAURET PLATFORM

The platform of LAURET is created by utilizing the ArcGIS Experience interface of ArcGIS Online by ESRI. ArcGIS Online grants access to its products through any type of license either institutional, public or paid. ArcGIS Online is an easily accessible, cloud-based and communicative community which offers a plethora of toolsets for digitizing, mapping, storing, visualising and exchanging both spatial and semantic data.

ArcGIS Experience entails a wide range of widgets for creating personalized, modular, online and interactive interfaces and platforms that can be publicly distributed for wider usage. It offers a plethora of toolsets for merging datasets from different sources and combining various information. An extensive presentation of the operations and functualities of the various widgets of ArcGIS Experience is presented in the previously conducted research that can be found in [37].

ArcGIS Experience is also chosen as it is a GIS-generated environment that it can host alternative, seamless and multiple BIM-GIS compilation options. BIM data and more specifically IFC files are interconnected easily within the GIS environment as online links or embedded shortcuts. So basically, the IFC files are easily converted into uniform research locators (urls) which later are incorporated in the interface of the constructed platform.

LAURET is an open, low-cost and communicate platform for uploading, managing and analysing BIM-generated 3D land use data in a GIS environment. It is built aspiring to be able to host future crowdsourced and cooperative procedures for the registration of volumetric land use prisms for optimal urban neighbourhood management and land distribution.

Consequently, LAURET entails all the needed tools for tracking, modelling, categorizing, managing, storing, visualising and analysing volumetric land use prisms under one low-cost and cloud-operated interface with future crowd-enabling expansions.

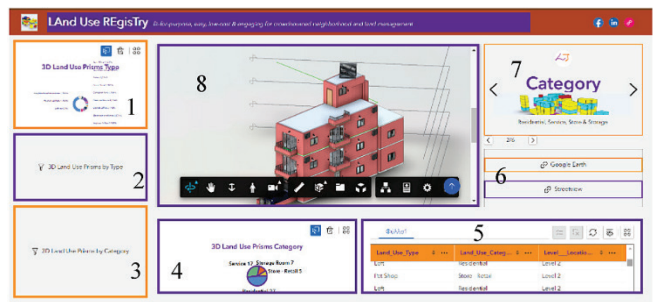

Figure 8 The platform of LAURET with enumeration of the widgets

LAURET consists of many interactive widgets, as shown in Fig. 8 with them being:

1) Statistical pie chart showcasing the percentage of each "type" of volumetric land use prism i.e. pet store, office, storage, loft, etc.
2) A redirection button which seamlessly opens up another window in the user's browser, enabling the visualisation and management of the 3D land use prisms according to the "type" classification.
3) A redirection button that immediately and easily grants access to the visual and semantic classification of the land use prisms according to their "category" i.e. residential, retail, service, repository.
4) An interactive pie chart that presents the numeric allocation of each land use "category".
5) The 2D semantic registry of the volumetric land use prisms that entails informative and geometric information.
6) Two embedded links that seamlessly transcend the user to the official portals of either Google Earth Pro or Streetview.
7) An interactive frame with alternating photocards of the 3D land use prisms and their according visual classifications.
8) The embedded official portal of "Online BIMViewer" as an interactive window in which the BIMs can be

uploaded, viewed, edited and managed straight through the LAURET platform.

In [37], a thorough explanation of the operation of embedded pages, pop-windows, interconnected official portals and graphs is given. As mentioned above, the BIMs can be seamlessly incorporated in the GIS environment of the LAURET platform. In Fig. 9 the inside modelling of a BIM is presented in detail while it is completely incorporated in the platform.

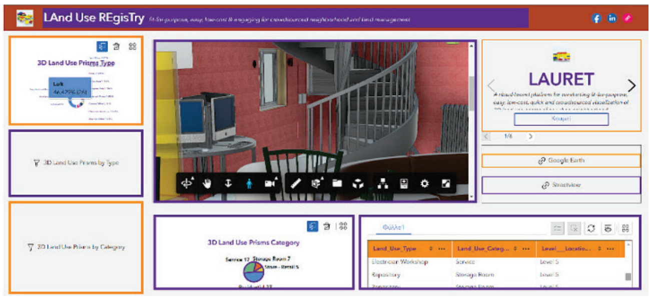

Figure 9 The interchangeable and interactive interface of the platform

Fig. 10 presents the pie graph of the percentage that each "type" of land use covers in the neighbourhood under study.

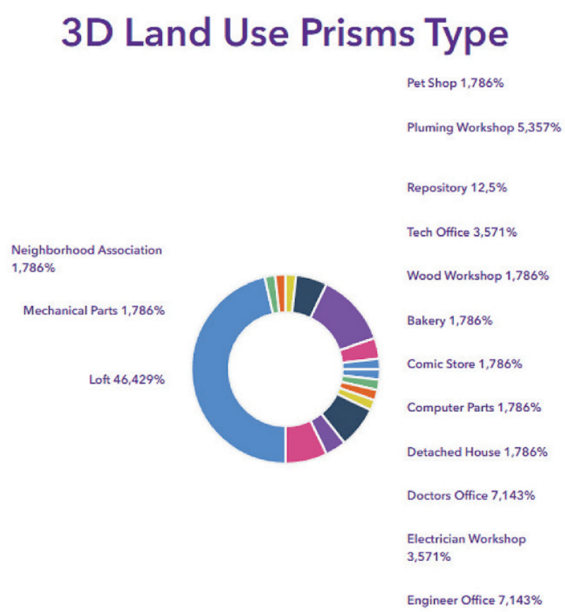

Figure 10 Land Use percentage pie graph

Fig. 11 displays the pie graph of the numeric distribution that each "category" of land use has in the neighbourhood under study.

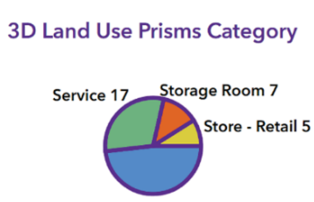

Figure 11 Land Use percentage pie graph

Fig. 12 showcases the embedded semantic and geometric land use registry in the form of a table.

Fig. 13 presents the entirety of the platform from a closer view.

Land_Use_Type	Land_Use_Categ...	Level__Locatio...	Area__m2_	Perimeter
Loft	Residential	Level 1	72	40
Repository	Storage Room	Level 1	26	20
Mechanical Parts	Store - Retail	Level 1	67	38

Figure 12 Land use prism 2D registry in the platform

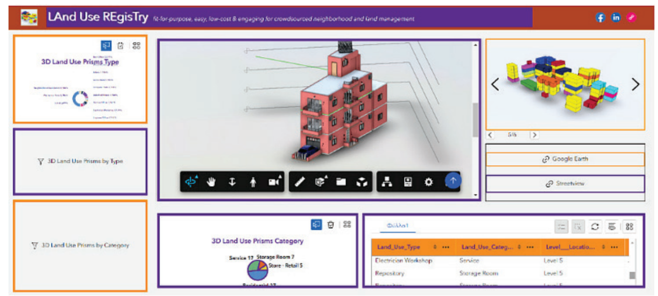

Figure 13 The entirety of the platform

4 CONCLUSIONS

One homogenous interface is created by utilizing the ESRI tool of ArcGIS Online, the ArcGIS Experience. With ArcGIS Experience a personalized, modular, openly accessed and low-cost platform for future crowdsourced 3D land use registration procedures is created. This interface presents all the needed tools for conducting 3D crowdsourced urban land management processes, in a singular, engaging and interactive platform.

The platform is seamlessly linked to:

- 3D BIM Online Viewer.
- Tandem interface where all the 3D land use prisms are categorized and stored.
- Google Earth Pro.
- Streetview.

Statistical diagrams and graphs such as pie graphs can also be provided by the platform, presenting analyses and further information on the 3D land use prisms. A thorough land use registry is also presented as a table storing vital information for each 3D land use prism.

The described methodology is satisfactory for the purposes of creating a fast, low-cost and approximate yet detailed geospatial infrastructure of an urban neighbourhood. It is also adequate for conducting 3D urban land management procedures utilizing available 2D data as the architectural, floor and topographic plans can be either provided by the stakeholders or by accessing the electronic building identity (especially for new constructions).

The proposed platform can easily host 3D crowdsourced land use registration procedures as it is easy to use, enables cooperation and it is available online without a charge. Gamification elements, rewards and motivations can also be inserted in the future, for boosting further the dedication of users. In many countries, crowdsourced cadastral procedures are prominent thus making it easier to be applicable and adapted. The compilation of the approximate BIMs of existing building with BIMs of newly made constructions is going to result in a 3D homogenous geospatial basemap for viewing simultaneously both the 3D models and the 2D semantic information.

The methodology also showcases seamless, easy and fast BIM-GIS compilation options as the IFC datasets are either uploaded as online URL extensions directly to LAURET platform of interconnected with the GIS environment through redirection buttons. The proposal presents a programming-free and conversion-deprived BIM-GIS combination method for the simultaneous distribution of both 3D BIM data and GIS widgets.

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